

# **A NEW ALGORITHM FOR LOAD SHEDDING IN AN INDUSTRIAL COGENERATION POWER PLANT**

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A new algorithm for load  
shedding in an industrial  
cogeneration power plant

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## Dedication

I dedicate the seven chapters of my thesis, to the seven eternal promises of my Lord and Saviour **JESUS CHRIST**.

(1) **“I am the bread of life. He who comes to me will never go hungry.” - John 6:35**

(2) Once more Jesus addressed the crowd. He said, **“I am the light of the world. He who follows me will not be walking in the dark, but will have the light which is life.” - John 8:12**

(3) Jesus said to him, **“I am the way and the truth and the life. No-one comes to the Father except through me.” - John 14:6**

(4) **“I am the true vine, and my Father is the Vinedresser.” - John 15:1**

(5) **“The Father and I are one.” - John 10:30**

(6) **“I am the good shepherd. The good shepherd risks and lays down his own life for the sheep.” - John 10:11**

(7) Jesus said to her, **“I am the resurrection and the life. Whoever believes in me, although he may die, yet he shall live. And whoever continues to live and believe in Me shall never die at all. Do you believe this? ” - John 11:25 & 26**

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Lastly and mostly, I thank the Lord God Almighty, for extending both his correction and his grace upon my life.

---

## Statement of Authorship

Except where reference is made in the text of the thesis, this thesis does not contain material published elsewhere or extracted in whole or in part from a thesis presented for another degree or diploma.

The work is entirely original; acknowledgment in the text of the thesis is given to all authors referenced.

This thesis has not been submitted for the award of any other degree or diploma in any other tertiary institution.

  
**Rushan Muttucumaru**

15th November, 1999

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## Abstract

This thesis presents a new algorithm for an industrial power plant with cogeneration in operation. The new algorithm was developed to satisfy industrial cogenerator's requirements in Load Shedding.

Focus, evaluation and developments of this project are to fulfil the justifiable demand of an Industrial Cogeneration Plant operator's dream of managing a cogeneration plant with a suitable load shedding scheme to operate during diverse scenarios. These scenarios range both peak or normal operating hours.

The disciplines required to realise a load shedding scheme for an Industrial Cogeneration Plant have been investigated first. Background information such as the role of cogeneration, commercial viability, cost and performance and protection principles have been identified. Literature survey into cogeneration and renewable energy connection of generators to the power system have been conducted to identify further, specific issues that an Industrial Cogeneration Plant operator would be concerned with.

The load shedding methodology is analysed. The objective set out was to shed unemergency loads, with an efficiency as close to world's best practise. Specific attention has been made to the load shedding criteria as well as the development of the new algorithm.

The outcome of this research is to produce a user friendly and efficient load shedding software tool that would facilitate the analysis of load shedding. A number of limitations such as close to zero shed difference and tolerance of shed size were required to ensure that reasonable results could be obtained in the allocated time.

The logical steps taken in the system development of load shedding aspects in an Industrial Cogeneration Plant have been described. The interaction of parameters such as fuel inputs, local power and heat generation, power exports, power imports, total generation, load demand

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profile have been analysed in determining the load shedding requirement as well as load shedding and restoration strategies.

The simulation focused on modelling the load shedding and restoration responses to several generation and load demand opportunities, as pertinent to various Industrial Cogeneration Plant requirements.

The overall performance of the new algorithm load shedding strategy has been verified with an IEE journal paper. The new algorithm load shedding strategy has been also tested on the load shedding scheme at the Shell Refinery. In order to assess the effect of variables on load shedding, each variable was varied while keeping all other parameters constant. The load shedding procedure was observed for several diverse instances. A feasibility analysis of load shedding has been conducted to answer the very important question of is load shedding viable in a given case from an Industrial Cogenerating Plant operator's standpoint.

Performance analysis of the new algorithm load shedding strategy indicated that results obtained were within acceptable levels of world's best practice. The unfolding of the stages of the thesis are presented. Concluding remarks have been made on the basis of the results obtained.

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## Publications

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## List of Terms

CB	Circuit breaker
CCT	Circuit
CO <sub>2</sub>	Carbon dioxide
CST	Current Setting
CT	Current transformer
CVT	Capacitive voltage transformer
DSG	Distribution system generation
EHV	Extra high voltage
EPRI	Electric Power Research Institute
ERDC	Energy Research and Development Corporation
ESI	Electricity Supply Industry
F(P <sub>g</sub> ), F <sub>p</sub> <sub>g</sub>	Fuel input energy rate in MKCal/hr
GFC	Gas and Fuel corporation
G(loc), G <sub>loc</sub>	Local generation
G(t), G <sub>t</sub>	Generation limit at time t
H(P <sub>g</sub> )	Heat rate in MKCal/MWhr
I(c)	In-house requirement of the industrial cogeneration plant
IEE	Institution of Electrical Engineers
ICP	Industrial cogeneration plant
LD	Load demand profile
LP	Linear programming
LPG	Liquid petroleum gas
L(t)	Total load demand at time t
NO <sub>x</sub>	Nitrogen Dioxide
P(exp), P <sub>exp</sub>	Power exports
P <sub>g</sub>	Cogenerated power in MW
P(imp), P <sub>imp</sub>	Power imports
PW	Pilot wire
ROCOF	Rate of change of frequency
SAGASCO	South Australian Gas Corporation
SEC	State Electricity Commission

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Sc(c)	Shed requirement
UPS	Uninterrupted power supply
VF	Voice frequency
VT	Voltage transformer
X/R	Source Impedance/Resistance

## 1.0 Introduction

Government regulations to privatise power authorities have lead to an increase of focus on power production and delivery with increased efficiency, reliability and cost savings. Hence, energy management has become more important than ever before, in the power industry. Cogeneration combines the generation of heat and electricity in a single unit in a way that is more efficient than producing heat and electricity separately in boiler plant and at the power station [1]. Cogeneration has been encouraged and supported by the Energy Supply Authorities of Australia together with the Energy Research and Development Corporation.

Industries that generate heat in their day to day operations have the option of coordinating their process control systems to also generate power. The generated power could be useful for the industry's own requirements as well as for exporting power to the utility grid during contracted hours.

As it will be shown during the contents of this thesis, load shedding complements cogeneration. When fuel input available is lesser than that required to drive the process control system, ICPs have the added flexibility to perform load shedding and keep faithful to its commitment of exporting power to the utility.

The specific focus of this research was to develop a new algorithm for load shedding. The recommendations given by various authors on cogeneration and load shedding have been used as a platform on which the aforementioned new algorithm was built upon.

Initial investigations were performed on CYME ( CYME International INC, Canada ) to ascertain useful concepts in the general field of cogeneration. Object oriented programming and genetic algorithm approaches were tried and tested to produce an improvement to the existing load shedding algorithms. Good in its own right, the above two approaches did not converge in producing effective load shedding solutions at reasonable time delays. The genetic algorithm approach and the OOP approach has not been included in the thesis. Also expert system and Fuzzy Logic based approach was not considered whilst undertaking this

research. This set the stage for further analysis to be performed, incorporating a new algorithm for load shedding.

In the new algorithm developed, Pascal code was created together with Matlab graphical representations to capture the useful and controllable parameters in the load shedding alternative for ICPs.

Power engineers could utilise the end product load shedding software developed to evaluate the feasibility of load shedding as well as the optimum strategy to go about load shedding in ICPs.

## **1.1 Motivation for the thesis**

This thesis involves the application of load shedding in cogeneration schemes.

The evaluation, technology, selection, approval, financing and operating arrangements of cogeneration schemes are quite complex, with many different possibilities. The relationship between the many different parties have to be defined in contractual agreements, which needs to provide for all kinds of future possibilities [51].

The motivation for the thesis was to analyse various cogeneration technologies, equipment, protection schemes and operating arrangements that could influence different parties in arriving at contractual agreements. The development of the new algorithm load shedding software tool, provided a platform to analyse cogeneration and the benefits of cogeneration.

### **1.1.1 Why Cogeneration Now ?**

Regardless of the engineering case for cogeneration, it will not "take off" unless it is economically attractive. The two fundamental parameters that dominate commercial viability are:

(a) primary fuel costs;

(b)the capital costs of cogeneration schemes.

#### **1.1.1.1 Fuel Prices**

Most cogeneration schemes currently being developed are fuelled by gas. Until comparatively recently the pricing policy, did not encourage the development of gas-fired electricity generation. It was argued that gas was a premium fuel, too valuable for this application. This view has now changed. Gas and Fuel Corporation (GFC) and other independent gas suppliers saw the opportunity to expand the gas market by fuelling electricity generation. The development of combined cycle plant, achieving efficiencies of around 50% and, of course, cogeneration schemes achieving up to 90% plus, weakened the arguments against using gas for power generation. Such has been the success of gas entering this market that Gas and Fuel Corporation have started reviewing the prices for large long term contracts. Small to medium sized cogeneration schemes are usually supplied under medium term (up to ten years) gas contracts. The economics of such schemes are sensitive to the future gas price [1-4].

#### **1.1.1.2 Capital Cost**

Industrial cogeneration schemes in general utilise either reciprocating engines or, more commonly now for larger installations, gas turbines. Concentration here is on gas turbines because they are generally preferred for schemes of several megawatts. Gas turbine technology has been improving rapidly in recent years producing more efficient machines. The market is developing with more players offering a greater range of machines. Most importantly, the specific capital cost of manufacture of gas turbine plant (in terms of \$ per kW) has been falling in real terms and could continue to do so. However, the recent weakness of the dollar could have a serious effect on the price of equipment manufactured overseas.

There have, therefore, been developments favourable to cogeneration in the two key areas determining commercial viability. However, other factors are also seen to encourage the development of cogeneration in the 1990's, and beyond [1].

### **1.1.1.3 ESI Privatisation**

There is little argument that when the ESI was in the public sector it was dominated by the actions of large utilities and municipal electricity authorities. The utilities designed and built one of the best integrated electricity supply systems in the world. However, its preference for large power stations and its control over electricity prices worked against small scale generation. Further, the surplus capacity within the utilities, experienced through the 1980's, meant that new plant had little capacity value and this was reflected in the prices offered for privately generated electricity. One immediate effect of the privatisation of the ESI is anticipated to be the fall in prices to many larger customers - a force acting against cogeneration. However, a more enduring effect is that a true competitive market for electricity will be established, encouraging new players to enter and more innovative approaches being applied. It is inevitable that supply and demand will come closer into balance and in the medium term this should produce a more favourable commercial environment for the development of cogeneration [1].

### **1.1.1.4 The Green Ticket**

Cogeneration can genuinely be labelled a "Green" technology. The overall thermodynamic efficiency of cogeneration is very high. Further, when gas fired, no sulphur dioxide is produced and  $NO_x$  can be effectively controlled either by steam injection or dry  $NO_x$  control through the design of burners. Finally, the application of cogeneration reduces the production of  $CO_2$  compared with the grid/boiler approach. Although it is difficult to put a value on "green" benefits, in money terms, it can do no company any harm to be associated with environmentally friendly technology [1].

### **1.1.1.5 Ageing Boiler Plant**

In the fifties and sixties falling electricity prices, in real terms, encouraged industry to import electricity and produce steam and hot water in conventional boiler plant. Significant amounts

of low cost, efficient package boilers were installed in the 1960's. Much of this plant is now reaching the end of its useful life [1].

#### **1.1.1.6 Security Of Supply**

Security of supply can be of paramount importance in industrial environments. An on-site Cogeneration scheme can enhance the security supplies. In particular, it is possible to design the electrical connections to ensure continuity of supply for the complete failure of the Grid. Such arrangements can prove most beneficial from both commercial and, in certain situations, safety viewpoints [1].

#### **1.1.2 Why Load Shedding?**

Out of a number of interconnection issues relating to cogeneration schemes the focus of the system designed was narrowed down to Load shedding, for the following reasons:

- Load shedding provided a mechanism to maintain generation/load balance in ICPs.
- A load shedding algorithm could enhance an ICP's reliability during contracted hours.
- Facilitates the safety of operation of ICPs during islanding condition.
- Efficient load shedding of non essential loads could offset fuel costs in ICPs. [54 - 57].

### **1.2 Scope**

The intended outcome of this research was to analyse cogeneration in general and load shedding in particular.

The scope of the research included:

- an investigation into cogeneration
- cogenerator's role in the power industry
- an investigation into protection and control aspects relating to ICPs

- an investigation into interconnection issues affecting an ICP
- an investigation into load/generation imbalance and associated hazards
- study of conventional load shedding strategies
- development of the new algorithm load shedding strategy and verification
- integration of load shedding strategy in a user friendly software package
- analysis of load shedding function with its alternatives

### **1.3 Purpose**

The purpose of this research was to investigate cogeneration interconnection issues and specifically the load shedding alternative.

One of the main goals of this research was to develop a simulation strategy to investigate load shedding with its alternatives such as power imports. Energy management was foremost in mind during the development process.

This thesis contains the logical development of the new algorithm load shedding strategy. Performance analysis of results have been carried out to study important cogenerator parameters and compare results with practical applications.

### **1.4 Original contributions of the thesis**

The original contributions of this thesis are summarised as follows:

1. Load shedding software for ICPs was developed in Pascal and enhanced to operate with a user friendly interface.
2. The new algorithm load shedding strategy was developed to facilitate the safe and reliable operation of cogeneration schemes in various cases as highlighted as follows:

(A) When facing the challenge of exporting power to the utility grid.

(B) When cogenerator has to sustain its own generation requirements.

(C) When cogenerator imports power from utility grid.

3. New algorithms for load shedding that were developed incorporated four unique features, for the benefit of ICPs. This was evident from the results obtained in Chapter 6.1.

The four unique features of the algorithm developed are:

(A) Shed Size matched closely with Shed Requirement.

(B) Minimum number of circuits were shed.

(C) Shed circuits during one time slot were restored during next time slot.

(D) The application of load shedding ensured periodicity of load shedding.

4. The new algorithm load shedding software facilitated the analysis of controllable system parameters. The algorithm developed provided an open door for:

(A) Investigating the varying effect of fuel levels in determining Shed Size vs Shed Requirement.

(B) Examining the varying effect of import/export levels in determining Shed Size vs Shed Requirement.

(C) Studying the varying effect of load demand levels in determining Shed Size vs Shed Requirement.

(D) Analysing the varying effect of circuit numbers in determining Shed Size vs Shed Requirement.

(E) Observing the varying effect of higher shed requirements in determining Shed Size vs Shed Requirement.

5. In an effort to verify the validity of the developed algorithm, the new algorithm load shedding application was verified with a journal paper that performed load shedding on a utility. Hence the developed algorithm was tried and tested on a shed application of the utility.
6. The new algorithm load shedding strategy was tested on the Shell Refinery during an islanding condition as detailed in Chapter 6.3.
7. A feasibility analysis of load shedding was conducted to analyse the viability of load shedding for ICPs while also considering other alternatives.
8. The results obtained in the performance analysis of Chapter 6, provided an opportunity to analyse the benefits of load shedding from both the ICP operator and Utility distributor's perspective.

## **1.5 Organisation of the thesis**

The thesis consists of seven chapters. The remaining six chapters are organised as follows:

A background of cogeneration is given in Chapter 2. This chapter provides a summary of this background investigation and highlights the variety of issues and disciplines involved. Role of cogeneration, commercial viability and protection principles are discussed in this chapter.

The literature survey detailed in Chapter 3 looks into interconnection of the ICP to the utility grid. Renewable energy connection of generators to the power system is examined followed by assessing implications of interconnecting ICP to the utility. Out of a number of issues of concern, load shedding was chosen as the area for detailed research.

In Chapter 4 the objectives of the thesis have been set out. Limitations of system designed and assumptions made, are presented here. Various considerations of system design are highlighted within Chapter 4 to ensure that Quality of Service of the new algorithm is maintained.

The progressive development of load shedding strategies is given in Chapter 5, which details conventional methods adopted as well as the new algorithm load shedding model. In Chapter 5, various scenarios in load shedding are considered together with the load shedding methodology adopted. This is followed by the aims of the new algorithm load shedding tool and the software development methodology. Various specific scenarios that could affect ICPs were considered to make sure that the end product load shedding software was full proof within reason.

Chapter 6 presents the analysis of the performance of the developed load shedding strategy in several different scenarios. The opportunity to analyse various ICP operating standpoints was hence established. Verification of the developed new algorithm load shedding strategy have been made with results presented in journal paper publications. The developed new algorithm was also tested on the Shell Refinery plant at Geelong. Comparisons of parameters such as *shed circuits, shed load, restored load, shed difference* and *number of times all circuits have been shed* were made. A feasibility study of load shedding is also conducted in Chapter 6.

System performance conclusions of ICPs and load shedding alternatives were made in Chapter 7. The fulfilment of a number of objectives which were set out in Chapter 4 have been discussed in conclusion. Chapter 7 also outlines possible future research.

## 2.0 Background

This chapter examines cogeneration. The background information relating to cogeneration is of relevance to both utility distributors and industrial cogeneration plants.

The role of cogeneration is investigated initially in Chapter 2.1. The various cogeneration technologies and equipment types are inspected broadly. This is followed by the market trends for cogeneration as well as the data and incentives for cogeneration in Australia.

Commercial viability, cost and performance of cogeneration is presented in Chapter 2.2. Parameters that can influence commercial viability of cogeneration schemes are presented here. The costs and performance of small cogeneration schemes are also addressed in Chapter 2.2.

Cogeneration benefits have much higher fuel efficiency and lower environmental load compared with the levels achievable with purchased electricity and independent steam generation. With solid fuels, high pressure steam is usually raised in a boiler and passed through a turbine to generate power. The low pressure turbine exhaust steam is then available for process heating. With liquid and gaseous fuels, it is also possible to run a reciprocating or gas turbine engine to generate power from the hot pressurised gases and then recover exhaust heat for process use [51].

Protection is a vital part of cogeneration systems. Protection principles are investigated in Chapter 2.3. Out of a variety of protection mechanisms, overcurrent protection is reviewed as it would be both affordable and sufficient for many ICPs [1].

Protection considerations in industrial cogeneration schemes are identified in Chapter 2.4. This is followed with a summary of important ideas presented throughout the chapter.

### 2.1 Role of Cogeneration

This section introduces cogeneration.

In many businesses, the purchase of electricity and fuel for use of boiler plant is often regarded as a fairly unglamorous subject. The boiler house, transformers and switchgear are necessary, even though it detracts from an organisations mainstream activity; whether that be refining sugar, making cars, paper or chemicals.

Heat and power are the life-blood of any industry; essential for the operation of everything from the lowly light bulb and radiator to the most complex process technology. A secure supply of power and heat is therefore of paramount importance, and it must be provided at the lowest possible cost.

Obtaining these vital commodities at the lowest cost is traditionally the duty of the management. The privatisation of the electricity supply industry has brought competition in to the market place for electricity supply and buyers.

As well as the institutional changes in the electricity supply industry, there is also now an opportunity of reducing overall costs of energy supply by using cogeneration technology [1].

### **2.1.1 The Technology**

Cogeneration is essentially a philosophy. It describes the use of technology, that combines the generation of heat and electricity in a single unit in a way that is more efficient than producing heat and electricity separately in boiler plant and at the power station. In other words, cogeneration is the energy process whereby waste heat, produced during the generation of electricity, is utilised for steam raising or heating.

Cogeneration plants produce both electrical or mechanical energy and thermal energy from the same fuel source. The mechanical energy can be used for any mechanical application such as driving motors, compressors, extruders, etc. The electrical energy can be used to meet in-house demand and any surplus sold back to the electricity grid. The thermal energy can be converted to steam or hot water for process application, or for drying purposes.

The engineering principles behind integrating electricity and heat supply have long been understood, and the technology has been refined and developed over the years, so that now, modern cogeneration systems can achieve very high fuel utilisation efficiencies.

When fuel is burned in a conventional power station, much of the energy in the fuel is converted to heat, only a fraction of which is converted to electricity. In brown coal and gas fired power stations, 28% to 35% of the energy in the fuel is converted to electricity, the other 65% to 72% becomes heat which must be disposed of. In cogeneration, both the recovered heat and the electricity or mechanical energy are used, so efficiency increases to 70% to 82% depending on the prime mover used [1]. This heat may be made available as process steam for industrial complexes or in the form of hot water for use in commercial and domestic space and water heating [2]. This utilisation is well over twice that of a large conventional power station, Figure 2.1.

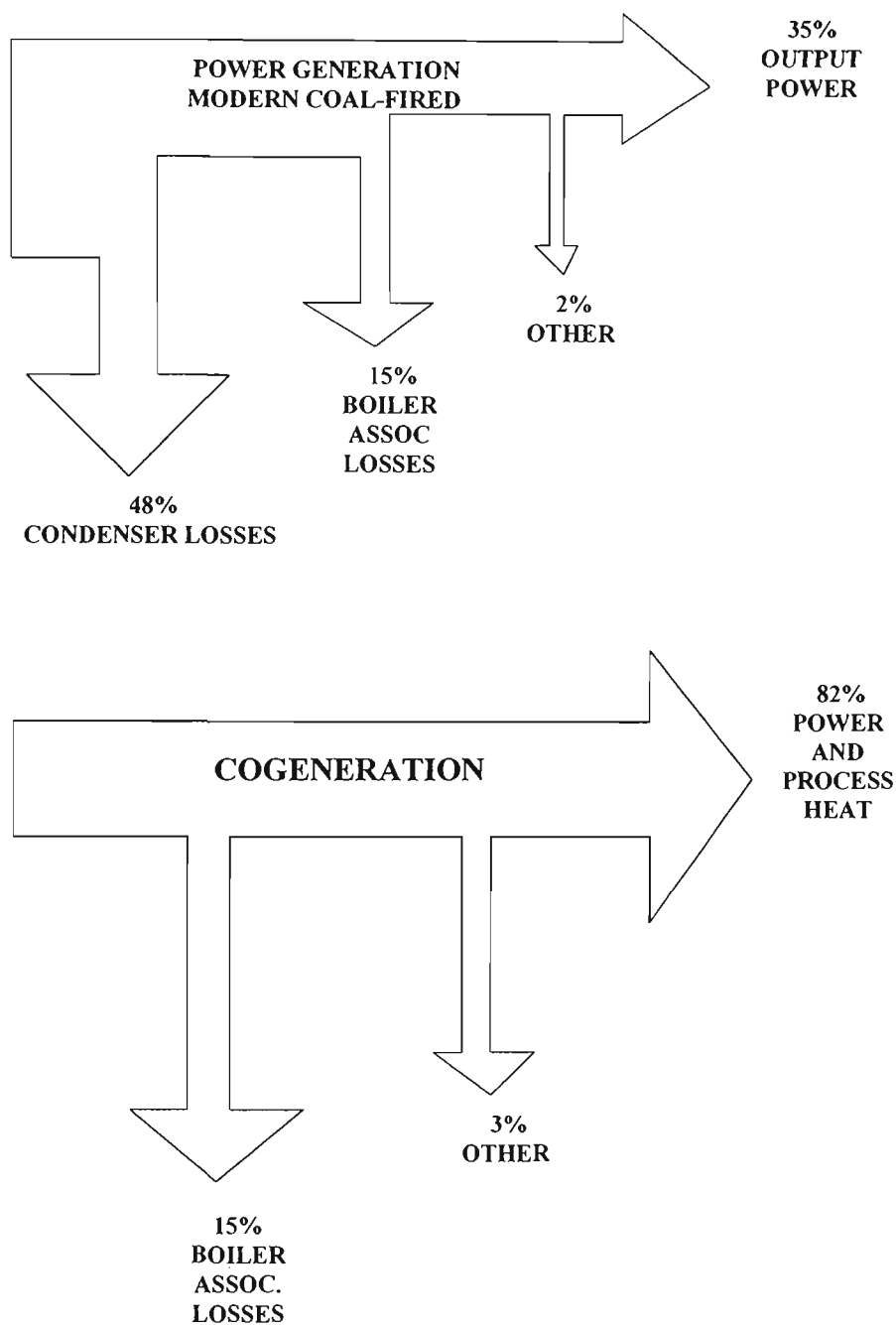
The economics of cogeneration schemes are most compelling for organisations with a high heat requirement. Units range from as little as 20 kW to hundreds of MW and can be linked to public and commercial buildings, industrial sites and community heating schemes.

Cogeneration has a very wide application in the industrial and commercial sectors, and also in public institutions.

In the industrial sector potential exists in manufacturing (petroleum, chemical, food and beverage, textiles, paper, iron and steel, motor vehicles, glass and clay), mining and forestry.

In the commercial sector potential exists in office buildings, supermarkets, hotels, restaurants, health clubs, computer centres and laundries. In public institutions, cogeneration is suitable for hospitals, nursing homes, schools, libraries and prisons.

There are two obvious times to consider investing in cogeneration: first, when existing boiler capacity needs to be replaced and second, when new buildings are being planned. Hospitals, for example are already being designed to include a cogeneration system from inception.



**Figure 2.1 Fuel Utilisation Effectiveness**

Once the economics have been worked out and the investment has been made, financial savings quickly offset the initial additional costs incurred, giving a payback in as little as two or three years [1].

The life of a cogeneration system can exceed fifteen years, so the savings accrue long after the initial capital costs have been recouped.

Cogeneration can run on virtually any fuel: solid, liquid, or gaseous. It also uses a wide variety of generating plant types. The other fuels include-wood/wood waste, landfill gas, municipal solid waste, industrial waste and agricultural waste. This offers good flexibility when choosing the scheme that best suits an organisation's individual circumstances.

The fact that so many combinations of fuel and plant type can be employed means that there can be a scheme to match most installations.

The fuels which one would normally associate with on-site generation schemes are oil, briquettes, LPG and natural gas. It must be remembered, however, that the price, availability and suitability of the fuel will govern its choice in any on-site generation scheme.

#### **2.1.1.1 Fuel Oil**

- Has to be stored safely in a tank farm;
- Has to be pumped, and the heavier fuel oils have to be heated, de-watered and cleaned before use in reciprocating engines;
- Require atomisation in combustion systems;
- Suffer from the presence of sulphur and metallic compounds, particularly the heavier fractions, and these cause undesirable deposits on, erosion and corrosion of gas-turbine blades, combustion chambers and engine valve seats and cylinders;
- May restrict the direct use of exhaust gases, and fairly extensive cleaning facilities may become necessary on the hot side of waste-heat boiler equipment;
- Require greater stack heights than other fuels, and control of atmospheric pollution is more of a problem;

- Give the highest shaft power efficiency in reciprocating engines, but heavy oils are not normally considered for gas-turbine operation.

#### **2.1.1.2      Briquettes**

- The solid fuel has to be stored safely under cover.
- Mechanical handling equipment are necessary to convey the briquettes to intermediate storage hoppers.
- The boilers are to be fitted with a moving grate for complete combustion of the solid fuel and ash removal.
- The steam quality raised in the boilers shall be of good quality to avoid corrosion or build-up on the steam turbine blades.
- The boiler installation will be required to have a relatively high stack and a method of cleaning the flue gas.
- Capital cost of equipment tends to be greater for solid fired boiler installations and steam turbine generator systems.

#### **2.1.1.3      LPG**

- Has burning characteristics similar to natural gas in gas-turbines, but in reciprocating engines performance down-rating is necessary;
- Must be stored in a pressurised tank which is costly, and heat is needed for vaporisation;
- Is heavier than air, and adequate safety precautions must be taken against leakage;
- Can be blended with air to produce a mixture compatible with natural gas;
- Is very clean and causes a minimum of corrosion or erosion of gas-turbine blade, engine valve and seat or waste-heat boiler.

#### 2.1.1.4 Natural Gas

- Is a piped supply, and no vaporisation is required;
- Requires no storage;
- Gives very clean combustion products in both engines and gas turbines, with no corrosion or erosion of gas-turbine blade and combustion chamber, engine valve and seat, or waste-heat recovery boiler;
- Imposes no restrictions on direct use of exhaust gases, and stack heights and temperatures may be reduced;
- Must be pressurised to be injected into the combustion systems of gas turbines and turbo-charged reciprocating engines; therefore pressure boosting on site may be necessary. Determination of gas supply pressures and supply availability should be given high priority since any associated capital costs may well have a significant bearing on the total cost of the project.

Therefore if the site is known where the plant will be installed and it has been decided whether turbines or engines will be used, the gas supply authority may be approached for costs of making gas available.

The gas supply authority is responsible for works required up to and including the meter/regulator assembly. There may be costs associated with this work. The consumer is responsible for the concrete base and chainwire mesh enclosure for the meter/regulator assembly and all works from the meter outlet to the appliance/s. The gas supply authority is also responsible for any water cooling facility for the interstage gas compression to provide the gas at the desired firing pressure.

The metering pressures available to consumers are dependent upon the pressure in the supply main and the minimum pressure that the appliance will operate. Pressures above the standard pressures are by special arrangement.

Just about all engines and turbines require pressures above standard. Gas Engines require a pressure between 40 and 400 kilopascals while gas turbines require a pressure of 1750 kilopascals.

It is most likely that the large engines and all turbines will require the supply gas pressure available at the meter to be boosted to that specified by the equipment supplier. All costs associated with boosting equipment are the customers responsibility and supply/installation should be arranged with the equipment suppliers.

The incentive for developing renewable energy sources is associated with:

- Ecologically Sustainable Development.
- Greenhouse gas targets.
- Resource diversity.
- Low or zero emissions of  $SO_2$  and  $NO_X$ .
- Low cost energy production.
- Business opportunities.

Australian utilities like Pacific Power have adopted a stage approach to developing renewables and allied technologies. This approach is to:

- carry out resource and technology assessments to gauge and potential, viability and technical readiness and alternatives.
- conduct targeted research and development to validate concepts, components and sub systems.
- install small scale demonstration plants to test and validate performance.

- conduct detailed engineering design and costing studies to allow for the development and deployment of selected technologies on a commercial scale.

Pacific Power examines and develops a number of renewable energy sources and technologies using the above approach [3].

### **2.1.2 Cogeneration Cycles**

A cogeneration plant basically comprises of a prime mover (gas or steam turbine or internal combustion engine) and a waste heat recovery boiler or steam generator.

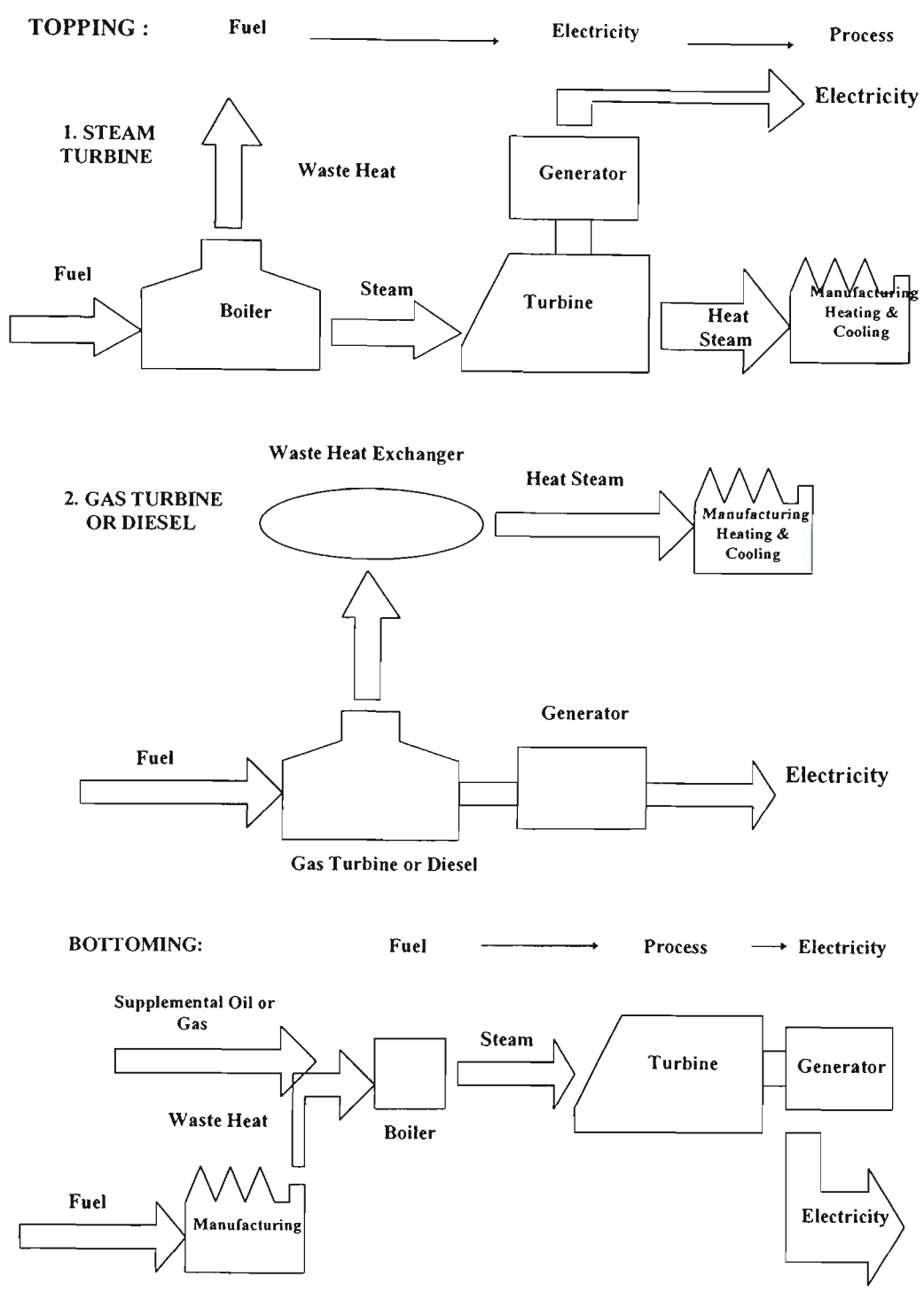
Electricity (or mechanical power) and thermal energy can be achieved through cogeneration by either a topping or a bottoming-cycle system, Figure 2.2.

In a topping cycle system, fuel is burned to generate electricity; the thermal energy exhausted from this process is then used either in an industrial application or for space heating.

In a bottoming-cycle system, the waste heat is recovered from an industrial process application and used to generate electricity.

Combined-cycle systems generally use a topping-cycle gas turbine; the exhaust gases are then used in a bottoming-cycle steam turbine to generate more electricity and process thermal energy. Heat pumps may also be used with a cogeneration system to upgrade low-temperature heat for process use.

In a topping-cycle system, fuel is burned to generate electricity and the thermal energy exhausted is used in a process application. This is the most common form of cogeneration. This process is applicable to any operation that uses boilers to produce steam or heat.



**Figure 2.2 Cogeneration Cycles**

Topping cycle cogeneration involves converting the boiler to produce higher pressure and temperature. This steam is then piped to a turbine which runs a generator to produce electricity. The heat is then used in the manufacturing process, or for heating or cooling.

Bottoming cycle cogeneration is generally used where an industry process produces waste heat at high temperatures (above 300°C). In the bottoming cycle, (shown in Figure 2.2), waste heat from a manufacturing process, generally with the addition of more fuel, is fed into a boiler to make steam. The steam is then sent to a turbine, which operates a generator to produce electricity.

Alternatively, other industrial plants or large institutions may operate a gas turbine to drive a generator for the production of electricity. Under ordinary operation, waste heat from the gas turbine is simply discharged.

With cogeneration, the heat discharged from the turbine goes into a waste heat exchanger which would be used to produce the heat or steam needed in the factory or institution.

Topping cycle cogeneration has wide application in the food, pulp and paper, and chemical industries, and in hospitals and other large institutions.

In bottoming-cycle system waste heat is recovered from a process application and used to generate electricity. Prime movers can also be combined to produce compound, or "combined cycle" cogeneration.

Bottoming cycle cogeneration is likely to be used in the metals, glass refractory and cement industries but is generally less wide-spread than topping cycle systems.

The turbines used in cogeneration process can also be linked to equipment to provide mechanical power, instead of to a generator to provide electricity.

Cogeneration plants vary widely in size and packaged micro-cogen units in the size range 20 kW to 60 kW are commercially available for suitable office buildings, restaurants, hotels, etc. For units below 800 kW, diesel and gas engines are the most common type of prime motor. From approximately 800 kW to 10 MW, gas turbines or large reciprocating engines can be used. Steam cycles (steam turbines) can also be used especially in coal, waste gas or biomass

fired cogeneration systems. For applications above 10 MW, gas and steam turbines are generally used.

There are several types of equipment that fall within the cogeneration philosophy. The four systems which are most commonly used are as follows.

#### **2.1.2.1 Diesel Engine**

Diesel engines have a higher electrical conversion efficiency than gas turbines, but also require petroleum-based fuels.

Diesel engines are less attractive for on-site generation, primarily because they require on-site fuel storage facilities, which add appreciably to the capital cost of the installation.

A typical diesel engine used for power generation has a thermal efficiency of 30% to 35% and the exhaust gases and the water jackets contain considerable heat that can be recovered to boost this efficiency.

Diesel engines are more efficient than either gas turbines or small steam turbines at full and partial load, and offer approximately twice the electricity per unit of steam produced as the gas turbine and ten times that of the steam turbine.

Figure 2.3 illustrates a Diesel Engine used in Cogeneration Plants. However, diesel engines are more difficult to site and their use is often limited because they are regarded as dirty prime movers and only suitable for low temperature systems.

#### **2.1.2.2 Gas Engine**

Gas engines are well developed and commercially available, (Figure 2.4). They are especially attractive for small cogeneration applications because natural gas is a relatively clean-burning fuel. While the diesel engine operates on a compression ignition system, the gas engine (also reciprocating internal combustion) operates on spark ignition (Otto cycle) and the system operation is similar to that for diesel engines as shown in Figure 2.3. The gas engine was

introduced in many topping cycle "total energy" systems during the early 1970's when natural gas became relatively cheap and plentiful. In addition to natural gas, these engines can burn propane, butane or methane.

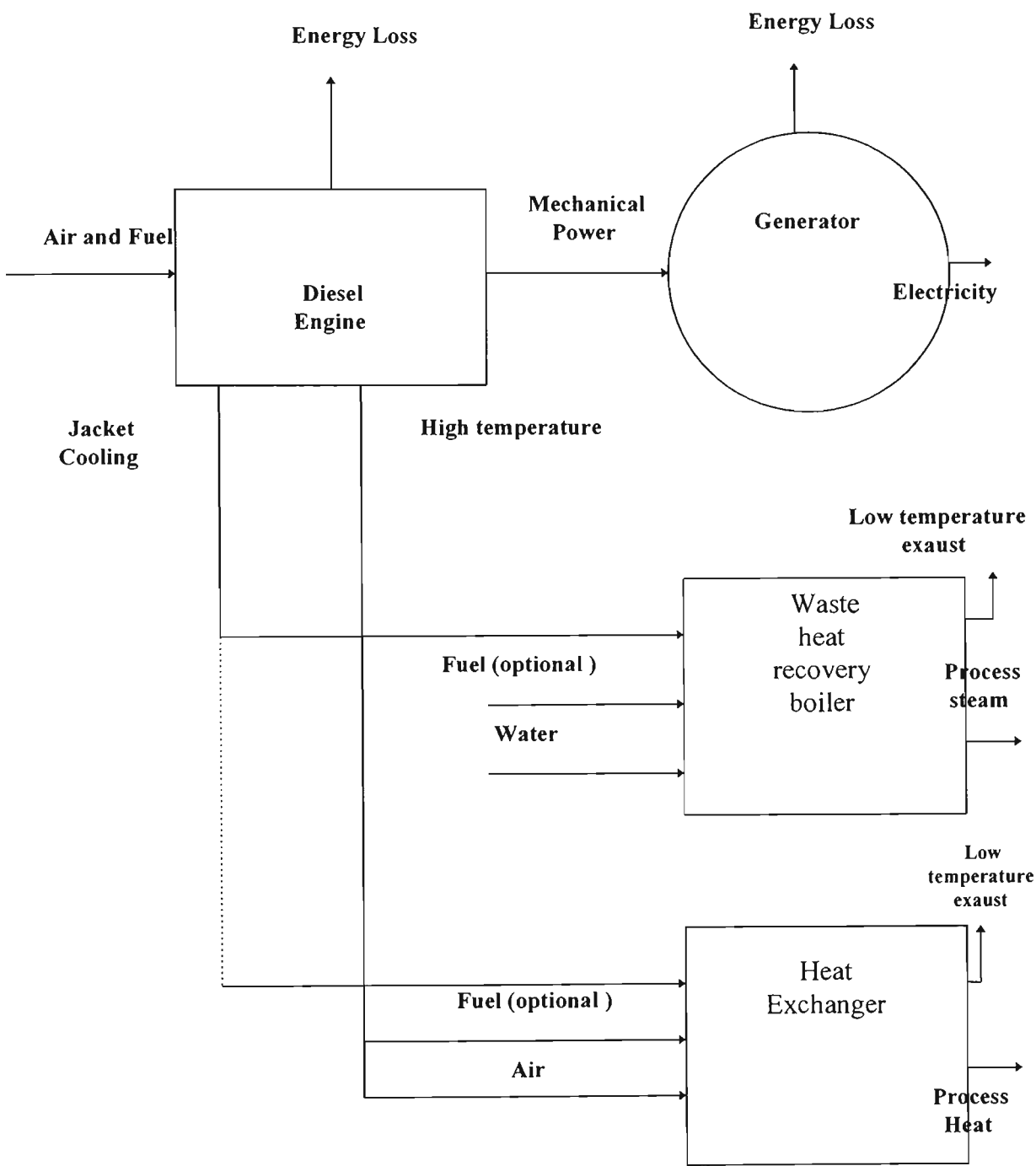


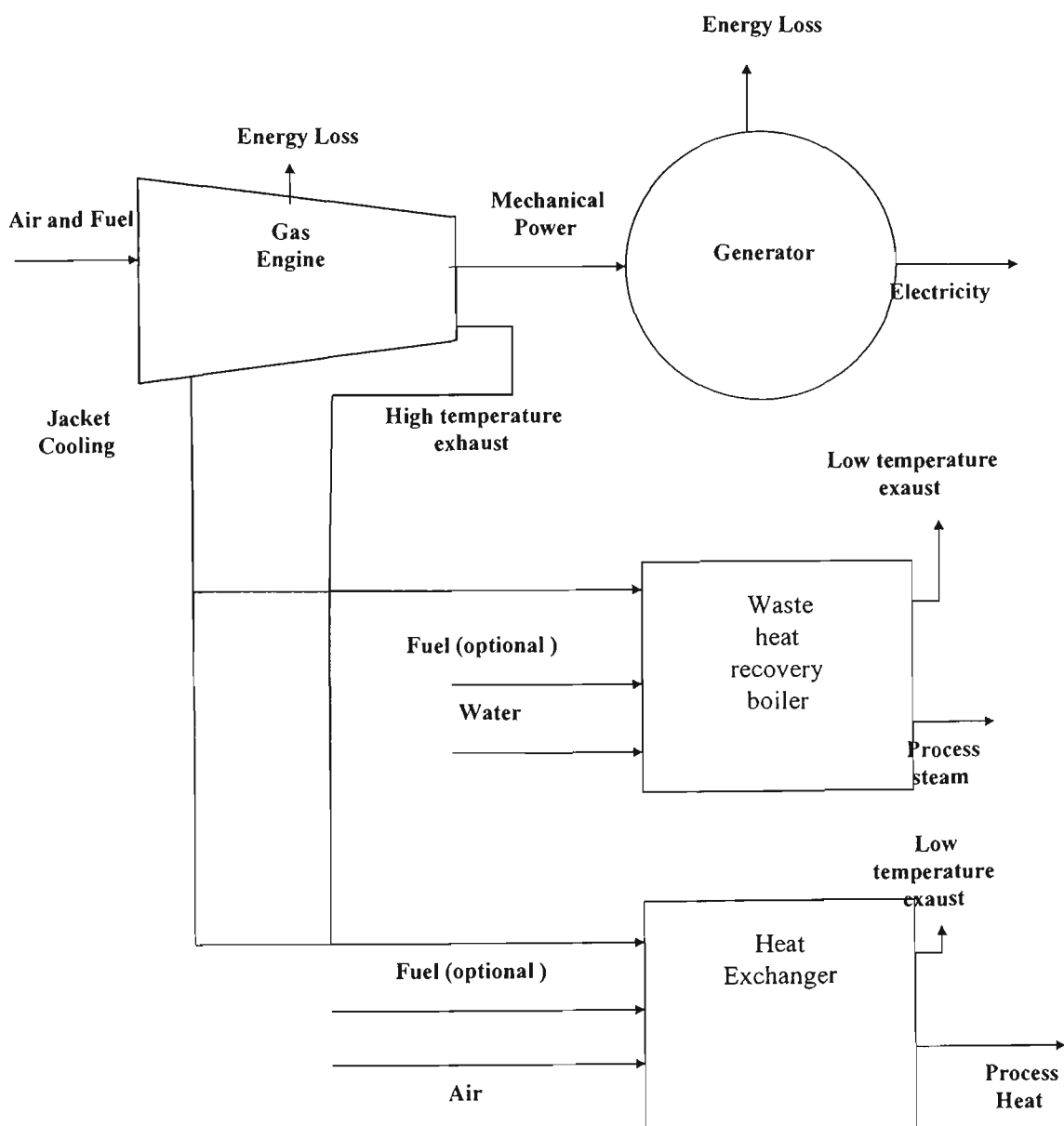
Figure 2.3 Diesel topping system

The reciprocating engine system is similar in many ways to the more familiar unit used in cars and lorries. The heat that is generated in a car engine is dispersed using cooling water through a radiator and the shaft power is used to drive the wheels. In a cogeneration unit, the heat is

dispersed in a similar way, usually through radiators in a building, and the shaft power is used to drive an alternator to produce electricity. These units range from several kW to around 10 MW and may burn gas or fuel oil depending on their size.

### 2.1.2.3 Gas Turbine

Gas turbines are essentially stationary jet engines, (Figure 2.4). Many utility use gas turbines for power generation at peak load. In this application, the mechanical shaft energy of the gas turbine drives a generator unit.



**Figure 2.4 Gas turbine topping system**

In cogeneration, the high-temperature (430°C-520°C) exhaust heat from a gas turbine can be used as a heat source for process use or as input to a waste heat boiler to generate steam. For a given amount of steam required, gas turbines can produce more electricity per unit of steam than steam turbines.

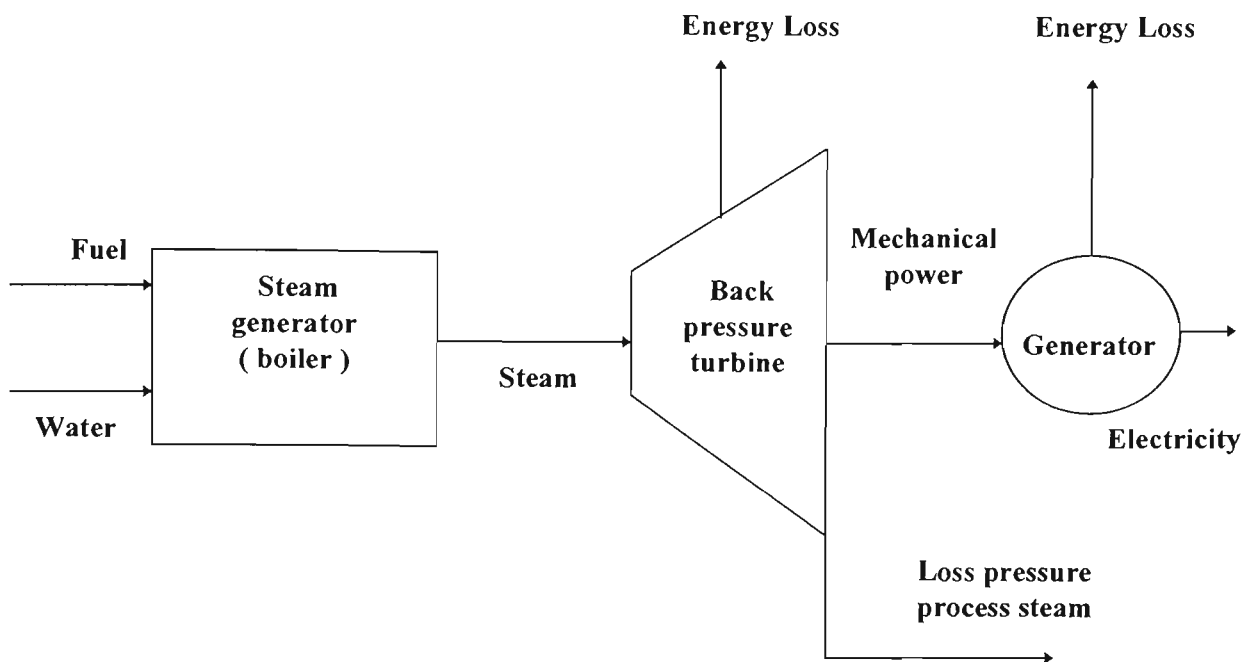
Gas turbines require natural gas or light distillate as fuel. Small gas turbines, because of their relatively low electrical efficiency and high excess air requirements, are generally of interest in applications where heat usage is four to five times electricity usage.

A gas turbine cogeneration system can be compared with an aircraft jet engine. The rotary motion of the shaft is again used to drive an alternator whilst the hot exhaust gases, rather than passing to the atmosphere at 32,000 ft, are passed into a boiler to generate steam or hot water. Their output range is from around 1 MW to hundreds of MW. This is increasingly becoming the most favourable technology for industry.

Stability studies were performed for 6 MW gas turbines used for cogeneration. Various short circuits faults were simulated to study transient stability. Results of the simulations showed that the turbines were steady state stable. The turbines were also dynamically stable for all normal operating conditions. The critical clearing time for three phase faults close to the turbines ranged from 180 ms to 210 ms [ 4 - 5 ].

#### **2.1.2.4 Steam Turbine**

Steam turbine topping cycles represent the most widely used method for power generation in Victoria at the present time, (Figure 2.5). In a cogeneration system, steam is taken from the turbine at a pressure and temperature appropriate for the process energy needs (generally at much higher pressure than conventionally rejected from a power plant). This is achieved by extracting the steam exhausted from the turbine at a high pressure. The result is a decrease in the amount of electricity produced per unit of steam and an increase in the availability of thermal energy.



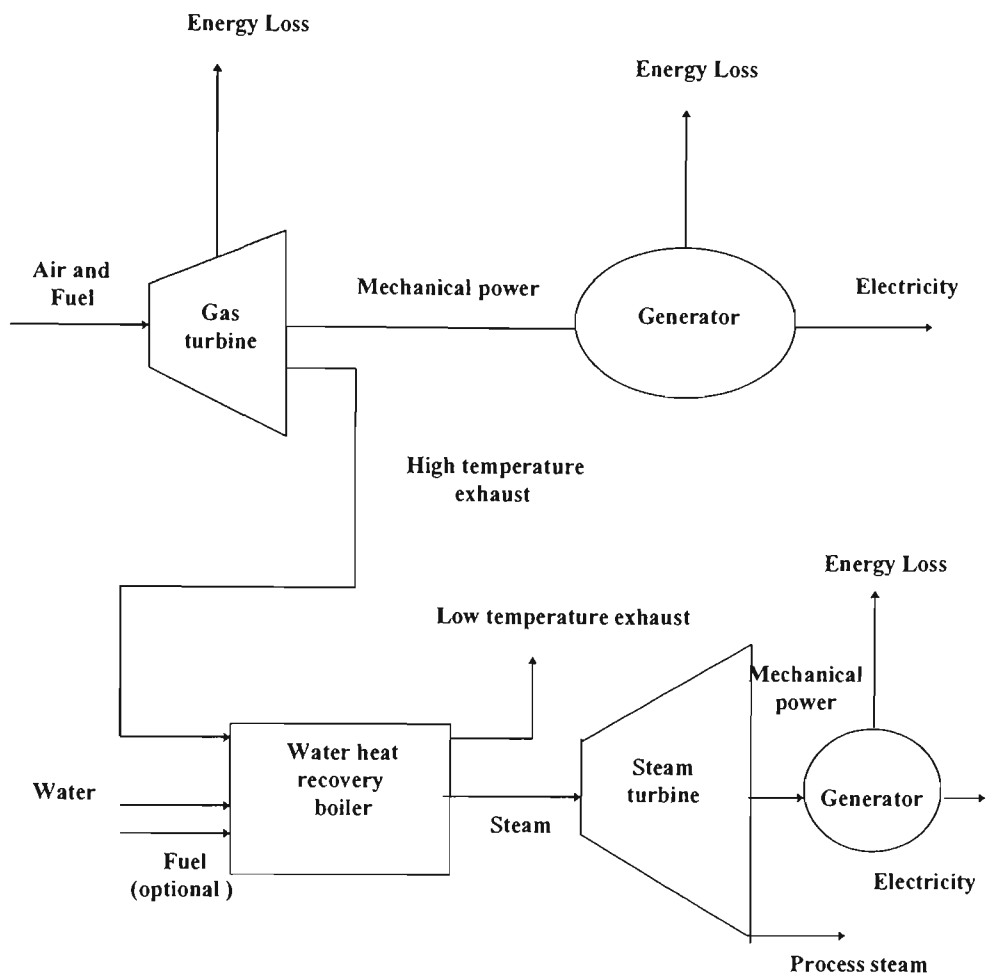
**Figure 2.5 Steam turbine topping system**

The steam turbine system is most commonly used in power stations and is best suited to large installations. At the power station fuel is burnt in a boiler to produce steam at high pressure that is then passed through a steam turbine generating electricity. The low grade steam that emerges from the turbine is condensed in cooling towers before completing its circuit back into the boiler. In a cogeneration scheme, the cooling tower element is replaced with a process that can successfully utilise the heat before returning the water to the boiler.

### 2.1.2.5 Combined Cycle

In combined-cycle cogeneration, a gas turbine with a waste heat boiler is combined with a steam turbine, (Figure 2.6). Both engines produce power and then use the exhaust heat or turbine exhaust steam for a heating process. A combined-cycle is most often used when the distribution of heat and power is such that a simple cycle will not meet load requirements effectively.

In a combined-cycle system, the gas turbine drives an electrical generator, and the rejected heat is recovered by a waste heat boiler. The steam produced in the waste heat boiler is used in



**Figure 2.6 Combined cycle topping system**

a steam turbine driving a generator to produce additional electricity. Steam rejected from the turbine is then used directly in the industrial process or for space heating.

**2.1.3 The Market**

Whichever energy or finance related magazine one chooses to read these days there is almost invariably an article on cogeneration; either by a scholar describing the thermodynamic harmony and increased efficiencies of the systems or by a shrewd business manager who is proud of the fact that savings have been made by installing this technology. Cogeneration has become an important issue and there is pressure on Finance and Energy Managers alike to investigate its application. The recent privatisation of the electricity supply industry (ESI), together with a number of business and technical changes, have provided new impetus to the development of cogeneration. It is not these factors alone that are providing renewed interest in cogeneration, but their conjunction at this time. Taken together, the factors provide a

window of opportunity for the exploitation of cogeneration. The development of cogeneration has increased since the restructure of the ESI, but there is still a long way to go to catch on to the rest of the world.

#### **2.1.3.1      60 years ago**

Before the development of the Australian's electricity grid system, power stations were sited close to centres of demand. This provided the opportunity, where appropriate, to utilise the waste heat from the power station.

#### **2.1.3.2      Growing Electricity Demand**

As the demand for electricity grew, the high cost of moving coal, the dominant fuel for generation, made it economically attractive to build large power stations on, or close to, coal fields. In response, the Grid grew to allow bulk transfers of electricity from the power stations to the demand centres-often referred to as coal by wire.

#### **2.1.3.3      The Situation Today**

The generating companies inherited an asset base predominantly centres upon coal-fired power stations remote from demand centres and unable to use about two thirds of their heat input. Gas is becoming established as a fuel for power generation and the traditional reservations about using it in this role are defeated by the efficiencies achieved with cogeneration.

#### **2.1.3.4      The Future**

In total contrast to coal, gas can be moved relatively easily and without impacting on the environment. Therefore, the engineering case for gas-fired cogeneration meeting local heat and power needs is very strong. There might well be seen a reversal of the trends of the last 60 years, with the use of the Grid declining and heat and power production being combined close to the point of need.

### 2.1.4 Cogeneration in Australia

Cogeneration has existed in Australia since the introduction of electricity. In the early days of electricity, industry often provided its own power Cogeneration where the balance of heat and power was right) and the public system provided domestic and public power. As public utility power became more available and reliable generation on-site reduced.

The 1980's saw an upturn in cogeneration for environmental and economic reasons particularly in Victoria and South Australia. In 1987 the Victorian State Government and State Electricity Commission (SEC) of Victoria introduced a Cogeneration Incentives Package and about the same time in South Australia SAGASCO established a Cogeneration division.

The 1990's presents an era of great opportunities and challenges for the Cogeneration industry as the energy supply industry is transformed by the break-up of vertically integrated utilities (in Victoria) and the introduction of competition between energy supplier and the Grid.

Cogeneration is not just a smart technical solution to provide heat and power to industry and commerce in a cost effective and environmentally sound manner. Cogeneration exists in a complex competitive and regulatory environment which has capacity to prevent the full development of its contribution to the economy and environment.

#### 2.1.4.1 Cogeneration data

The available estimate puts cogeneration capacity in Australia at about 1,747 MW, made up as follows:

State	Number of projects	MWs
ACT	1	0.1
NSW	16	300
NT	1	105

State	Number of projects	MWs
QLD	28	357
SA	25	38
TAS	2	16
VIC	31	350
WA	11	582

Cogeneration projects in operation and those under construction amount to 2082 MW and represent 5.1 percent of installed electricity generation in Australia [66].

#### **2.1.4.2 Victorian Support**

Within five years, it is conservatively expected that about 500 MW of Victoria's power will be fed into the Utility grid from private and public cogeneration and renewable energy projects, the equivalent to the output from one Loy Yang power station unit [1].

Currently, 350 MW of Victorian power is produced via cogenerating industries and institutions. Twenty two (22) Natural gas fuelled cogenerating plants produce a total of 128.5 MW of power. Waste gas fuels four (4) cogeneration plants to produce a total of 106.19 MW of power. Two (2) cogeneration plants are fuelled by Coal to produce a total of 110.2 MW of power. Landfill gas fuels two (2) cogeneration plants to produce 5.1 MW of power.

Appendix B details the register of cogeneration plants in Victoria. It is evident from appendix B, that twenty three (23) out of the thirty one (31) Victorian cogenerating plants were installed during the 1990's [66].

In Victoria, there are currently two (2) cogenerating plants operating at a capacity of above 30 MW. There are six (6) cogenerating plants operating at a capacity of 10 to 30 MW. Fourteen

(14) cogeneration plants operate between 1 to 10 MW. Nine (9) cogeneration plants operate below 1 MW [66].

#### **2.1.4.3 Utility support For Cogeneration**

Victoria has traditionally relied on its plentiful brown coal resources as a source of base load electricity and on natural gas and hydra for its peak load. It is clear, however, that great potential exists for industry and commerce to contribute economically to electricity production through cogeneration.

The Victorian Government has given cogeneration a high profile and its support for the development of the technology was outlined in the Government Economic Strategy Paper- "Victoria The Next Decade" released in 1984. This was followed by the Government's paper in June 1989 on the Greenhouse Challenge outlined Cogeneration as one of the vehicles to minimise atmospheric emissions of greenhouse gases.

**To further the commitment in promoting cogeneration in Victoria the following measures are taken:**

- Providing a market for cogenerated power by enacting a statutory commitment to purchase the power.
- Providing reasonable buyback rates for cogenerated power that reward cogenerators but are not subsidised by other customers. This can be done by buying excess power at the Utility's avoided cost, that is, the amount the Utility saves by not generating the power itself.
- Making payments to cogenerators who guarantee the availability of future capacity. These payments reflect the amount the Utility saves by the deferral or elimination of the need for some future power stations.
- Adopting a new approach to standby supplies to remove current discrimination against cogenerators.

- Examination of wheeling policies to encourage worthwhile cogeneration projects to proceed.

**The Utility has adopted the Government's policies in its Cogeneration and Renewable Energy Strategy. This strategy includes:**

- encouraging the efficient use of fuel and helping its customers gain the benefits of energy efficiency from cogeneration and renewable energy projects;
- promoting ways of reducing levels of  $CO_2$  emission into the atmosphere by encouraging technology such as cogeneration;
- considering opportunities for joint ventures in potential cogeneration and renewable energy schemes;
- encouraging and promoting commercially viable projects by introducing incentives to stimulate interest in cogeneration and renewable energy projects;
- encouraging the development of a professional and effective cogeneration and renewable energy industry.

## **EXAMINING FUEL POLICIES AND PRICES**

- In recognition that a high proportion of potential cogenerators are now burning natural gas to produce process heat or steam, users should be encouraged to convert to cogeneration as a small addition amount of gas burned can yield an overall energy saving.
- Encourage the use of coal in cogeneration systems.
- Examining the pricing structure of natural gas for cogeneration. Evaluation of the merits of a separate cogeneration gas tariff and its effect on the existing Government gas pricing policy.

- Encourage the use of renewable fuels and residues through provision of Government financial incentives.
- Provide financial assistance for feasibility studies for projects that on initial assessment look technically feasible and economically viable.
- Encourage projects to serve as local models and using early studies to evaluate effectiveness of efforts to promote cogeneration.

**The key elements of the Utility incentives package for projects smaller than 10 MW are:**

- for sites which take utility power in addition to cogeneration, the standby demand charge is waived for three years,
- Utility interconnection costs are repayable over the contract period,
- Utility buyback rates up to 10 MW are tied to the Utility's tariff rate and are linked to CPI increases,
- financial assistance is available for feasibility studies for special projects,
- a 10 year contract period which allows for escalation in buyback rates.

In 1987, the then SEC in conjunction with the Victorian Government took the initiative by launching the "Cogeneration & Renewable Energy Incentive Package" to further encourage the smaller potential cogenerators.

**ENCOURAGING COGENERATION IN THE PRIVATE AND PUBLIC SECTORS**

- Carrying out a detailed examination of cogeneration potential into public facilities  
e.g. hospitals, universities, libraries, nursing homes etc.
- Installing and promoting the installation of cogeneration plants instead of constructing additional new central power stations.

- Encouraging financing of Private and Public sector projects by outside investors.

## UNDERTAKING AN INFORMATION AND TECHNICAL ASSISTANCE PROGRAM

- Developing a marketing plan to promote the development and wider use of **cogeneration** .
- Developing publications to promote the awareness of the opportunities arising from **cogeneration** in the community, particularly the industrial and commercial sectors.
- Establishing a Cogeneration Advisory Group to help potential cogenerators and provide a consultative service.

Some people are still surprised that the utility synonymous with what they believe is a power monopoly, should be promoting alternative production. The reasons are not only economically and environmentally sound, but also ensure efficient utilisation of the State's resources. It costs the Commission about \$1.3 million to produce one megawatt of power. Therefore 500 MW of cogeneration power will save it \$650 million in capital expenditure. The utility benefits directly by avoiding capital borrowing's, particularly for the construction of new power stations.

Cogeneration also creates new electricity supplies much faster than the Commission could plan and build new power stations, which take many years from inception to production. Small generation plants whether cogeneration or renewable also meet environmental licensing requirements more easily than a new central power station. They can also introduce power into the system near to the point of use and reduce system losses [1].

## **2.2 Commercial Viability, Cost and Performance**

### **2.2.1 Cogeneration Commercial Viability**

Krishna et al described the operation of a computer aided distribution system planning and design code and its application on Indian distribution networks with a view to reducing high energy losses in the distribution systems [6]. The potential for significant increase in the number of cogeneration facilities will grow as energy costs continue to increase. Parallel operation provides for both utility and industry export of the surplus electricity and a source of imported power in an emergency [7].

It would be irresponsible to give the impression that cogeneration offers a panacea to all energy problems. Commercially viable opportunities are still small in number. The main factors influencing commercial viability are dependent on site's heat to power ratio and equipment utilisation.

#### **2.2.1.1 Heat / Power Ratio**

The balance of heat and power should be compatible with the cogeneration plant, of the order of 3:1 for a gas turbine based scheme[1]. This ratio should ideally be constant, not changing drastically either seasonally or daily. Schemes with a heat to power ratio greater or less than 3:1 would need to consider carefully the commercial implications of exporting or importing electricity.

#### **2.2.1.2 Utilisation**

Although the cost of cogeneration is falling in real terms, it is still relatively expensive compared with large generating plant and shell boilers. It is, therefore, important that the plant is fully utilised. The most viable schemes are, therefore, those that run continuously for 8000 hours/year or more.

### **2.2.1.3      Avoidable costs**

Where capital expenditure is required to replace existing boiler plant, provide extra boiler plant or increase electricity supply capacity the expenditure saved by employing a cogeneration scheme can be set against its capital cost. Any savings in maintenance, manpower or even plant outage times can also be credited to the scheme.

### **2.2.1.4      Fuel Supply / Electrical Connections**

It is helpful if a gas supply is available at the site with sufficient capacity to connect the gas turbine without reinforcement. If the delivery gas pressure is such that gas compression is not required, further capital and running costs are saved. At the electrical end of the cogeneration plant, it is almost inevitable that the scheme will be run in parallel with grid system.

A study model by Kwun et al presented the model that integrates the supply planning of potential cogenerating industries with that of the host electric utility suppliers [8]. It provides a tool for electric utilities and potential cogenerators to analyse the effect of cogeneration on their energy supply plans. The model can analyse how much the potential benefits of cogeneration might be and how the benefits might be distributed among the participating industries.

The Electric Power Research Institute has sponsored work to provide guidance on the specification and procurement of simulators in the fossil power plant industry. Both simulator vendors and utility personnel were contacted to identify what type of guidance was needed based on past experiences and projections for the future. This information was used as a basis for the development of a model of the simulator procurement process. This model includes pre-specification steps, specification development steps, and post specification steps [9-10].

Ideally, connection should be achieved without the need to reinforce the local distribution system, and without the need of expensive modifications to the site electrical system.

### 2.2.2 Costs of Small Cogeneration Systems

Arvey et al described the electrical requirements, including utility interfaces, engineering, and on site testing, as applied to the execution of a large, multi unit turnkey cogeneration project in California. The benefits of careful engineering efforts are shown to result in timely and cost effective completion of engineering, manufacturing, installation, testing and commercial operation [11]. The EPRI intelligent tutoring system described by Brennan et al supplements a utility's limited ability to schedule instructors and pull operators from normal station operational activities to attend shifts dedicated exclusively to training [12]. This innovative, cost-effective technique extends the amount of useful training time a utility ( or other industrial firm ) can obtain from their investment in a training simulator.

Identification of the optimum generation schedule by various methods of coordinating incremental generation costs and transmission losses has been described by Clapper et al [13]. This method expresses all the optimum plant generations as a cubic function of the load demand which readily gives the optimum plant generations on substitution of the load demand. Bengiamin presents an economic dispatching scheme for a cogeneration plant with thermal needs and power purchase facilities [14]. Part of the demanded electric power is generated locally in the plant while the rest is purchased, via a tie line, from a neighbouring utility company. The primary objective of the developed scheme was to share the load among the in-plant generating units and the tie line such that the best economic mix is achieved while the on-site process steam needs are satisfied.

The average total installed cost of small cogeneration systems is \$1,551 per kW (in 1988 dollars). The average cost of equipment only is \$902 per kW. The total cost of systems configured with emission control equipment is 13 percent higher than those without the emission control equipment. As the system size increases from less than 20 kW to over 1000 kW, the total costs in \$/kW decreases from \$2,080/kW to \$1,458/kW.

The average total installed cost of \$1,551 per kW is \$115 more than that reported in the earlier EPRI small cogeneration system costs and performance report. The distribution of costs about the mean is given in Table 2.1

**Table 2.1      Distribution of total costs of small cogeneration systems**

\$/kW Range	Number of Systems	Percent of System %
600-800	4	7.7
800-1000	1	0.2
1000-1200	6	11.5
1200-1400	7	13.5
1400-1600	12	23.1
1600-1800	5	9.6
1800-2000	11	21.2
2000-2200	3	5.8
2200-2400	1	0.2
2400-2600	1	0.2
2600-2800	1	0.2
<b>Total</b>	<b>52</b>	<b>100.0</b>

### 2.2.3      Performance of Small Cogeneration Systems

Dialynas presented a brokerage system that used linear programming ( LP ) to maximise the savings or profits to each utility subject to import and export constraints. The cost quotations can also be determined using an LP formulation. This method is useful since it provides an uncomplicated means of scheduling energy transfers that is fast, versatile and efficient [15].

A direct method to optimise generation schedules neglecting transmission losses has been developed. To minimise the total fuel cost  $F_t$ , it needs the determination of two constants which are expressions in terms of a, b, c constants of cost curve equations and the received power  $P_r$ . The optimum schedules including transmission losses may be obtained when the total received power is considered as total generation [16].

The average availability of the cogeneration units is 88 percent, the average service factor is 67 percent, and the average net output factor is 93 percent. The average availability determined in this study (88 percent) is 9 percent greater than that reported in the earlier EPRI small cogeneration system costs and performance report.

Over half the units were operating at an availability of over 95 percent. The average availability is 88 percent with a standard deviation of 17 percent. The distribution of the percent of units by availability range is given in Table 2.2.

**Table 2.2      Distribution by availability range**

<b>Availability Range</b>	<b>Per Cent of Units</b>
< 50%	<b>4.4</b>
50 - 55%	<b>2.2</b>
55 - 60%	<b>1.9</b>
60 - 65%	<b>1.0</b>
65 - 70%	<b>0.6</b>
70 - 75%	<b>3.8</b>
75 - 80%	<b>3.5</b>
80 - 85%	<b>3.8</b>
85 - 90%	<b>8.9</b>
90 - 95%	<b>15.6</b>
95 - 100%	<b>54.3</b>

Table 2.3 presents the performance statistics by operating year and calendar year. In the first year of operation, availability is lower because of start up problems. In subsequent years as technology and maintenance techniques improved, availability of the systems improved. Service factors do not show any improvement by operating year since they depend primarily on the sizing of the system, and facility load shapes do not change from year to year.

**Table 2.3      Performance of small cogeneration systems by year of operation**

<b>Operating Year</b>	<b>Availability %</b>	<b>Service Factor %</b>	<b>Net Output Factor %</b>
1	84%	68%	97%
2	88%	72%	96%
3	85%	66%	95%
4	87%	73%	96%
5	93%	67%	92%

## 2.3 Protection Principles

### 2.3.1 Role of Protection

This section deals with protection principles and how they could be deployed to solve some of the common protection problems encountered by industrial cogeneration plants today.

Protective devices and systems are installed at practically every node of the power system so that every plant item in the entire power system is protected against faults.

The most typical faults occurring in any electrical plant are short circuits, i.e. breakdown of insulation between metallic parts which should be at different potentials. There are also protections against other faults which are more specific to particular plant items, e.g. failure of a cooling pump, a break in a control circuit, excessive speed or pressure.

The fundamental role of protection systems is to:

**DETECT FAULTS and REMOVE FAULTY ELEMENT of the system so that the DAMAGE TO THE POWER SYSTEM IS MINIMUM.**

Some protection systems even prevent faults by detecting abnormal operating conditions of the protected plant.

Removal of the fault is effected through isolation of the faulty plant from the power system by opening (tripping) the nearest circuit breakers which connect the plant to the rest of the system. The power system is designed to remain fully operational after losing a limited number of plant items but such a loss sets a contingency which, if followed by another one, may lead to a breakdown of the system.

### 2.3.2 Faults and their effects

Faults in a three phase power system may occur between circuits of different phases or between the phase circuits and earthed metallic structures.

The phase to phase fault currents in the transmission and distribution systems in Victoria may exceed 25,000A[1]. For faults on the 220 kV part of the system this corresponds to a fault level of nearly 10,000 MVA.

Both transmission and subtransmission systems operate with solidly earthed neutral and, therefore, the magnitudes of earth fault currents in the power grid are usually as large as those for phase to phase faults. In many distribution areas neutral earthing resistors are installed to reduce the earth fault currents. These resistors, the grid impedances and, particularly, a fault resistance, e.g. that of the tree branch that has caused the fault and that of a rocky soil, may reduce the fault current to a small, sometimes barely discernible level.

Faults cause significant voltage disturbances near the fault point and a voltage collapse, often to zero at the point of the fault occurrence.

The voltage gradients in the ground and across earthing resistance make dangerous step and touch voltages in the vicinity of the fault.

The enormous dynamic forces of the great fault currents, the electric arc at the fault point, the thermal effect of the currents on the grid elements in the current path cause damages to the plant. The voltage and current disturbances interrupt the transmission of power and weaken the ties interconnecting the system which may result in loss of system stability and a break up of the system into non-synchronous parts.

Failure to remove a fault would usually result in rapid expansion of the damage to the system.

### **2.3.3 Protection Requirements**

All protection systems have to meet general requirements of protection philosophy: RELIABILITY and SPEED. There are two components of reliability: DEPENDABILITY AND SECURITY.

DEPENDABILITY means a high degree probability that the protection will operate correctly in every case it is required to do so i.e. that it will never fail to remove a fault in the protected

zone. One of the elements of reliability is SENSITIVITY of protection systems. Sensitive protection detects even relatively weak signals of a fault and by its early clearance prevents development of the fault into a more damaging form.

SECURITY means a high probability of protection remaining inert to all conditions which should NOT cause operation of the protection e.g. load on the system or faults external to the protected zone. Security is also called STABILITY as it requires that protection systems remain stable and do not interfere with the operation of the healthy plant.

To be reliable and secure the protection systems have to be SELECTIVE in their operation i.e. initiate trip of only those circuit breakers which must be tripped to isolate the faulty plant without affecting any other plant that can remain in service. Selective protection is also called DISCRIMINATIVE. Indiscriminative tripping of larger number of circuits than necessary is sometimes accepted in less important installations where only cheap protection is justified or in an emergency backup action when the proper protection has failed to operate discriminatively.

Requirements of high dependability and security are often contentious, sometimes incompatible. In this rivalry, the dependability is usually considered more important even with some sacrifice of the security.

High SPEED of operation of protection systems may be critical for the integrity of the power system where faults may cause loss of the system stability. Fast fault clearance is always desirable for limiting the effects of faults. Protection operating times vary from a fraction of a cycle to several cycles in the transmission system and may exceed one second in the distribution network. Typical total power grid fault clearance time which includes operating times of protection relays and circuit breakers is in the region of 50 to 150 milliseconds. In some areas of the power grid such speed is necessary to preserve system stability.

Maintaining high reliability and speed of protection systems requires expensive protection equipment and communication facilities for protection. The high investment is justified in the

extra high voltage part of the grid, because of the wide spread effects of disturbances in that part. The protection design, like any other design, is a trade-off between the quality and the cost.

### **2.3.4 Instrument Transformers**

Information about the state of the power system is supplied to protection and monitoring equipment via instrument transformers of two types: current transformers (CTs) and voltage transformers (VTs). Voltage transformers for extra high voltage systems are combinations of voltage transformers and capacitive voltage dividers and are often called capacitive voltage transformers (CVTs).

Instrument transformers isolate electrically the high voltage primary circuits of power plant from the low voltage secondary circuits of protection and measurement and reduce the magnitudes of voltage and currents to conveniently measurable levels.

Current Transformers in the Power Grid are formed in stacks of several toroidal cores that have common high voltage insulation but serve each different protection or metering circuit. Stacks of CTs are either installed in the bushings of transformers and switchgear or form free-standing posts in the switchyard.

CT rated secondary currents are standardised at 1A for 330 kV and 500 kV system and at 5A for the rest of the power system in Victoria. The standard secondary phase to phase voltage of VTs is 110 V throughout the system. The primary rated voltage is selected to the required primary system voltage from a range of typical values.

The transformation of the primary magnitudes to the secondary level must be accurate to 5% over wide ranges of the primary voltage and current. The phase angle of the primary quantities must also be accurately conveyed to the secondary instruments. Specifications of instrument transformers are based on Australian Standards [ 49 ], the power utility previous experience and the requirements of the project.

The protection instrument transformers are selected by the engineer designing the protection. The ratios, VA ratings, and accuracy classes are based on the predicted load, expected fault levels and the requirements of the protection equipment.

Nonlinear magnetising characteristics and saturation of the iron cores of current transformers cause loss of accuracy of transformation at high primary currents. The errors have steady-state and transient components and depend on the magnitude of primary current, burden in the CT secondary circuit, dynamic characteristics of the primary and secondary circuits, magnetic remanent in the CT core, instant of the fault inception and other factors. The saturation occurs some time after the fault and there is usually an initial period of at least a few milliseconds of reasonable accuracy of transformation in the CT. This may be utilised for protection measurement provided the design of the protection systems is precise, the relays are fast enough and they can distinguish the accurate signal from that already corrupted.

Possibility and severity of CT saturation should be predicted by the designer of the protection systems. This can be done by mathematical modelling of the primary and secondary systems. After determination of the parameters of such a model the engineer can use computer programs for solving the differential equations describing the transients.

Transient errors of CVTs during faults and a possibility of their ferroresonance may also affect the operation of protection systems and have to be taken into account in the protection design [17].

### **2.3.5 Overcurrent Protection**

Overcurrent protection devices detect short circuits by monitoring the magnitude of the current flowing in the circuit. Due to its nature of detecting current greater than the maximum allowable current the overcurrent protection cannot detect short circuit currents which happen to have a value less than the maximum load current.

Fuses and overcurrent relays are typical overcurrent protection devices. These devices make the least expensive form of fault protection and they are very common in distribution systems and networks.

The main transmission systems are protected by more sophisticated and expensive protection schemes because of the high requirements of operating speed and more complex criteria of discrimination applicable to those systems [18].

### **2.3.5.1 Fuses**

These are the simplest form of overcurrent protection, capable of detecting and breaking faults. They interrupt the fault circuits by blowing the fusing element connected in series with the circuit. Fuses are generally designed to break the circuit in a very short time which, however, depends on the current magnitude and the fuse size. Grading of the fuse sizes in distribution systems allows for discriminative elimination of faults.

In a typical tree configured supply system the fuses are graded so that the biggest fuse is fitted in the trunk of the tree and smaller and smaller fuses are in the consecutive step down branches. At every step from the trunk to a remote branch the fuse ratings typically decrease by half. This allows for quick interruption of the remote faulty circuit by the smaller 'minor' fuse in this circuit without affecting the next fuse toward the supply source. This next fuse is called 'major' with respect to the 'minor' fuse in the more remote branch.

Fuses operate very quickly on large fault overcurrents eg. in 4ms the circuit may be interrupted preventing the fault current from reaching the full magnitude determined by system parameters. The great operating speed of the fuse limits not only the amount of energy released into the faulty circuit but also the dynamic effect of the fault.

Fuses need replacement after every operation and cannot break fault currents in very high voltage circuits. Fuses also cannot be graded to discriminate in the circuits supplied from both ends.

Fuses are used in radial supply, low and high voltage installations up to 33 kV. They protect feeders, transformers, motors, small generators and other plant.

With the increased use of larger, higher voltage, substations and distribution systems, industrial plants are faced with more possibilities of potential transformer ferroresonance. Hoerauf et al review the basic phenomenon of ferroresonance and provide general guidelines for the application of potential transformers in avoiding ferroresonant problems in industrial systems [17].

### **2.3.5.2 Overcurrent Relays**

Overcurrent Relay operates when the current in its coil exceeds the pre-set operating threshold of the relay called the current setting or the pick-up current. The relays feed directly from Current Transformers which provide a proportional value of the current in the monitored primary circuit. An operation of the relay initiates tripping of the Circuit Breaker (CB) in the monitored circuit and, thereby, causes isolation of the circuit from the supply source. When the CB has opened the fault current no longer flows, the relay resets but the CB remains open.

Overcurrent relays are made in the wide range of technologies from electromechanical, to microprocessor based and with a variety of performance specifications.

The operating time of instantaneous and definite time relays is, practically, independent of the magnitude of the fault current once this magnitude exceeds the operating threshold of the relay.

The inverse, very inverse and extremely inverse characteristics offer faster operation for greater fault currents and very slow operation for currents close to the threshold. A discriminative protection plan for radially fed distribution system can be developed using grading of Overcurrent settings. Methods of discrimination are: grading by current, grading by time and grading by current and time.

### **2.3.5.3 Discrimination of Overcurrent Protection**

#### **2.3.5.3.1 Grading by Current**

In a radial system the fault current magnitude is greater if the fault occurs close to the source than in case of a remote fault because the impedance of the fault path increases with the distance from the source.

The simplest type of protection grading would be to use instantaneous relays with such increasing settings of their operating thresholds  $I_a > I_b > I_c > I_d$  so that the relay closer to the source, say relay A, would not operate for fault beyond the next substation, B, relay B would not respond to faults beyond C and to continue this grading throughout the network. This method, however, relies on substantial differences between the fault levels at the consecutive stations which is not often the case. In no case, the current grading may be used as the sole protection scheme of a plant because the protection operation zones of such a scheme do not overlap and large 'blind' sections of the network remain unprotected. This method is, therefore, used mainly in a supplementary capacity in some schemes.

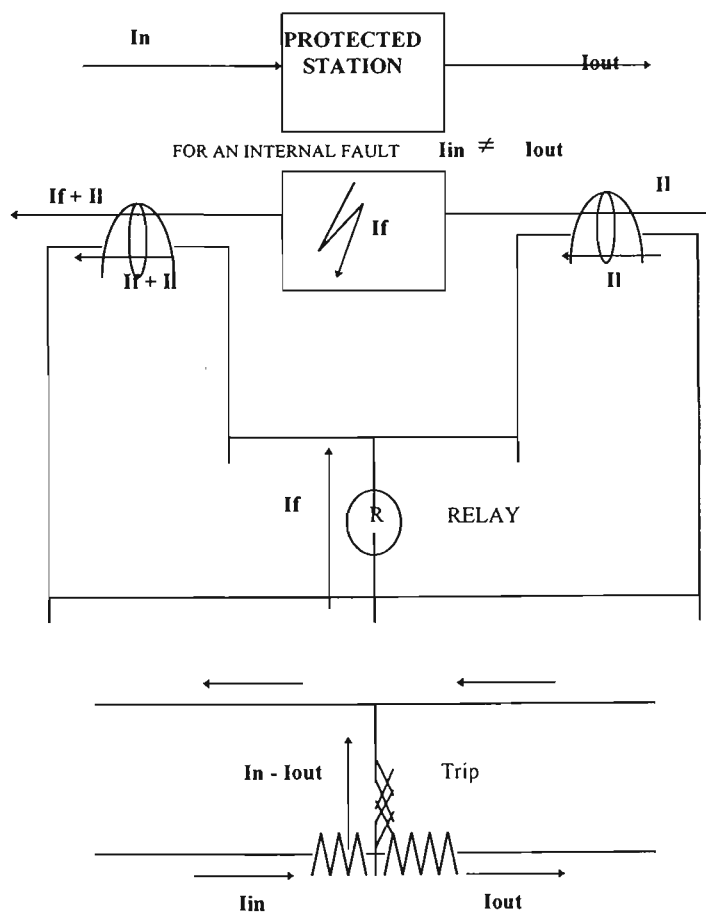
#### **2.3.5.3.2 Grading by Time**

Grading by time is based on use of definite time relays, which may have current settings far below the minimum fault current for the whole network. The discrimination is achieved through increasing the time delay by the grading margin, usually 0.5 second, at every step toward the supply source. This method is suitable for networks where the fault currents has little dependence on the fault location. This method, but with a small number of steps, is commonly used in Europe. The big drawback of the method is a build-up of the operating time towards supply source which results in very slow clearance of faults occurring close to the source.

### 2.3.5.3.3 Grading by Time and Current

If the fault level falls substantially from substation to substation with increasing distance from the source then much faster fault clearance than that in the time grading method may be achieved through grading by time and current. By proper selection and setting of the inverse I-t characteristics a discriminative plan of relatively fast tripping can be developed, Figure 2.7.

Although the proper grading margin of 0.5 second is maintained for faults near the more remote substations yet the clearing of a fault near the source is almost as quick in this scheme as clearing a fault a long way from the source. The 0.5 grading margin is required to cover such delays as circuit breaker clearance time, relay overshoot time and relay timing errors.



**Figure 2.7 Differential system with bias coils**

## **2.4 Protection considerations in cogeneration schemes**

Chen et al presented detailed three-phase cogenerator and transformer models for analysing a large scale distribution system. The cogenerator model represented the inherent generator phase imbalance due to distribution system imbalance. The cogenerators can be synchronous or induction and can be on either primary or secondary systems [19].

Power capacitor is an ideal source of leading reactive power to compensate the lagging reactive power consumption of the loads on industrial power systems and thus to achieve an improved power factor of the plant. If due importance is not given in the selection and design of its switching and protective devices, it may lead to sudden failure of the capacitor installation. Pandian dealt with the design of protections and various considerations while applying capacitors on industrial systems [20].

Close corporation between the Utility and the DSG owner and serious efforts to resolve any potential problems that may be encountered when interconnecting a DSG will ensure safe and effective parallel operation of dispersed generation [21].

Voltage disturbance at the interface between the utility and a major industrial customer can have a catastrophic impact on the utility, the customer, or on other seemingly unrelated customers in the vicinity. While methods of moderating the severity of these excursions can be found in some cases it is not always possible to eliminate them entirely; in many instances the solution to the voltage disturbance problem is to design the system to operate in spite of deviations from the nominal applied voltage [22].

Pattern et al described an analysis of utility protection problems associated with small wind turbine interconnections. In general, utility protection interference problems are not likely to arise until a significant feeder penetration of small turbines exists on the distribution system. It is recommended, though, that the protection equipment should be designed to accommodate a

high penetration situation to avoid retrofit or modification problems in the event such a situation arises [23].

The frequency and duration method has been developed for the evaluation of generating system reliability in the planning of electric power systems. This method makes it possible to determine all major reliability Indices: probability and frequency of system deficiency states and the expected energy not supplied to the consumers [24].

Voltage flicker on secondary circuits was found to be a potential problem for induction generators. If dedicated distribution transformers are not required for customers with wind turbines, excessive voltage flicker may result on some secondary circuits [25].

Richards et al brought together consistent constants for the study of small induction and synchronous generators utilised in DSG applications. A series of calculations of consistent machine data was presented based on manufacturers' constants and test data [26].

Rizy et al presented the operational and design considerations for electric distribution systems with dispersed storage and generation. The purpose of the studies was to determine the adequacy of the electric utility industry's traditional practices, hardware, and design for the operation of dispersed power sources on electric distribution systems [27].

## **2.5 Chapter Summary**

This chapter was dedicated to the background information relating to cogeneration. Various aspects of importance in setting up cogeneration plants were broadly examined.

The role of cogeneration was studied first. Cogeneration technologies that have become popular over the years were examined in Chapter 2.1.1. Cogenerating cycles were reviewed in Chapter 2.1.2.

The market for cogeneration has been inspected in Chapters 2.1.3. Cogeneration data and incentives that relate to industrial cogeneration plants have been presented in Chapter 2.1.4.

Commercial viability, cost and performance of cogeneration plants have been discussed in Chapter 2.2. Parameters such as Heat/Power ratio, utilisation, avoidable costs and fuel supply /electrical connections were identified in relation to its effect on commercial viability.

In Chapter 2.2.2 and Chapter 2.2.3 the costs of small cogeneration schemes and the performance of small cogeneration schemes have been considered.

Protection principles were analysed in Chapter 2.3. Overcurrent protection was focussed upon because of its affordability and effectiveness for most cogeneration schemes.

The research conducted in the broad area of cogeneration, was narrowed down to identify protection considerations in cogeneration, presented in Chapter 2.4.

The background investigations in cogeneration lead to the literature survey of Chapter 3. Control, connection and operational issues in interconnecting cogeneration plants to the utility grid is of utmost importance to both industry and academia, Chapter 3.

## 3.0 Literature Survey

This chapter identifies the interconnection of cogeneration schemes to the Utility. A number of issues required to realise a load shedding scheme are presented.

Many facilities such as businesses have a need for simultaneous power and heating or cooling, and therefore offer some prospect for cogeneration. In the commercial sector, major buildings such as shopping centres, city or police office buildings and sport and entertainment facilities may draw all or most of their energy requirements from cogeneration schemes.

Large institutions such as hospitals or universities can also benefit from cogeneration schemes. If viable, electricity distributors can purchase power from cogenerating industries or institutions and sell power to the commercial sector [51].

Industries operating on oil and gas, mineral processing, sugar, timber, dairy products, fruit, meat, petrochemical, chemical, electromechanical alongside with institutions such as hospitals and universities are potential cogenerators. The safe, reliable and effective interconnection of aforementioned industries and institutions to Utility distributor is vital [1, 51].

Cogeneration and renewable energy connection of generators to the power system is discussed in Chapter 3.1. Various topics including generation limits, differing priorities in private generation and customers quality of supply are discussed in Chapter 3.1.

Chapter 3.2 deals with issues relating to the interconnection of a cogeneration plant to the Utility grid. The case for load shedding is presented in Chapter 3.2, while an introduction to various cogenerator issues are presented at various stages in the chapter.

This is followed with a summary of important ideas presented throughout the chapter.

### **3.1 Cogeneration and Renewable Energy Connection Of Generators to The Power System**

The most common configuration of small private generation being connected to the South East Australian power grid is approximately 3- 10 MW of synchronous machine generation connected to a joint use distribution feeder.

Operation of the feeder is normally carried out locally at the substation from which the joint use feeder is supplied, although remote control from a central location is also common.

#### **3.1.1 Limitation on Generation**

##### **3.1.1.1 Fault Levels**

The connection of a generator to the distribution network will increase the fault level at the distribution authority's substation. This may cause the fault level to exceed the rupture capability of the switchgear at the substation.

Connecting parallel generation to distribution system may create a situation where under fault conditions existing components might be exposed to short circuit values which would exceed their ratings. Alternative means of this problem have been proposed by Brown et al [28].

The phase-to-phase and three phase faults are largely a function of generator size and distance from the substation. If such phase faults are excessive, modifications that need to be carried out may include installation of series reactors or segregating buses at the substation. The contribution to faults involving ground can be most conveniently controlled at the generator installation by appropriate selection of impedance earthing.

##### **3.1.1.2 Agreed Limits**

Most small private generation projects have only become economic in recent years as a consequence of government initiated incentive buyback rates. These rates were determined to encourage the installation of environmentally friendly generation, and are not commercially

desirable to the distribution business. Only a fixed amount of generation was approved by government, and agreed limits for the export of power are defined for each generator under this buyback regime[1].

### **3.1.2 Differing Priorities on Private Generation**

There are two main categories depending on the nature of their business:

- a) Renewable energy schemes which do not consume significant amounts of electricity themselves and are primarily focussed on cost effectiveness of generation;
- b) Hospitals and industrial plants which are significant customers in their own right and place a high importance on the reliability of their power supply.

### **3.1.3 Types Of Generation**

Synchronous or Induction machine.

Small remote induction machines may sometimes be connected with minimum Protection & Control modifications, as induction machines will generally be unable to generate when isolated from the grid and the reactive power for machine excitation that it provides.

Problems can occur when generation is situated near capacitor banks which have been installed at the end of remote feeders to provide voltage support. These capacitors can provide enough reactive power to maintain the excitation of the induction machine even after being islanded from the rest of the power network.

### **3.1.4 Other Customers Quality Of Supply**

The connection of a private generator to the system must not be allowed to detrimentally affect the quality of supply of other customers. The inertia of the main system can usually ensure a satisfactory supply quality, even for other customers sharing a feeder with the generator, so long as the feeder is still connected to the main system.

The risk to other customers comes from islanding of the feeder, with the voltage and frequency of the customer's supply being solely determined by the private generator. The emphasis when connecting such private generation is to ensure that other customers cannot be supplied from an isolated generator when isolated from the main system.

### **3.1.5 Stability Studies**

Studies are performed to assess the transient stability between the generator and the rest of the system after a fault. The generator and its voltage regulator are modelled in software, along with a simulation of the rest of the power network. The results of these studies determine the maximum fault clearance time the system can tolerate before the generator loses synchronism.

Dispersed storage and generation ( DSG ) devices connected to electric distribution system can cause operational problems such as reenergisation of distribution feeders under repair by Utility personnel, production of harmonics by DSG power inverters, and voltage regulation because of fluctuating DSG generation, on an electric Utility system. Many of those problems can be avoided by carefully applied and automated control schemes [29].

To prevent damage to the generator whilst pole slipping after loss of synchronism, protection must isolate the generator from the system. This can be achieved by either ensuring the line protection operates within stability clearance time, or the installation of pole slip protection on the generator.

As the number of dispersed storage and generation units connected to the power system increases, the need to control and monitor them in an integrated fashion will become increasingly evident [30].

Most modern industries require reliable, uninterrupted power to maintain productivity to avoid costly outages. This is especially true of continuous process industries where an extended outage can result in extensive process equipment damage, excessive downtime costs and loss

of productivity. A system that can supply automated monitoring, data retrieval and fast, computer aided fault analysis is needed [31].

### **3.1.6 Protection Considerations**

The presence of generation on a distribution feeder can necessitate changes to protection circuitry and settings.

The protection needs to discriminate with downstream protection, including that at the generator's works. In the absence of pole slip protection the feeder protection must also clear feeder faults within stability time. This is not so much of a problem when the generator is connected via a dedicated feeder with pilot wire protection.

When the contribution from the generator represents a large proportion of the total fault current on another feeder, the overcurrent protection on the generators feeder can be made directional. This avoids the possibility of tripping the generator for faults on other feeders.

All other protections at the substation which could cause islanding with other customers must initiate tripping of the generators incoming circuit breaker. Outputs from protections such as Bus Differential and Bus Overcurrent initiate remote trips over the signalling channel.

#### **3.1.6.1 Pole Slip up Protection**

Pole Slipping Protection identifies loss of synchronism of the machine by detecting a sequential transition of the measured real and reactive power of the machine. Use of Pole Slip Protection avoids the need for protection clearance times to be reduced to meet stability clearance times.

#### **3.1.6.2 Reverse Power Protection**

One of a number of protections including under excitation/loss of field protection which are likely to be installed to protect the generator from undesirable events in the generator's works.

Reverse Power protection measures the direction of real power flow, and will detect failure of the prime mover by measuring real power flow into the machine from the system.

Under-excitation protection measures the direction of reactive power flow and uses this to detect loss of field on a synchronous machine.

### **3.1.7 Interlocking Circuit Breaker Closing**

The facility for synchronising the generator to the system is associated with the private generator's incoming circuit breaker. Any attempt to synchronise the machine using another circuit breaker could cause serious damage to the generator.

The main exposure to risk comes from the possibility of closing the circuit breaker at the supply authority's substation whilst the generator is connected and operating at the other end of the feeder. This could be initiated by auto-reclose circuits, or a manual close at the substation or control centre.

Should there be an alternative feeder available as a standby supply to the generators facility (most common for hospitals where reliability of supply is a more critical issue), interlocking circuits must be installed to prevent generation during connection to the alternate supply.

### **3.1.8 Signalling**

There are several alternatives for VF(Voice Frequency) Signalling between the private generation site and the Power Authorities substation signalling mediums:

- pilots (copper pairs)
- radio/microwave
- leased Telstra pairs

The most commonly used is leased circuits from Telstra. These are the cheapest, and experience to date indicates that they provide adequate security and reliability for these applications.

Leased lines are used, one line for telemetry and one providing a v.f. channel in each direction as below.

a) The status of the generators incoming circuit breaker is transmitted to the Distribution Authority's substation to inhibit closure of the feeder C.B. unless the generator is disconnected from the system.

Should the pilot tone used by the v.f. signalling scheme to check continuity of the signalling medium be lost, logic will assume the worst case, i.e. will assume the status of the cogenerator's C.B. as closed.

To cater for the possibility of the cogenerator's C.B. being "racked" out of service for maintenance, an auxiliary "a" switch in the cogenerator's C.B. is used to initiate the v.f. channel transmitting the C.B. status.

b) In the reverse direction, a v.f. signalling channel is used to initiate a remote trip of the generators incoming circuit breaker. Should the pilot tone indicate failure of this communication link, automatic tripping of the generators C.B. will be initiated after a short time delay.

### **3.1.8.1 High Voltage Isolation**

Austel regulations define the requirements for isolating equipment to be installed on the leased copper pairs entering any high voltage installation. Fault currents at high voltage installations can generate dangerously high earth potential which can be hazardous for technicians working on the v.f. circuits.

### **3.1.9 Auto Reclose**

Supply Authorities often desire to reclose the C.B. and re-establish supply to other customers on the feeder. The risk of reclosing out of phase with cogenerator can be avoided by inhibiting reclose for a number of criteria including line live and generator main CB closed.

The synchronising function is performed at cogenerator's site only. This can necessitate changes to Auto-reclose circuits at other stations when a single radial sub-transmission could island the generator as a result of a single contingency.

#### **3.1.9.1 Single Pole Tripping and Automatic Reclosing**

This can be beneficial when the contribution of the generator to the system is large enough that its loss would have a noticeable impact on the system, and the generator is connected via a single radial line [1]. This facility is provided on the 220 kV line connecting the 150 MW Dartmouth Power Station in North East Victoria.

Single pole tripping is not usually justified for small generators located close to the network load centre.

### **3.1.10 System Tests**

As part of the commissioning process, tests are performed to measure electrical disturbances that occur on the system during

- a) load rejection by the generator;
- b) other switching at the substation that may initiate disturbances, e.g. resonance with capacitor banks.

### **3.1.11 Revenue Metering**

Digital Measurement revenue meters with dial-up modem access have become the standard in most states as a basis for energy billing between the generating body and the distribution

Authority. These devices are also able to provide access to a range of instantaneous and historical measurements of electrical quantities.

The facilities provided are similar to those now being installed at the interfaces between the new bodies recently created by the dis-aggregation of the former State Electricity Commission of Victoria.

### **3.1.12 Local Metering and Indications**

The transducers and local displays at the substation for MW and MVAR quantities need to be modified to be bi-directional. Ambiguous readings could confuse operating staff.

Often digital readouts for mimic displays require bipolar (+/- milliamp) quantities, and if the primary transducer does not represent a zero quantity with zero milliamps a mA/mA transducer can shift the zero point.

### **3.1.13 Remote Telemetry**

Analogue quantities MW, MVAR, single phase current and voltage, along with the status of the main circuit breakers at the generators site are transmitted via remote telemetry equipment over v.f. circuits to the appropriate location for the Distribution Authority's operating staff. This may be the substation, the Authority's Control room, or both.

### **3.1.14 Voltage Control**

Load on a high voltage feeder results in a progressive voltage drop along the feeder. The voltage drop will be maximum at the remote end of the feeder when maximum load is flowing. There will be negligible voltage drop along the feeder when no load is flowing. Transformer tap changer controls at the substation are set to supply nominal voltage to the feeder for zero load, and progressively greater than nominal voltage as the load increases. This results in the feeder voltage close to the substation varying between nominal, and several percent above nominal.

The voltage at the remote end of the feeder varies between nominal and several percent below nominal. This variation of voltage along the feeder can be catered for by selecting different fixed taps on the distribution transformers which convert the feeder voltage to 415 Volt supplies for the customers along the feeder. When long feeders make this variation too large, Automatic Voltage Regulators are installed along the feeder to distribute the effect of voltage increase along the feeder.

Capacitor banks installed on the system provide reactive power locally, thereby increasing the feeder voltage.

A generator connected to the remote end of a feeder can be a source of a varying amount of both real and reactive power. The variability of the machine output makes its effect on the feeder voltage more difficult to predict.

Synchronous generators will have an Automatic Voltage Regulator to control the machine terminal voltage by adjusting the machine field excitation.

The terminal voltage of induction generators can be controlled to some extent by switching segments of the generator's excitation capacitor bank in stages.

The net effect of all influences on feeder voltage need to be determined for all possible loading, switching and generating conditions to ensure that other customers along the feeder do end up with supply voltages outside acceptable limits [1].

Evaluating problems and identifying issues in the interconnection of cogeneration plants to the Utility grid is analysed together with the need for an effective load shedding strategy, Chapter 3.2.

## **3.2 Assessing Implications And Solving Issues Of Concern In The Interconnection Of Industrial Cogeneration Plant To Utility's Distribution System**

This section presents detailed scenarios which may be observed due to interconnection of industrial cogeneration plant in to Utility's distribution system and evaluates its impacts on Utility's system vis-a-vis industrial plant and will suggest potential means of solving the associated problems. This section culminates with the selection of the specific area of cogeneration research, load shedding.

### **3.2.1 Introduction to Issues of Concern**

Economic performance of an industrial cogeneration plant depends on its connection to Utility grid with power transfer facility. Rising costs in power generation and energy prices force industrial consumers to go for cogeneration specially due to its high economic performance [32]. Moreover, it provides an alternative design scheme for achieving lower system operating costs and ensures industries requirement of uninterrupted supply of electric power to maintain continuous productivity and costly outages.

The basic technologies involved in cogeneration are quite old. However the concept of integrating power generated in industrial cogeneration to Utility's distribution is relatively new. The impact of cogenerators upon the Utility's existing system must be studied because of its significant contribution of power flow and short circuit current.

### **3.2.2 Observations of issues of concern, in industrial cogeneration schemes**

Normally industries require large amount of reactive power because of its special nature of loads. These requirements are met by the cogenerators, when cogeneration is in operation in the industry and there is no significant reactive power flow from Utility. But in case of sudden stoppage of its own generation, the total reactive power requirements of the industry are to be met from Utility's source and the same leads to an undervoltage condition in an industrial system.

An increase in system impedance may also bring about a reduction in voltage due to reactive power transfer [33]. Contingencies on the Utility system, including both scheduled and unscheduled switching of transmission lines can produce an increase in system impedance under circumstances when reactive demand is near normal. This condition will also produce a reduction in supply voltage. Some industrial loads are noted for placing extremely large step increases in the reactive demand on the power system. Starting of a large motor impacts the industrial distribution system with an increased reactive power requirement, lasting for the starting period of the motor. Operation of arc furnaces during the early melt-down phase and some kinds of thyristor controlled adjustable speed DC drives all have the unfortunate characteristics of suddenly demanding from the system very large magnitude of low power factor current. However, the step increase in current will produce reactive losses in the system which will cause a reduction in voltage. In addition, any major unbalance in reactive and active power flow in the system will contribute to variation in voltage, current and frequency of the systems. If a sudden surge of reactive power flows from the Utility substation to the industrial cogeneration plant shown in the Figure 3.1, then there will be an undervoltage condition developed at other customers connected to the same 11/22 kV feeder.

Rectifiers, inverters, static var compensators and other nonlinear loads, used in industrial system, generate harmonic voltages and currents. Due to bidirectional flow of current, these harmonic currents also flow to the Utility's distribution system and can cause interference to communication systems and can also cause hazards to nearby industries, as harmonic currents cause higher operating temperatures in motors and transformers.

In an industrial power system the step down transformer supplies most of the impedance and the line or cable impedance is insignificant from a harmonics point of view. These systems are very compact and a large percentage of plant load may be producing harmonic. Harmonic sources in the manufacturing processes of a plant may include:

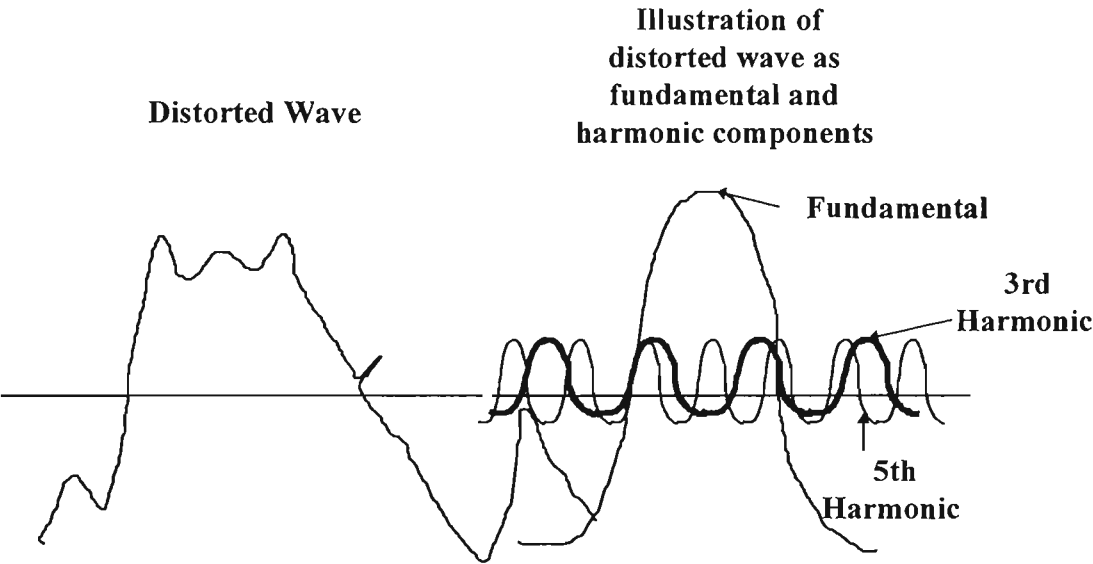
- \* Rectifiers
- \* Thyristor-controlled, variable speed motor drives
- \* Arc furnaces

\* Transformers

Harmonic generation during transformer energisation is not as significant as the other sources. The mix of harmonic producing loads, capacitor banks, and high X/R of the source impedance can result in harmonic problems.

A capacitor bank selected for industrial loads may frequency resonate with source impedance at the fifth harmonic [34]. Figure 3.1 illustrates the distorted wave as fundamental frequency plus predominant fifth harmonic components.

Harmonic resonance leads to high harmonic voltage which creates peak in the distorted phasor



**Figure 3.1    Decomposition of a distorted wave**

waveform which are greater than the normal fundamental frequency crest voltage magnitude. These high magnitude peaks have the same effect as instantaneous fundamental frequency overvoltages. Also, the distorted waveform may contain troughs at points other than the normal fundamental frequency waveform zero crossing. These troughs have the same effects as instantaneous undervoltage at the fundamental frequency.

Another important scenario which is common in industrial cogeneration system, following the loss of supply from Utility, due to severe power swings or loss of generation or due to a fault at Utility side, is the islanding condition of the industrial system [35].

During islanding condition, the industrial system either will have excess load or excess generation, thereby there will be load/generation unbalance.

Excess of loads, overload the generators and thereby causes frequency to drop. However, during light load condition, generation will be more than the load, thereby creating overvoltage condition in the system [36]. This overvoltage may adversely affect the loads connected with the cogenerators feeder.

### **3.2.3 Considerations to Aforementioned Problems**

Most of the problems discussed in Chapter 3.2.2 can be solved by appropriate system design at the pre-commissioning stage.

Proper industrial power system design provides optimum isolation between the point at which the disturbance is applied to the system and the important loads which are adversely affected by the systems.

#### **3.2.3.1 Reactive Power Compensation**

Power capacitor is an ideal source of leading reactive power to compensate the lagging reactive power consumption of the loads on industrial power system.

Synchronous condensers have been traditionally used to generate or absorb reactive power in those cases where better control of voltage is necessary. Hence, immediately after loss of in-house generating source, it would therefore be desirable to achieve a reactive power balance within each part of the industrial power distribution system [37]. This sudden requirement of reactive power means that some form of control is necessary.

Nowadays, reactive power requirement can be best controlled by thyristor-controlled compensators. Two basic principles of thyristor controlled compensations are used. In one of

these the reactive power is varied by means of thyristor-switched capacitor steps and in the other the power is controlled by means of thyristor-controlled reactor.

Depending on the desired control range of the reactive power, a thyristor-controlled compensator may be built up using one or both of the aforementioned principles. In most cases the optimum solution is a combination of both.

A suitable control strategy for the combination concept ensures that it can have impressive and valuable features for the system [38].

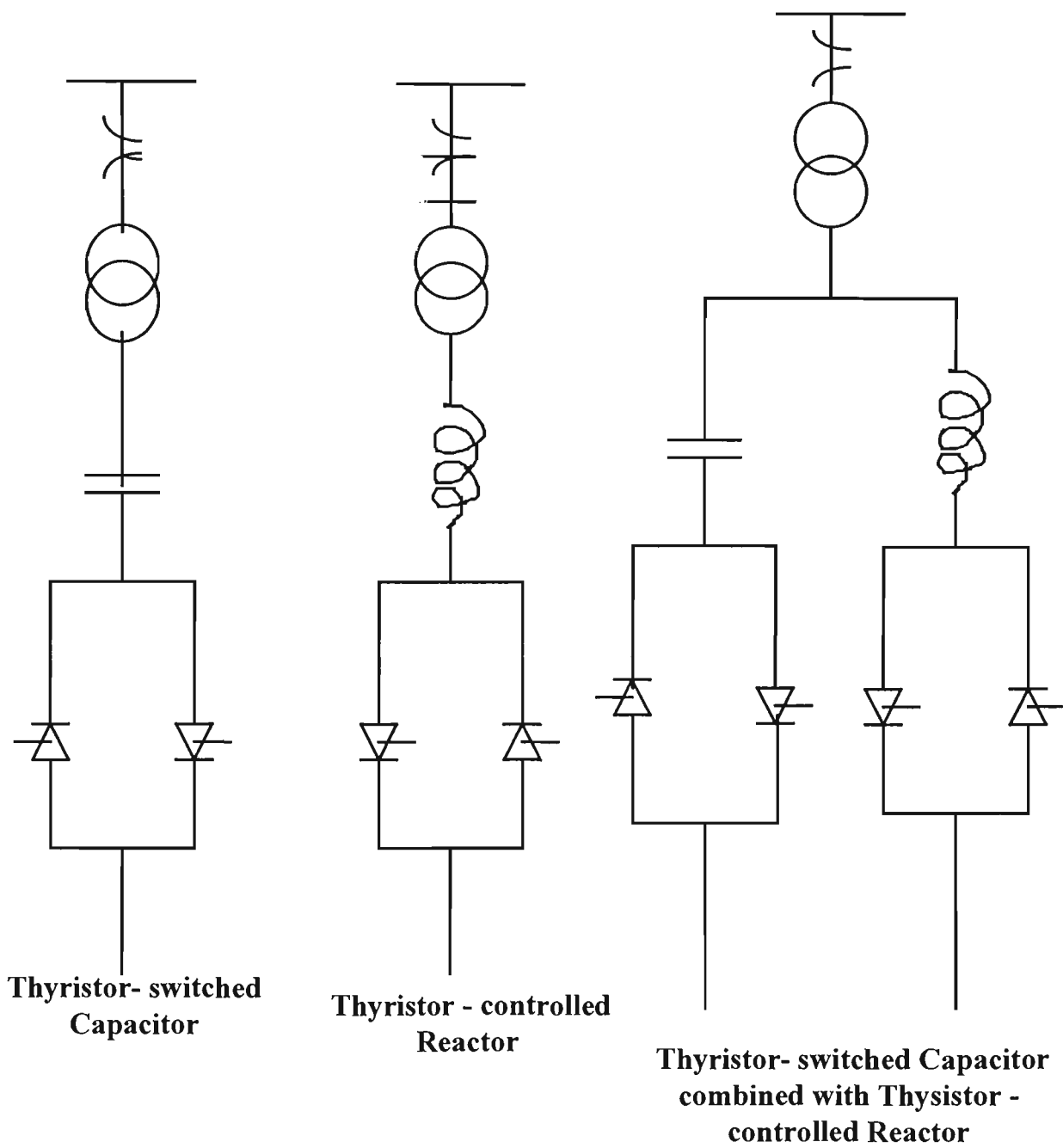
The thyristor-controlled compensator will be able to perform a number of different tasks automatically, through the change-over from one control strategy to another, when so demanded by the system. These tasks include:

- \* limiting overvoltages
- \* improving system stability
- \* normal voltage regulation

Fundamental connections for the three control strategies of thyristor controlled shunt compensator are shown in Figure 3.2.

### **3.2.3.2 Harmonic Elimination**

When the harmonic magnitude is severe and the quality of voltage must be improved, a series of harmonic filters formed by splitting the capacitor banks, connecting reactors in series and tuning them to the objectionable harmonics, can provide a short circuit path for these harmonics, eliminating them from the system.



**Figure 3.2    Fundamental Connections For Thyristor Controlled Shunt Compensator**

### 3.2.3.3 Load Shedding

Caballer et al described computer controlled load shedding for a cogeneration facility [39]. The description of work done was a foundation, on which the research conducted as part of this thesis was further enhanced.

The aforementioned paper described the installation of a load shedding and restoration system used in conjunction with a cogeneration installation at a major pharmaceutical facility in Puerto Rico.

The plant load of 7 MW exceeds the 5.18 MW capacity of the two base load low speed diesel generators which operate in parallel with the local Utility. When the Utility source fails, the generators will be shut down by their under-frequency relays unless the overload is shed.

The load-shedding system continuously monitors the sheddable loads as well as the generator and Utility source capabilities. When any of these sources fail, loads are shed on a predetermined but changeable priority basis before the under frequency relays operate to shut down the generators.

This same project involved the installation of synchronising and paralleling equipment for smaller high speed standby generators.

#### 3.2.3.3.1 Description of Power System facilitated by Load Shedding

The sample facility examined consisted of a three plant complex. These plants manufacture a variety of pharmaceutical products, which require uninterrupted power supplies to prevent loss of product yield and to maintain sterility.

Each of these plants had their own separate 38 kV service from the local Utility company. Two small high-speed diesel electric generators ( 750 kW and 800 kW ) were installed at the second plant for emergency loads, segregated through open transition transfer switches.

Also a somewhat less reliable 1100 kW gas turbine driven electric generator with manual synchronising equipment was installed at the first plant where it was initially constructed.

Two low-speed diesel-driven electric generators ( 2.96 MW and 2.27 MW ) were installed in 1987 as base load cogeneration units. At the same time, three plants, which were located nearly adjacent to each other, were combined electrically at 38 kV such that power was taken from the Utility through one service.

Other than a short road crossing and some transitions from above ground, the 38 kV distribution system is underground, solid electric cable. The combined load of the three plants at the beginning of the project was approximately 6.5 MW normally and 7 MW peak. The combined capacity of the diesel generators is 6.73 MW [ 39 ].

The cogeneration units were financially justified on the basis of avoided power bill costs, while using the Utility as a back-up source, with the added advantage of providing a stable electric power source when the Utility power source was lost.

At the time of the installation, it was known that some form of load shedding would be required when the Utility source lost in order to keep the generators running, avoiding under-frequency tripping when the load exceeded the capacity. This was initially conceived as merely opening a few main circuit breakers on substations.

Further investigations revealed that a more sophisticated system with priority capabilities would be required. This was first conceived and budgeted on the basis of a system using programmable logic controllers.

Investigations revealed that a computer based system with continuous monitoring of loads and on-line interactive capability, in combination with the capability to operate all the generating sources in parallel, was needed in order to have maximum speed and complete flexibility for dispatching electric power consistent with the loads and sources available. Such a system was needed to continuously monitor the sheddable loads, match the total loads with the source capability, and shed or restore power sources accordingly.

A power system with diesel-generators as the main source has a characteristic that is different from steam or gas turbine-generator sources.

The diesel-generators have a relatively low inertia so that the frequency changes in such a system is more rapid than the turbine-generator sources. As a result the load shedding system must react faster to ensure that the frequency does not decrease to the point that the system cannot be restored ( under frequency relays will shut down the generator).

The microprocessor based system presented by Caballer et al [39], ensures that the load shedding system will operate fast enough to limit the frequency excursion to prevent under frequency relay operation.

### **3.2.3.3.2 Load Shedding Hardware Description**

The sample system examined consisted of an operator's console, a control room terminal and three remote terminal units.

The remote terminal units are located in each of the three plants. Communications between the operator's console and the remote units are accomplished using fibre-optic links.

The operators console includes the main computer, a colour graphics screen, a typical computer keyboard, a "track ball" (mouse) for operator input, a printer for event logging, alarms, and reports, and several mass storage devices including a hard disk, a floppy disk drive and a tape drive.

The remote stations monitor the analog inputs from the load transducers, power (watts) and circuit breaker status, OPEN or CLOSED. These signals are changed to digital form and transmitted to the main control console. Each remote unit has its own Uninterrupted Power Supply ( UPS ).

All sheddable loads are monitored through a Watt transducer. All sources are monitored for power, reactive power and voltage. Watt and VAR transducers were added to feeders and sources. In addition, the fuel flow rate, the fuel type and bus frequency were monitored [ 39 ].

### 3.2.3.3.3 Load Shedding System Operation

The load shedding system of reference [40] is a real-time computer system. It monitors both power generation and power importation for the plant. In addition, the system monitors the loading of system loads.

The system has control over the breaker operations for these loads. These loads are referred to as sheddable loads. Figure 3.3 is a simplified load shed logic flow chart.

The other noteworthy paper that was used as a reference in developing the new load shedding algorithm and comparing similarities and differences was the paper titled “algorithm for load-shedding operations in reduced generation periods “ by Wong and Lau [40].

The aforementioned paper developed an algorithm for selection of load circuits to shed in periods of reduced generation, which may occur owing to industrial action or if the installed generation capacity is insufficient to meet the load demand.

Reference [40] developed strategies for the selection of substations and circuits to be shed and restored.

### 3.2.4 Identified issues and selection of specific area that was researched

The main difference of the new algorithm load shedding strategy with the load shedding strategy proposed by Caballer et al [39] as well as Wong et al [40] was, that the new algorithm load shedding strategy was not based on detection of an under frequency condition as mentioned in Chapter 5.

The ICP considered in this research thesis operated in synchronisation with the Utility grid and is connected to an infinite busbar [1].

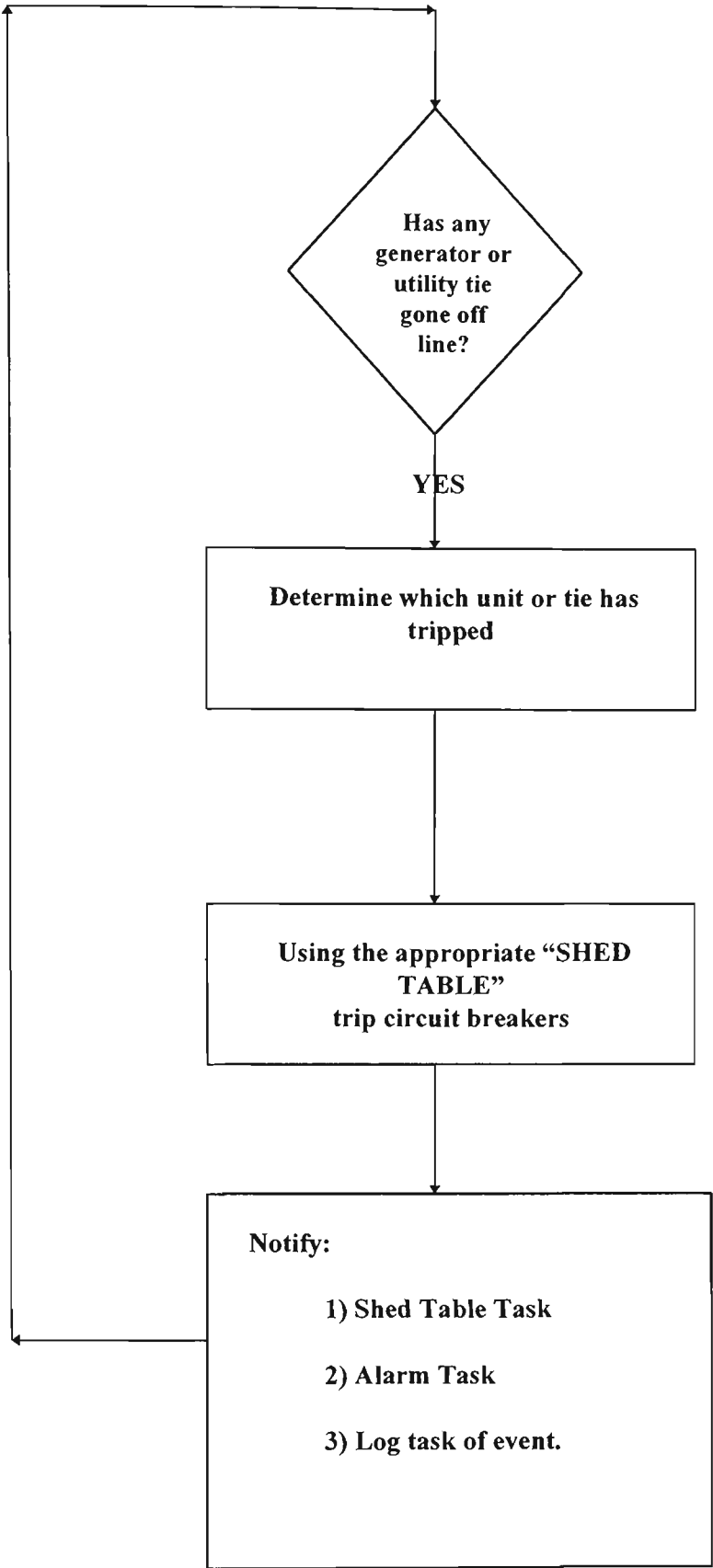


Figure 3.3 Load Shed Logic Flow Chart [40]

Chapter 3.2 illustrated the scenarios which would affect the performance of the power system due to interconnection of the industrial cogeneration plant with the Utility. Reactive power flow control of industrial system is essential to maintain acceptable voltage profile on contingency condition to avoid costly outages. Quality of supply to all customers is a major concern to Utility and effective harmonic filtering at industrial plant can only solve this problem to a great extent.[41 - 45]. Protection of industrial equipment during islanding condition is an important priority that has been addressed by the new algorithm load shedding strategy, alongside other priorities which are described in detail in Chapter 5.

### **3.3 Chapter Summary**

This chapter was dedicated to the framework and justification for the work carried out in the analysis of cogeneration and load shedding strategies of a cogenerating plant.

Interconnection of a cogeneration plant to the Utility's distributor was examined. Cogeneration and renewable energy connection of generators to the power system was followed with assessing implications and solving issues of concern in the interconnection of an ICP to the Utility's grid.

Focus, evaluation and developments of this project are to fulfil the justifiable demand of cogenerator's and Utility distributor's dream of managing a cogeneration plant with a suitable load shedding scheme to operate during diverse scenarios. These scenarios range both in peak or normal operating hours.

With the adoption of load shedding a private generator has the added alternative of supplying contracted power, coping during times when fuel cost is high and operating effectively during islanding condition.

This chapter both introduced the practical scenarios and justified the work carried out as part of this research thesis. Evaluation of connecting cogeneration plants to the grid, interconnection issues that are of concern and the need for load shedding has been established in Chapter 3.

## 4.0 Objectives

This thesis details research into the analysis of load shedding strategies in ICPs interconnected to the Utility. The load shedding methodology is analysed. It was intended to shed unemergency loads, with an efficiency as close to worlds best practise. Specific attention is paid to load shedding criteria as well as the development of the new algorithm. The outcome of this research was to produce a user friendly and efficient load shedding software tool that would facilitate the analysis of the load shedding option in contrast to other available options[40] as well as the analysis of alternative load shedding strategies.

Investigations into combinations of circuit selection strategies were carried out, to determine a close to optimal circuit selection strategy for a particular ICP's load shedding facility.

Cogeneration concepts were examined in view of its importance in energy management. The role of cogeneration in Australia was investigated. A cost and performance analysis for small cogeneration systems were conducted, in Chapter 2.2.2 and 2.2.3.

Protection aspects of cogeneration systems were analysed. The role of protection as well as protection devices were discussed in view of its operation and capability to protect the ICP's personnel and equipment. Protection is vital for the safe and reliable operation of the ICP.

Control, connection and operational issues were investigated. Problem areas in the interconnection to the Utility were studied. The need for load shedding was established as well as the study of important criteria and parameters in load shedding scenarios.

### 4.1 Scheme Viability

Although it is dangerous to generalise about the type of schemes that are viable, however the schemes of around 5 MW and upwards, can be shown to be commercially viable. In contrast, small schemes of up to 1 MW based on reciprocating engines and connected at low voltage, can also be shown to be attractive as electricity prices in the franchise market can still be

relatively high. Between these two limits commercial viability can still be achieved, but certainly cannot be taken for granted.

## **4.2 Cogeneration - The Competition**

The most valuable product of a cogeneration scheme is the electricity it produces. The real competition for cogeneration is, therefore, going to be Pool delivered electricity. The establishment of a competitive market for electricity in the "above 1 MW" sector will have reduced prices to these customers.

There is a continuous debate about what will happen to electricity prices in the next few years. The market is currently over-supplied. As supply and demand come more into balance, it is possible that prices will rise, enhancing the economic attractions of an investment in cogeneration [1].

## **4.3 Cogeneration - The Barriers**

Constraints and uncertainties surrounding fuel availability, siting requirements, financing, licensing delays and demand forecasts have made it increasingly difficult for Utilities to add large-scale capacities and/or additional interconnections to their supply and delivery systems [10].

Barriers to the development of cogeneration still remain. A number of them are:

### **4.3.1 Institutional Arrangements**

It could be argued that one downside to the ESI privatisation is the institutional complexity of the restructured industry:

- (a) the licences;
- (b) Pool membership and rules;
- (c) Council connection agreements and power plant operating agreements;

- (d) Use of System agreements;
- (e) the Grid and Distribution codes.

### 4.3.2 Market Position

The behaviour and attitude of the municipal Council's are a key factor. Some of them may see cogeneration, developed by other parties, as a threat to their business whilst other actively encourage its use. It is, therefore, somewhat contumacious that they maintain a position where they have a direct input to the viability of a scheme by means of charging connection costs where they consider reinforcement work to be necessary on their distribution system. Although it is accepted that costs may be required to reinforce the network it is often difficult for the lay-person to establish whether such costs are fair and reasonable.

### 4.3.3 Pooling and Settlement

Selling excess of electricity is not just a matter of choosing a buyer. An owner of plant wishing to export power into the distribution or transmission system generally has to follow established guidelines [1].

## 4.4 Limitations

The results within this thesis are entirely based on simulation. The impact of *Fuel Levels* on *Shed Requirement vs Shed Size* vs as well as the impact of *Import/Export Levels* on *Shed Requirement vs Shed Size* were determined by simulations. *Variable Load Demand levels* were analysed with *Shed Requirement vs Shed Size* as it permitted the modelling of various instances that are likely to have an effect on ICPs in a highly dynamic environment. A variety of *circuit numbers* and *relatively high shed requirement levels* and its effect on *Shed Requirement vs Shed Size* in ICPs were studied while exploiting the capabilities and simulation platforms that the new algorithm load shedding software provided. Cyme (CYME INTERNATIONAL INC, CANADA) was initially utilised as a learning tool which provided

the framework for further modelling of scenarios affecting the operation of ICPs. Matlab 4.2 (Mathworks, Mass, USA) was used to plot numerical results obtained from simulations.

Both the object oriented approach and the genetic algorithm approach was initially investigated in view of achieving satisfactory load shedding results. The results of OOP or genetic algorithms has not been included in this thesis.

A number of limitations were required to ensure reasonable results could be obtained in the allocated time. The new algorithm load shedding strategy had the following limitations:

- Not suitable for activating real time load shedding operations in an operational ICP.
- The shed size achieved was as close as possible to the shed requirement, however without zero shed difference at every time slot.
- In trying to achieve a small shed deviation of shed size from shed requirement while maintaining maximum energy utilisation, a tradeoff had to be made in that, at times the shed size was below the shed requirement within  $\pm 10\%$  tolerance limits. Within Chapter 5.7 it is shown how an ICP can select circuits and group them for shedding purposes in order to overcome these limitations.
- In scenarios where the shed requirement is much larger than the circuits available for shedding, the new algorithm load shedding model would only be able to realise a finite shed size.
- All loads available for shedding are of equal priority.

## 4.5 Assumptions

The research undertaken combined cogeneration in general and load shedding in detail to analyse load shedding strategies in cogeneration plants. To obtain a basis on which to assess the outcomes, certain constraints were needed to ensure that reasonable analysis could be made.

- A single generic ICP interconnected to the Utility grid was considered. Although distribution schemes can be interconnected to many potential ICPs, the emphasis placed with the modelling and simulation associated with this research project was to focus on one interconnection between the ICP and the Utility grid and the function of load shedding from the ICP's perspective.
- Various models of ICPs were derived, in order to analyse the useful effects of controllable system parameters given limitations in loads available for shedding or limitations in fuel input.
- An ideal state of operation was considered in the performance of generators, loads, relays, and circuit breakers, assuming a very high availability and reliability.
- For an ICP connected in synchronism to the Utility grid, the shed requirement could be represented as follows:

$$\text{Shed Requirement} = \text{Total Load Demand} - \text{Total Generation} \text{ [54 - 56]}$$

- The assumption that load was shed at time slots of 15 minutes, was implemented in the new algorithm developed as in reference [40].
- The entire load shedding time duration was considered to be 3 hours, comprising of 12 time slots.

The new algorithm load shedding strategy provided the following advantages :

- Useful primarily as a planning tool for power engineers, interested in the feasibility and setting up of a load shedding scheme in a ICP.
- It does not require expensive hardware to realise the architecture of the load shedding scheme in an ICP.
- It is possible to interpret results related to both high capacity ICPs as well as small heat producing industries that are looking at the possibility of cogenerating and load shedding.

- It is suitable for an ICP's efficient modelling of exporting and importing power.
- It is suitable for analysing the comparative performance of shed requirement vs shed size in various ICP generation and load configurations.

## 4.6 Outcome of the thesis

In order to ensure quality of service is maintained in the end product load shedding software, a number of issues were considered. The performance analysis was explored from different perspectives.

The outcome of the thesis could be summarised as follows:

- (1) The development of a software tool for planners of ICPs.
- (2) Criteria such as reliability and efficiency should be incorporated in the algorithm development of load shedding software.
- (3) The operation of load shedding should be applicable for a variety of data relating to different ICPs.
- (4) Power engineering students should be able to use the software tool to study the effect of various system control parameters of load shedding.
- (5) The load shedding software should be usable as a design tool.

## 4.7 Quality of load shedding

Quality of load shedding aimed at, could be summarised as follows:

- (1) Load shedding results should be acceptable according to world's best practise.
- (2) The software tool should be user friendly as well as interactive.
- (3) The software should enable the user to carry out a feasibility analysis of load shedding.

- (4) The load shedding software should be applicable on an industrial application.
- (5) The system control parameters of load shedding, should be open for analysis.
- (6) The load shedding algorithm developed, should enable the user to analyse trade off between load shedding and additional fuel costs.

#### **4.8 Application of load shedding on a local industrial application.**

Within system design in Chapter 5.7 the following load shedding considerations were made, during the process of algorithm development.

How should system parameters be defined to cater for cases such as:

- (1) More load and less generation.
- (2) Both large loads and large generation amounts.
- (3) Both less loads and less generation amounts.
- (4) Constant load shedding requirements in each time slot.
- (5) When only a few circuits are available for shedding.
- (6) A reasonably large number of circuits are available for shedding.
- (7) A number of circuits are being grouped for shedding purposes.

#### **4.9 Issues of concern from an ICP operator's standpoint**

The following concerns from an ICP operator's perspective were aimed at being addressed in the performance analysis:

- (1) Can the load shedding scheme successfully offset additional fuel costs while the ICP operates both safely and reliably ?

- (2) When load shedding is implemented for a particular ICP, what are the variable amounts of fuel that could be used ?
- (3) When load shedding is implemented for a particular ICP, what are the variable amounts of power that could be exported ?
- (4) When load shedding is implemented for a particular ICP, what type of load demands can it cater for ?
- (5) How should loads best be grouped by an ICP for shedding purposes to cope up with load demands, generation levels and contracted export levels ?
- (6) In the event of large shed requirements, how should loads be grouped for shedding purposes ?
- (7) Will the load shedding mechanism sustain the ICP during diverse scenarios ?

#### **4.10 Issues of concern from the Utility's standpoint.**

The following concerns from the Utility's perspective were aimed at being addressed in the performance analysis:

- (1) Can the Utility distributor engage the services of a particular ICP to purchase power ?
- (2) How many ICPs could the Utility's distributor purchase power from ?
- (3) What sort of incentives such as buy back rates would motivate a load shedding industry to go for cogeneration ?
- (4) Would a load shedding ICP be able to keep faithful to its commitment of exporting contracted power during peak hours ?
- (5) Is load shedding a viable alternative for the ICP to operate successfully or are other options more beneficial ?

(6) Will purchasing power from cogenerating industries be more viable than distributing that same amount of power that is transmitted from Utility's generation houses ?

#### **4.11 In which cases are load shedding viable ?**

It was aimed at developing load shedding software that could provide answers to the following questions:

- (1) During contracted hours of exporting power, what is the saving in additional fuel costs for an ICP ?
- (2) During periods when an ICP is sustaining its own load, how much savings of fuel costs can effective load shedding bring about ?
- (3) During periods when an ICP imports power from the Utility, how much savings of additional fuel costs can load shedding bring about ?
- (4) When will the case for load shedding be unfavourable ?
- (5) Can load shedding in ICPs, complement energy management ?
- (6) When available fuel input is less, is load shedding viable for ICPs ?
- (7) Can a load shedding scheme manage when an ICP is contracted to export large amounts of power ?
- (8) When load demand levels are high, can the ICP manage with the load shedding mechanism in operation ?
- (9) Would having a large pool of loads available for shedding make the load shedding mechanism more efficient ?
- (10) Would the load shedding scheme of an ICP be able to manage during high shed requirement levels ?

## 4.12 Chapter Summary

The objectives of this research thesis have been set out in this chapter.

To achieve commercial viability of cogeneration schemes will be of interest to all parties such as ICPs, Utility distributors, councils and customers. Scheme viability has been discussed in Chapter 4.1.

The competition for cogeneration has been highlighted in Chapter 4.2. The real competition for cogeneration is, going to be pool delivered electricity[1]. A number of issues such as fuel availability, siting requirements, financing, licensing delays and demand forecasts present itself as barriers for the case for cogeneration [10]. Fuel availability is one such barrier that is addressed in this thesis, which presents the possibility of load shedding for cogeneration schemes.

It was progressively discovered that the benefits of load shedding software, if properly applied, could have an impact and influence on pool membership and rules, council connection agreements and power plant operating agreements and the use of system agreements.

Limitations of system design were discussed in Chapter 4.4. Assumptions made during system design were highlighted in Chapter 4.5. The system design of the algorithm developed took into consideration various perspectives from “outcome of the thesis” presented in Chapter 4.6 until “in which cases are load shedding viable?” presented in Chapter 4.11.

The frame of the thesis was presented in Chapter 1, titled “introduction”. The spirit of the thesis has been presented in this Chapter 4, titled “objectives”.

## 5.0 System Design

This chapter describes the steps taken during the project. The description is divided into seven parts, to mirror the seven phases of the project.

A short discussion of simulation platforms in Chapter 5.1 introduces the various software tools that were used and developed during the entire period of analytical research into cogeneration in general and load shedding in particular.

Chapter 5.2 contains an introduction to the new algorithm method of load shedding. This is followed by scenarios in load shedding in Chapter 5.3.

Chapter 5.4 contains the load shedding strategy adopted by reference [40]. The aforementioned reference is examined from shed size constraint, selection of circuits, substation selection strategies to load shedding and restoration strategies.

The specific research work carried out in this thesis in the development of the new algorithm load shedding strategy is next examined, in Chapter 5.5. Aims of the new algorithm, description of circuit selection strategy adopted by the new algorithm are analysed next together with the load shedding and restoration strategy.

Chapter 5.6 focuses on the programming outcomes and software development methodology. In this section the software capability as well as the interaction between subroutines and the main program is examined.

In Chapter 5.7 various load shedding options are examined by considering various scenarios that could be encountered in an ICP.

A summary of the major phases of the system design concludes this chapter, Chapter 5.8.

## 5.1 Simulation Platforms

This section discusses software tools utilised throughout the project. The benefits of each platform are argued in order to rationalise the final choice of the simulation environment selected.

A wide variety of tools were used throughout this project. Preliminary investigations into cogeneration planning, protection, control and operational issues were carried out using CYME. The visual and layered analytical models provided by CYME allowed systems to be broken into functional blocks. Thus complex systems could be constructed from the standard library blocks. The CYMFLOW, CYMEDIT, CYMBASE, CYMPLOT, CYMSTAB, CYMHARMO, CYMIEGEN, CYMFAULT, CYMLINE and MOTORP simulation model sections within CYME provided a suitable platform for preliminary investigations into the background of research work carried out.

Genetic algorithms were next analysed, to see if both more accurate and faster solutions to that existing could be obtained in either load flow or load shedding analysis of ICPs. A population of schema ( or useful genes ) were combined using genetic algorithm operators of reproduction, crossover and mutation until more precise solutions were obtained. It was observed that genetic algorithms provided generally accurate solutions only when linear solutions were unavailable, although with a considerable time delay. Genetic algorithms or OOP simulations has not been included in this thesis. These solutions provided light into the specific programming methodology that was finally chosen.

Pascal was used as the platform in the new algorithm load shedding strategy. The aims of the new algorithm load shedding and restoration strategy were best realised by the source code developed via the interaction between subroutines and the main program.

In summary this project combined a variety of software tools. Initially, CYME to establish the background for cogeneration, genetic algorithms that provided light into why load shedding and why the Pascal based programming approach was suitable. The Pascal user interactive

load shedding software tool was developed, tested and demonstrated to the Energy Research and Development Corporation of Australia.

The results obtained in the developed software were graphically analysed and plotted on Matlab.

## **5.2 What is Load Shedding?**

This section introduces load shedding.

In an ICP, load shedding schemes with under frequency relays are not necessarily applicable for all situations. Furthermore, recent methods, operating on the principle of the rate of change of frequency (ROCOF), which is used by the Utility, is also not applicable for ICPs in every situation [46-47]. There may be three possible scenarios which might force industrial cogeneration systems to go for load shedding operations as described in Chapter 5.3.

The Utility normally charges different rates during peak hours. Also, industries that generate and sell power to the Utility, have such differential rates. Moreover, if power can not be supplied as per the contracted quantity during peak hours, the Utility might impose a heavy penalty for the non-supply of agreed quantity. In order to avoid this penalty during peak hours, industries may require to have a suitable load shedding scheme so that the contracted power is supplied to the Utility. On the other hand, failure to make full use of the power for its in-house requirement is also uneconomical [47 - 51]. Industries, which generate electricity in order to meet part of its requirement, are allowed to draw a fixed amount of electricity from the Utility during peak hours. It is of utmost importance that industries should fully utilise the average demand allowed during peak hours. Exceeding average demand results in very high costs, on the other hand failure to make full use of it is uneconomical. This also necessitates a suitable load shedding scheme. During faults at Utility side, the cogenerators feeders connected to the Utility substation might be switched off, and it is possible for cogenerators to be left supplying part of that feeder in an "island" and probably unearthed mode which may persist for some period if the load is reasonably matched. If islanded, a cogenerator, connected

to the Utility grid, should be disconnected until supplies are restored, proved normal and firm before re-synchronising. This normally requires a suitable "loss of mains" protection, which may be based on detecting a rate of change of frequency or the sudden change in reactive or active power which should occur when supply connections are lost. Immediately after the disconnection at the mains, the industrial system invariably have generation/load imbalance. Excess load, overloads the generating units, thereby causing the frequency to drop some times to levels that may cause permanent turbine damage. To avoid this kind of damage load shedding is applied throughout the system to provide a means of attaining a balance of the load to the remaining generation of the island [1].

Utility power grids have generation capabilities in the very high range. These grids appear to be infinite in size as compared to cogenerators. To further appreciate, the magnitude of the grid in terms of the available power, energy stored in the rotating machinery loads are drained in to the grid when voltage reduction transients occur. This tends to provide additional capacity to the grid. From the standpoint of load, the grid is infinite. Therefore, when operating in parallel with a Utility grid, the Utility acts as an infinite busbar with almost constant frequency and controlled voltage. Hence, the load shedding requirements, can not be sensed by normal dropping of frequency. This thesis develops a load shedding and restoration algorithm for an ICP considering the scenarios as stated in Chapter 5.3 [46 - 49].

## **5.3 Scenarios in Load Shedding**

### **5.3.1 Constraints in finding out the circuits to be shed**

Some circuits in an ICP are connected to emergency systems and process control systems, which should not be shed [51 - 53 ]. Hence those circuits are to be excluded from the shedding list. One of the methods which can be implemented is to create a group of circuits according to various shed sizes, and depending on shed size, the group can be selected. The main disadvantage of the above method can be summarised as follows :

- \* If the shed size is same at each interval of 15 minutes, the same

circuits will be selected all the time.

- \* Shed size can not be optimised, if there is a large difference between the calculated shed size and the shed requirement.

Applications involving circuit selection and shed size are described in Chapter 5.7.

Figure 5.1 illustrates the load shedding strategy of the new algorithm. The load shedding strategy of the new algorithm was programmed and enhanced to an interactive menu driven software package.

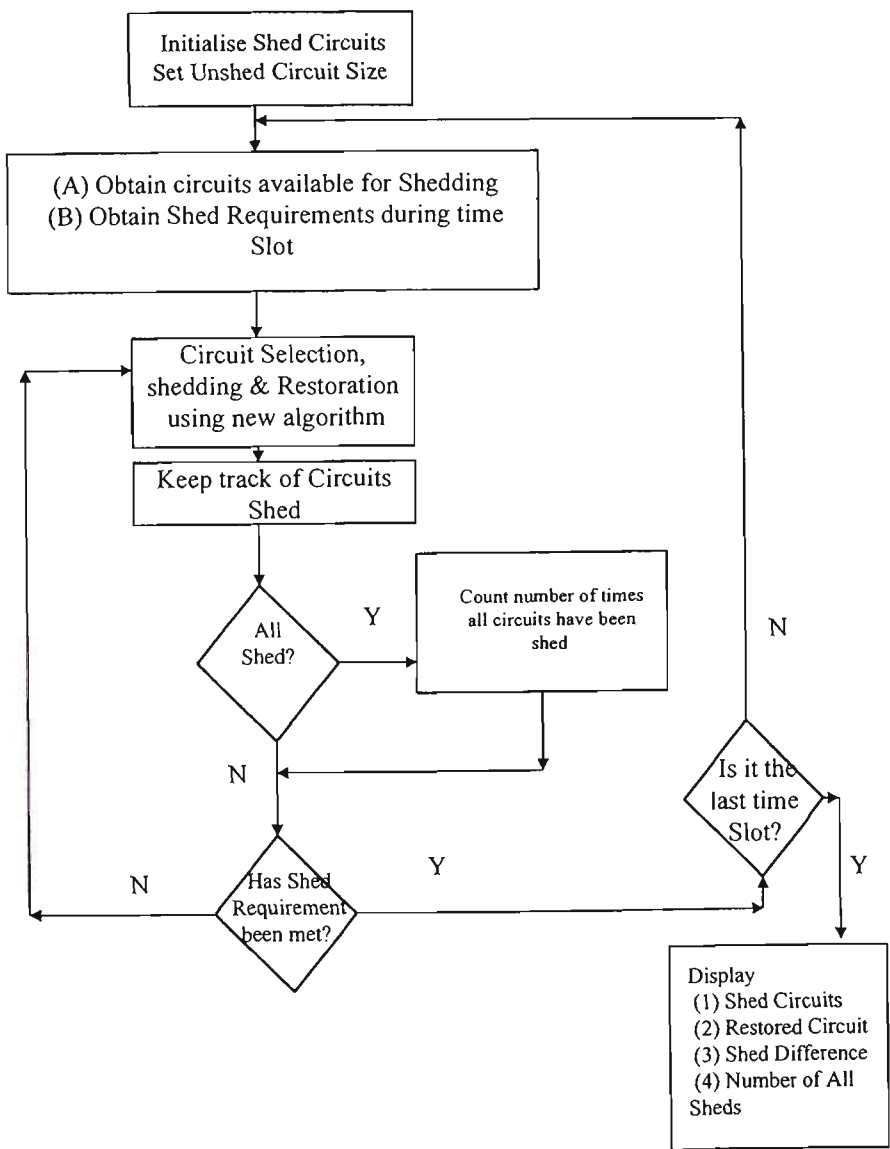


Figure 5.1 Load Shedding Strategy of New Algorithm

### 5.3.2 Circuit Selection Strategy

A strategy for selecting circuits can be stated in the following way. The option of load shedding is applicable only if the ICP's total load demand exceeds its total generation. From the readings of the exported power for the first 15 minutes of the peak period, the average power to be exported for the next 15 minutes period can be found out.

From the calculated exported power, generated power and the in-house power consumption, the shed requirement for the next 15 minutes can be found.

Depending on the shed requirement, the circuits required to be shed could be selected, optimising the calculated shed size and the size of the actual circuits to be shed. For the next 15 minutes period, the same procedure has to be followed with one exception that the circuits selected for the first 15 minute period should not be taken into consideration while optimising the size of the actual circuits to be shed. During this period, the circuits which were shed earlier are to be restored first. This procedure should continue till the completion of the peak period.

However, if a situation arises that the calculated shed requirement, is more than the total size of circuits available for shedding, then all the circuits for the second phase of load shedding have to be taken in to consideration. This strategy will satisfy the fairness criterion and at the same time maximise the power available for consumption [47 - 55].

- **Case (1)**

In order to find shed requirement, if the total local generation of the ICP is  $G(\text{loc})$  and the power to be supplied to the Utility is  $P(\text{exp})$  and the in-house requirement of the ICP is  $I(C)$ , then at any instant the shed requirement  $Sc(C)$  can be calculated as follows :

$$Sc(C) = I(C) - G(\text{loc}) + P(\text{exp})$$

Since energy exported  $P(\text{exp})$  and energy generated  $G(\text{loc})$  are required to be kept constant, shed requirement  $Sc(C)$  is to be calculated based on the ICP's own power consumption at

every 15 minutes interval of the peak period and corresponding to calculated values of the shed requirement, the load shedding scheme is to be implemented.

- **Case (2)**

If the ICP does not import or export power, then :

$$Sc(C) = I(c) - G(loc)$$

- **Case (3)**

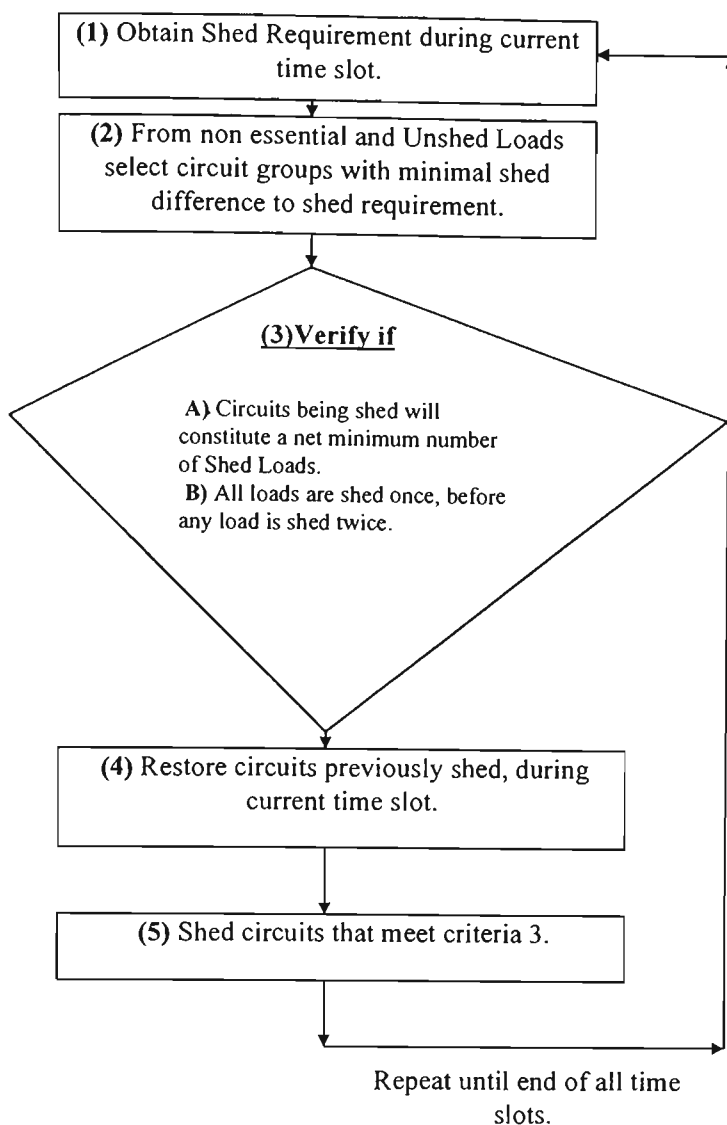
In order to find shed requirement, if the total local generation of the cogenerators is  $G(loc)$  and the power which can be imported from Utility is  $P(imp)$  and the in-house requirement of the industrial system is  $I(C)$ , then at any instant the shed requirement  $Sc(C)$  can be calculated as follows :

$$Sc(C) = I(C) - G(loc) - P(imp)$$

Since energy import  $P(imp)$  and energy generated  $G(loc)$  are required to be kept constant, shed requirement  $Sc(C)$  is to be calculated on the basis of ICP's in-house requirement at every 15 minutes interval of the peak period and corresponding to calculated values of the shed requirement the load shedding scheme is to be implemented.

After calculation of shed requirement, the strategy for selection of circuits should be followed; the same as for cases 1 and 2 [56 - 60 ].

The circuit selection, shedding and restoration strategy of the new algorithm is shown in Figure 5.2.



**Figure 5.2 Circuit Selection, Shedding and Restoration Strategy of New Algorithm**

## 5.4 Load Shedding Strategy From Reference [40]

### 5.4.1 Requirements and Constraints in reduced generation periods

The main requirements of the load-shedding operation during this period are:

- (a) To limit the load demand on the system by load shedding to meet the pre specified generation limits.

- (b) To maintain a continuous power supply to all essential services, such as hospitals and essential industries.
- (c) To allocate the available power generation to all customers in a fair manner so that the impact of power disruptions can be kept to a minimum.
- (d) To minimise the number of shedding operations.

These requirements are met when the load-shedding procedure satisfies the shed-size constraint and the circuit selection constraints. By requirement (a) above, the load in excess of the generation limit, at any time  $t$  during the reduced generation period, must be shed. If the total load demand and the generation limit at time  $t$  are  $L(t)$  and  $G(t)$ , respectively, the shed size at the same time can be defined as

$$S(t) = L(t) - G(t) \quad (1)$$

The actual amount of load to be shed  $S_s(t)$  at time  $t$  must lie between the shed size  $S(t)$  and the shed size plus a tolerance  $E$ . The shed-size constraint can therefore be expressed as

$$0 \leq S_s(t) - S(t) \leq E$$

In practise, the total load demand  $L(t)$  may not be known, although the overloading condition is demonstrated by a reduction of frequency.

#### 5.4.2 Shed Size Constraint

The objective of shedding load, is to ensure that the resultant load demand profile is as close as possible to the generation limit.

#### 5.4.3 Constraints in the selection of circuits

Although any substation can be a candidate in the selection of substations, the selection of circuits must satisfy the following constraints.

1. In load-shedding operations, the number of circuits allowed to be shed in any substation at any time is a pre specified percentage of the total. When the circuits shed in a substation are restored, the other circuits in a substation will become available for shedding if required. The rotation of circuits in this manner improves the fairness of the shedding procedure.
2. Circuits supplying essential services as outlined in requirement (b) of Chapter 5.4.4.1 must not be selected. In addition, the selection of circuit should not include circuits monitored by under frequency load-shedding relays.
3. A circuit which has been restored is excluded from the selection process until some specified time interval has elapsed.
4. A circuit that is shed for a period equal to or greater than a pre specified interval can be selected for restoration. The fairness requirement can be met partly by restoring these circuits and by selecting other circuits to be shed if necessary.

#### **5.4.4 Selection Strategies**

##### **5.4.4.1 Substation Selection Strategies**

Any substation can be a candidate in the selection of circuits for shedding. However, a substation-selection strategy for the determination of the most important substations is used so that the fairness requirement mentioned in Chapter 5.4.3 can be met.

The strategy comprises the following approaches:-

- (a) The heaviest substation is always selected first.
- (b) The substation with the smallest number of previous load-shedding operations is selected first.

In approach (a), a substation table is formed in which substations are arranged in descending order according to their loading levels. In aforementioned approach (b), the substation tables established by approach (a) is rearranged by initially grouping all the substations having the same number of previous load-shedding operations into substation groups. These groups are subsequently arranged in ascending order according to the numbers of operations, whereas the relative orders of the substations according to approach (a) within each group remain intact.

The order of substations in the substation table determines the sequence of substation selection. When system load exceeds the generation limit, causing the operation frequency to drop, the substation table will be updated and a new order of substations obtained. Based on this order, substations are selected one by one in turn. In this way, a fair selection of substations for shedding can be achieved. For each substation selected, corresponding load circuits are shed subject to the shed size and circuit selection constraints.

Although the above strategy will enhance fairness in load shedding, better performance can be achieved by the use of an improved strategy, in which the substation table is updated only by approach (a) in the initial interval of the reduced generation period. In the period subsequent to the initial interval, however, the table established by both approaches (a) and (b) of Chapter 5.4.4.1 is applied. The improved strategy ensures that, in the initial period, circuits will be selected from more heavily loaded substations.

#### **5.4.4.2      Circuit Selection Strategy**

A strategy for selecting circuits can be stated in the following way. First, circuits from a substation will only be selected if the number of circuits in service in the substation is greater than a pre specified percentage of the total number of circuits in service at the beginning of the reduced generation period. If this condition is satisfied, the heaviest circuit in the substation is considered; it is selected for shedding if it satisfies the shed size constraint; It is restored for a time interval greater than the minimum specified; and it supplies only nonessential services. The implementation of this strategy is easily achieved by forming a list

of circuits in service for each substation at the same time as the substation table is updated. The circuits in each list are arranged in descending order according to their loadings. This strategy has the advantage of selecting the minimum number of circuits given any order that the substation appear in the table. Consequently requirement (d) of Chapter 5.4.1 can be satisfied.

#### **5.4.5 Shed Restoration Strategy**

To satisfy the fairness criterion, any circuit shed is to be restored after some pre specified interval of time.

However the need for restoring circuits may:

- (a) coincide with the occurrence of an overload and necessitate load shedding to rectify the system balance.
- (b) arise alone.

In situation (a), circuits are selected and shed to rectify the existing overload condition first. When the power imbalance has been corrected, circuits to be restored according to circuit restoration constraint in Chapter 5.4.5 are identified. To avoid an underfrequency operation when restoring these circuits, the expected overload due to circuit restoration is estimated and a selection of circuits are shed. These circuits are to satisfy the requirements and constraints of this Chapter 5.4.5 and the total of their loadings must offset the expected overload. The expected overload when restoring circuits is given by the anticipated restored load minus the generation reserve which, in this situation, is the difference between the actual amount of load shed and the shed size.

In situation (b), the expected overload due to the restoration of circuits is also given by the difference between anticipated restored load and generation reserve. However, the generation reserve is the generation limit minus the actual amount of generation. To avoid overloading

when restoring circuits, a selection of circuits satisfying the requirements and constraints in Chapter 5.4.3 are shed.

### 5.5.1 Aims Of The New Algorithm

The creation of the algorithm centred round four main aspects.

**(1) The Shed Size should match the Shed Requirement as closely as possible:-**

The new algorithm will try to match the shed requirement with the shed size, initially. If this is not possible, the new algorithm will try to shed circuits so that the total shed size is close as possible to the shed requirement. The number of circuits available for shedding as well as the value of the circuits available for shedding will largely contribute to shed size being as close as possible to the shed requirement [53 - 56]. If shed load varies from the shed requirement within tolerance levels as specific to the load shedding application, then governor control can be applied to compensate for small shed variations [57 - 60].

**(2) Minimum number of circuits to be shed:-**

For each specific selection, the same circuits will be shed. Therefore, minimum number of circuits to be shed, will translate to the same circuits to be shed for a specific selection of circuits.

From an ICP operators point of view, it will be preferable to have a minimum number of loads unavailable at any given time. If 15.5 MW of total load needs to be shed, it would be unadvisable to shed load in the order of 4.4, 3.2, 2.5, 1.7, 1.6, 0.7, 0.5, 0.4, 0.3, 0.2 and 0.1 MW. It would be better to shed one 15.5 MW load. If a single 15.5 MW load is unavailable for shedding, as the next step it would be advisable to shed two loads that will be, in total close to 15.5 MW. Else, the next possible best solution is to shed three loads that will, in total be close to 15.5 MW.

The load shedding algorithm was designed not to shed more than a minimum number of loads, from the loads available for shedding.

**(3) Circuits Shed in one time slot should be restored during next time slot:-**

It would be unfavourable to have a load ( or circuit ) unavailable for a long period of time. The fairness criteria of having loads unavailable for a minimum time would be met, if circuits shed during a particular time slot are made available during the subsequent time slot.

In the new algorithm load shedding strategy every effort is made to make sure that loads shed once are restored during the subsequent time slot.

**(4) No circuit should be shed  $(X + 1)$  times before all circuits are shed  $X$  number of times:-**

In the entire 'system design' it was assumed that all loads available for shedding are of equal priority. This limitation has been included in Chapter 4.4.

Private cogenerators such as the Austin Hospital, Ballarat Hospital and the Ballarat Piggery expressed that they would appreciate having access to a load shedding software that would shed load periodically. The periodicity of shedding and restoring loads, would ensure that the fairness criteria is met.

The availability performance of loads is enhanced, while the load/ generation imbalance met by maintaining periodicity in load shedding.

### **5.5.2 Description of Load Shedding Strategy in the New Algorithm**

The load shedding strategy of the new algorithm as shown in Figure 5.1 is described as follows:-

- From the fuel input the local generation is initially evaluated.

- The user inputs of the imports, and exports are then utilised to work out the total generation.
- Once the total generation is known, the next step of obtaining the load demand profile is performed via user interaction. Load shedding is only applicable when there is load/generation imbalance such that the load demand is greater than the total generation.
- The shed requirement is calculated by taking away the total generation from the load demand corresponding to the current time period.
- The shed circuit numbers are initialised, to reflect that no circuit has been shed as yet. A track of the circuits shed will be maintained throughout the simulation. The unshed circuit size will be set as equal to the shed requirement.
- The circuits available for shedding shall be obtained via user interaction. The shed requirement correspondent to the current time slot, shall be passed on together with circuits available for shedding to the circuit selection, shed and restoration algorithm.

The circuit selection, shed and restoration algorithm is described in Chapter 5.5.3.

- Keep track of circuits that have been shed.
- A check will be done, if all loads have been shed. If all loads have been shed, a count will be performed on the number of times all loads have been shed.
- The next step would be to check if the shed requirement has been met. If the shed requirement has not been met, then the circuit selection, shed and restoration algorithm will be invoked. The aforementioned algorithm will be invoked until shed requirement matches shed load or is tolerably close to shed requirement.

- Once the shed requirement has been met, a boolean check will be performed if it is the last time slot.
- If it is not the last time slot, then the updated circuits available for shedding shall be obtained as well as the shed requirement of the next time slot. The aforementioned process shall continue until the last time slot.
- Finally, results of shed circuits, restored circuits, shed difference, number of all sheds shall be displayed correspondent to fuel inputs, local generation, net imports, total generation and demand profile.

### **5.5.3 Description of Circuit Selection, Shedding and Restoration Strategy of New Algorithm**

The circuit selection strategy adapted by the new algorithm is shown in Figure 5.2 and can be described as follows:-

- The shed requirement during the current time slot is ascertained.
- Only non essential and unshed loads shall be considered, with a potential of being shed.
- The next step would be to select a group of a minimal number of circuits with a minimal difference to the shed requirement. The aforementioned unshed circuit group with a minimum number of circuits that closely equates to the shed requirement will be selected.
- The intelligence of the algorithm centres around quickly working out the optimum trade off of a circuit group matching the following criteria:
  - ( a ) Circuits being shed will constitute a net minimum number of shed loads.
  - ( b ) Periodicity of load shedding is maintained.
- More details of the trade off of the criteria a) and b) are detailed in Chapter 5.6.

- The subsequent step is to restore circuits, that were shed during the previous time slot.
- The final step involves shedding circuit groups that meet criteria (1) to (4) of Chapter 5.5.1. Else, another search will be conducted until a suitable circuit group that can be shed is worked out.

## **5.6 Software Development Outcomes and Programming Methodology**

- Load shedding software has been developed to handle up to seventy five (75) circuits to be utilised for shedding purposes, which is well within the limits appropriate for a cogeneration scheme.
- The circuits available for shedding need to be entered in ascending order.
- The number of time slots in the analysis considered were twelve (12). These twelve (12) time slots were sequenced at fifteen minute intervals in this software as consistent with worlds best practice.
- The software would perform load shedding only when the load demand is more or equal to the total generation, as consistent in a practical scenario.
- The software would bring out the realisation of effective load shedding only when the circuits available for shedding could handle the shed requirement, as consistent in a practical scenario.

### **5.6.1 Main Function**

The main function of load shedding software is to calculate the load shedding strategy given:

- A) Circuits available for shedding.**
- B) Load demand.**
- C) Fuel inputs & other parameters such as power imports or power exports.**

Please Note that A), B) & C) need to be entered in coherence with a practical scenario prior to viewing a meaningful load shedding strategy.

#### 5.6.1.1 Circuits Available For Shedding

The maximum number of circuits that could be selected are seventy five (75). The circuits need to be entered in ascending order. Both real and/or integer values for circuit capacities are accepted by the software. All circuits are input in MWs.

#### 5.6.1.2 Load Demand

The load demand is input for twelve(12) fifteen minute time slots. It would be desirable to try out practical values of load demand. All load demand values are input in MWs.

#### 5.6.1.3 Fuel Inputs

The fuel input is read in units of (MkCal/hr). The generator capacity together with the generator constants need to be entered as appropriate here. Power imports and/or power exports are required to be entered as sequenced in this section of the software, so that total generation could be calculated. The total heat and power cogenerated together with the total power exports or imports are displayed alongside the total power generation corresponding to each fuel entry at the end of this section of the software.

#### 5.6.1.4 View Load Shedding

The user has been given options to choose from in the software package. Given options 1,2 & 3 have been entered as appropriate in a practical scenario **option 1 or v** when chosen displays the load shedding procedure. The **shed requirement, shed load, restored load, shed deviation** as well as the **number of all sheds** are displayed corresponding to each time slot.

### **5.6.1.5 Help**

The load shedding software analyser could obtain a brief description of each menu selection item during any stage of the analysis by choosing the help option, providing the software analyser is interacting with the main menu.

### **5.6.1.6 Quit / Dos Shell**

The load shedding software analyser could select either to quit or shell to Dos upon selecting option 6 from the main menu.

## **5.6.2 Programming Methodology**

### **5.6.2.1 Main Program**

The main program consisted of the following main instructions:

Initialising arrays of the *number of loads, shed loads, restored loads and number of times all loads have been shed.*

- Opening of data files to keep track of shed loads and restored loads
- Initialising global programming parameters of time slot, shed requirement, shed size, and total shed load.
- Sets up screen viewing format and sets background information for the user interface.

### **5.6.2.2 OpenShedFile Subroutine**

Opens file *shed.dat* to keep track of shed load.

### **5.6.2.3 InitShed Subroutine**

Initialises the array to keep track of the shed load.

#### 5.6.2.4 InitCancelShed Subroutine

Initialises the array to keep track of the restored load.

#### 5.6.2.5 Load Demand Subroutine

Through user interaction obtains load demand profile.

#### 5.6.2.6 TotShedReq Subroutine

Works out the heat and power generation correspondent to the fuel input.

#### 5.6.2.7 DisplayAllShed Subroutine

Displays the amount of times all circuits have been periodically shed.

#### 5.6.2.8 PerformShedding Subroutine

This is the subroutine where circuit selection, load shedding and load restoration is performed, as follows:-

- The shed requirement corresponding to time slot in concern ( any time slot between 1 to 12 ) is initially obtained.
- The boolean operators correspondent to *restored loads*, *shed difference* and *complete* (indicating that shedding is complete for a time slot ) are initialised to false.

**The steps below are iterated, until effective and quick selective solutions are obtained:-**

- Determine the loads that make up the smallest shed difference with the shed requirement.
- Once the shed difference is worked out, select only loads that were not already shed in current time slot or periodically shed more often.
- Refine the load selection until one load solution is obtained.

Once selection of load to be shed has been determined load shedding is performed by updating data files that keep track of shed load, restored load and arrays that keep track of shed load, restored load as well as the number of times all loads have been periodically shed.

The boolean operator indicating that the load shedding procedure is complete shall be reset to true, if load shedding is complete for all time slots.

#### **5.6.2.9 DisplayResults Subroutine**

This subroutine displays load shedding results. Parameters in display are the time slot, shed requirement, shed circuits, restored circuits, shed load and number of all sheds.

#### **5.6.2.10 DisplayGen Subroutine**

This subroutine displays the cogenerated power breakdown. Other parameters in display are time slot, fuel content, heat generated, power generated, local generation, net imports and total generation.

#### **5.6.2.11 User Interface Subroutine**

This subroutine handles the interaction between user and the software as follows:-

- If option 1 or 'C' is chosen from menu window

The user will be given the opportunity to enter the load values of the circuits that are available for shedding by the program executing subroutine *SelectCapacity*

- If option 2 or 'M' is chosen from menu window

The user will be given the opportunity to enter the load demand profile by the program executing Subroutine *LoadDemand*.

- If option 3 or 'F' is chosen from menu window

The program will open the file containing data of total loads shed, number of loads and arrays containing fuel input, local power generation, local heat generated, net imports and total generation. This segment of the software will interactively receive fuel inputs, exports, imports and work out local power generation, local heat generation and total power generation. This is followed by a display of aforementioned parameters.

- If option 4 or 'V' is chosen from menu window

The subroutine action will be executed. The action subroutine will simply perform load shedding by calling up the *PerformShedding* subroutine and if load shedding is complete for all time slots the *displayResults* subroutine will be executed. All data files, arrays and global program variables will be reinitialised accordingly.

- If option 5 or 'H' is chosen from menu window

The program will call up subroutine *LS\_Help* to display helpful guidelines to user, in the operation of load shedding software.

- If option 6 or 'Q' is chosen from menu window

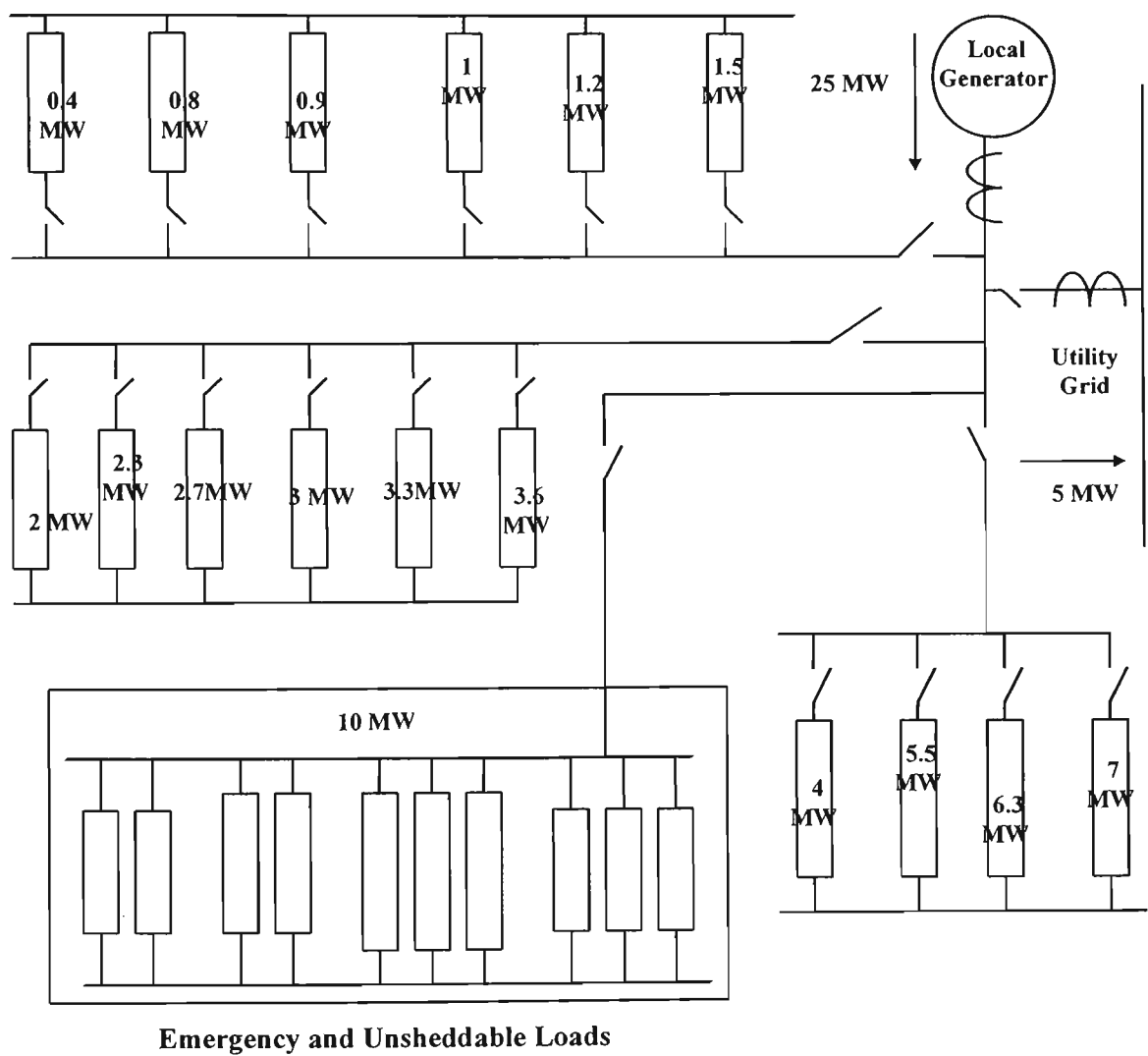
The program will provide the user with the option of shelling to DOS or quitting from the program by invoking the "Dos\_Shell" or "quit" subroutines.

The source code of the load shedding program is contained in, Appendix A.

### **5.7.1 Load Shedding Considerations in Cases with more Load and Less Generation**

Figure 5.3, depicts a case with more load and less generation.

- Situation could arise typically during peak hours, when cogenerating plant is contracted to export power ( ie 5 MW of exports, considered ).
- Considering that the local generation is constant at 25 MW.
- Total generation = local generation - exports  
$$= 25 - 5$$
$$= 20 \text{ MW}$$



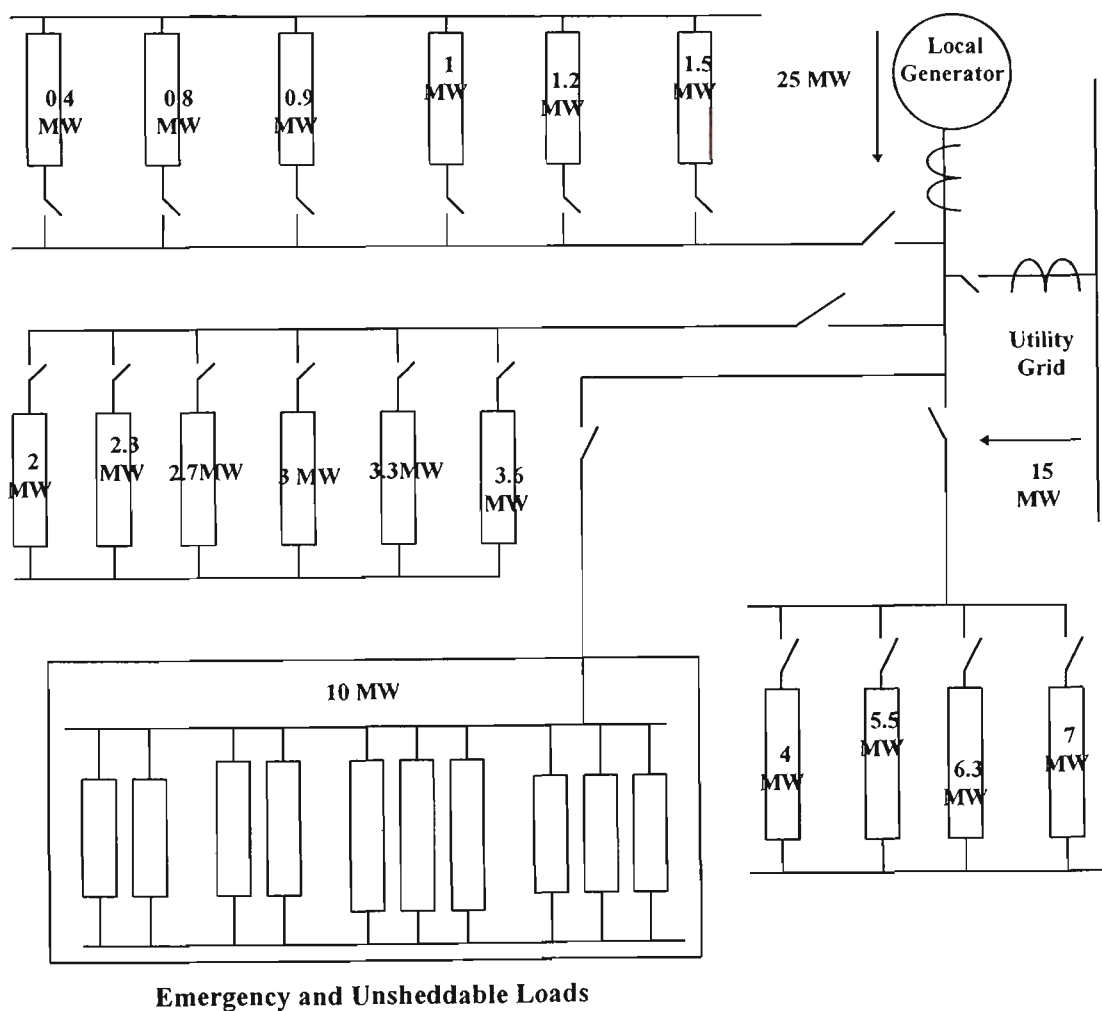
**Figure 5.3 Load Shedding considerations in cases with more loads and less generation**

- Total load demand varies from 55.5 MW to 50 MW.
- Emergency and unsheddable loads = 10 MW.
- 40 MW to 45.5 MW worth of loads are available for shedding, during contracted hours.
- 30 MW to 35.5 MW worth of loads need to be shed, during contracted hours.
- The maximum single load that could be shed is 7 MW.
- The minimum single load that could be shed is 0.4 MW.
- There are sixteen (16) given loads (circuits) available for shedding.
- A large number of circuits need to be shed during each time slot.
- In the given scenario, the loads available for shedding will be unavailable most of the time.

### **5.7.2 Load Shedding Considerations in Cases with both Large Loads and Large Generation Ratings**

- Situation could arise typically during normal operating hours, when cogenerating plant is importing power as well as generating power ( ie 15 MW of imports, considered ).
- Considering that the local generation is constant at 25 MW.

- Figure 5.4 depicts a case with large loads and large generation ratings.
- Total generation = local generation + imports
- $$= 25 + 15$$
$$= 40 \text{ MW}$$
- Total load demand varies from 55.5 MW to 50 MW.
- Emergency and unsheddable loads = 10 MW.



**Figure 5.4 Load Shedding considerations in cases with both Large loads and large generation ratings**

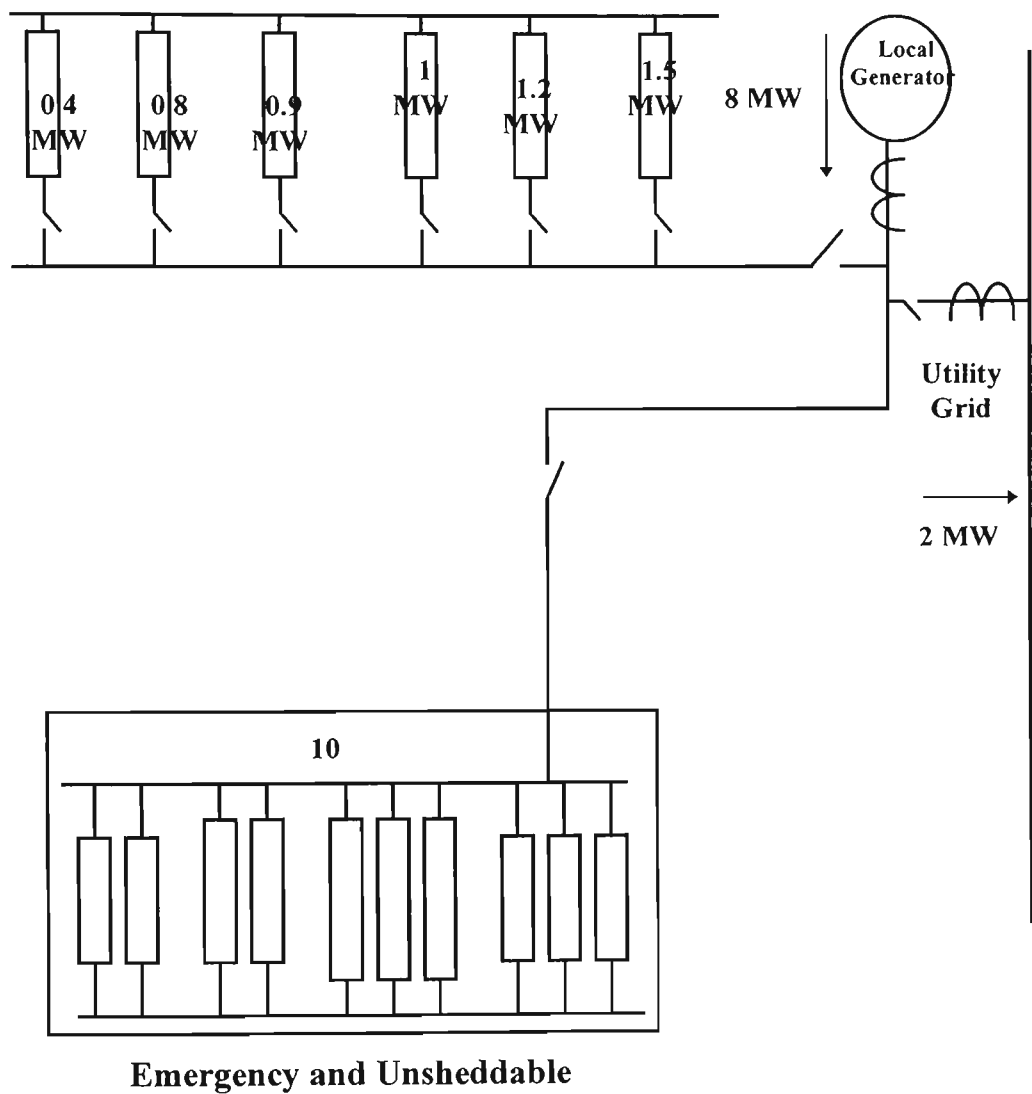
- There are sixteen (16) given loads (circuits) available for shedding.
- A few number of circuits could be shed during each time slot.
- In the given scenario, the loads available for shedding will be available most of the time.

### 5.7.3 Load Shedding Considerations in Cases with Less Loads and Less Generation Ratings

Figure 5.5 depicts a case with less loads and less generation ratings.

- Situation could arise typically during peak hours, when cogenerating plant is contracted to export power ( ie 2 MW of exports, considered ).
- Considering that the local generation is constant at 8 MW.
- $$\begin{aligned} \text{Total generation} &= \text{local generation} && - && \text{exports} \\ &= 8 && - && 2 \\ &= 6 \text{ MW} \end{aligned}$$
- Total load demand varies from 15.8 MW to 10 MW.
- Emergency and unsheddable loads = 10 MW.
- 0 MW to 5.8 MW worth of loads are available for shedding, during contracted hours.
- 4 MW to 9.8 MW worth of loads need to be shed, during contracted hours.
- The maximum single load that could be shed is 1.5 MW.
- The minimum single load that could be shed is 0.4 MW.

- There are six (6) given loads (circuits) available for shedding.
- A large number of circuits need to be shed during each time slot.



**Figure 5.5    Load Shedding considerations in cases with both less loads and less generation ratings**

- In the given scenario, the loads available for shedding will be unavailable at most time slots in order to meet the shed requirement.

The total load available for shedding 5.8 MW, is insufficient to meet the shed requirement.

5.7.4 Load Shedding Considerations in Cases with Constant Load Shedding Requirements in each time slot

Figure 5.6 depicts a case with constant load shedding requirements in each time slot.

- Situation could arise typically during islanding condition.
- Considering that the local generation is constant at 50 MW.
- Total Generation = local generation - exports

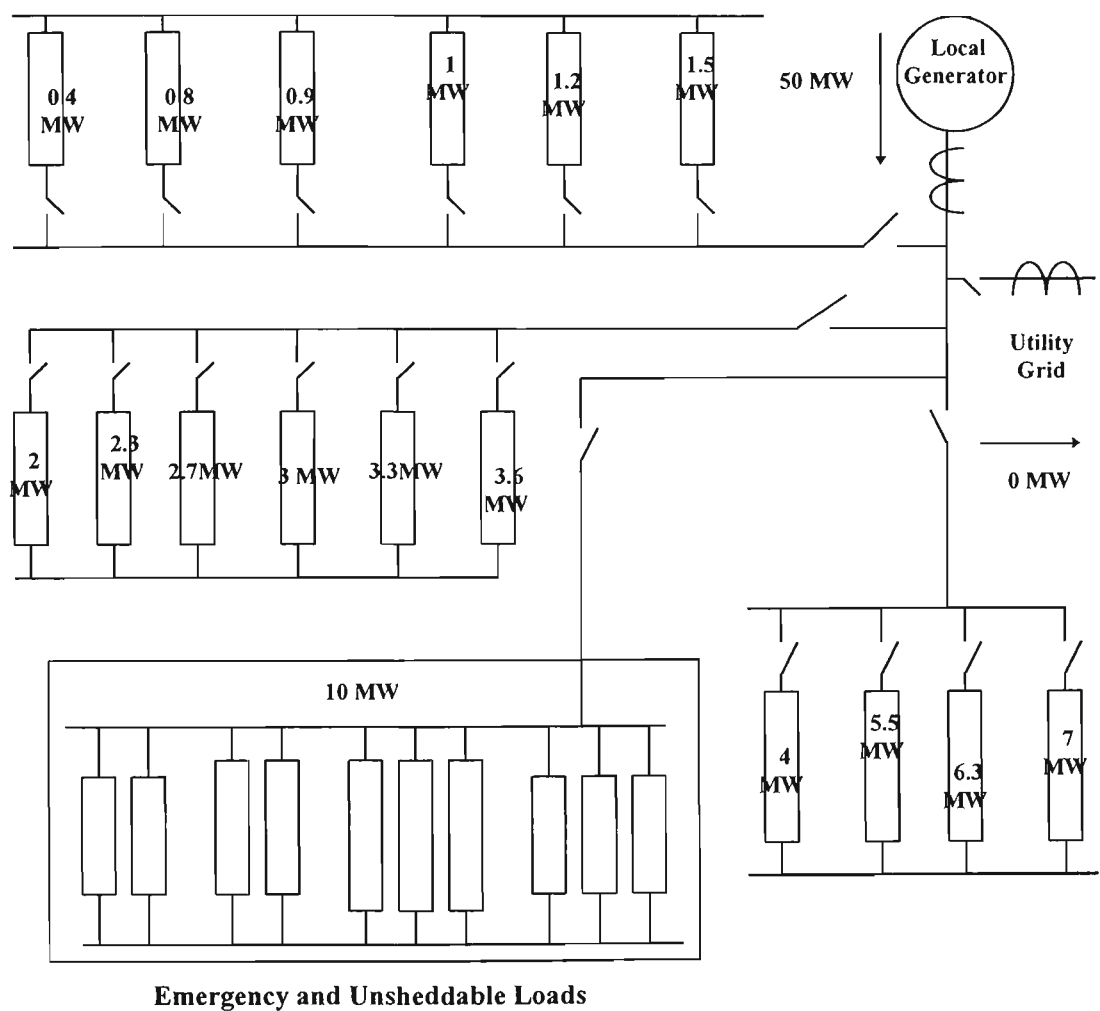


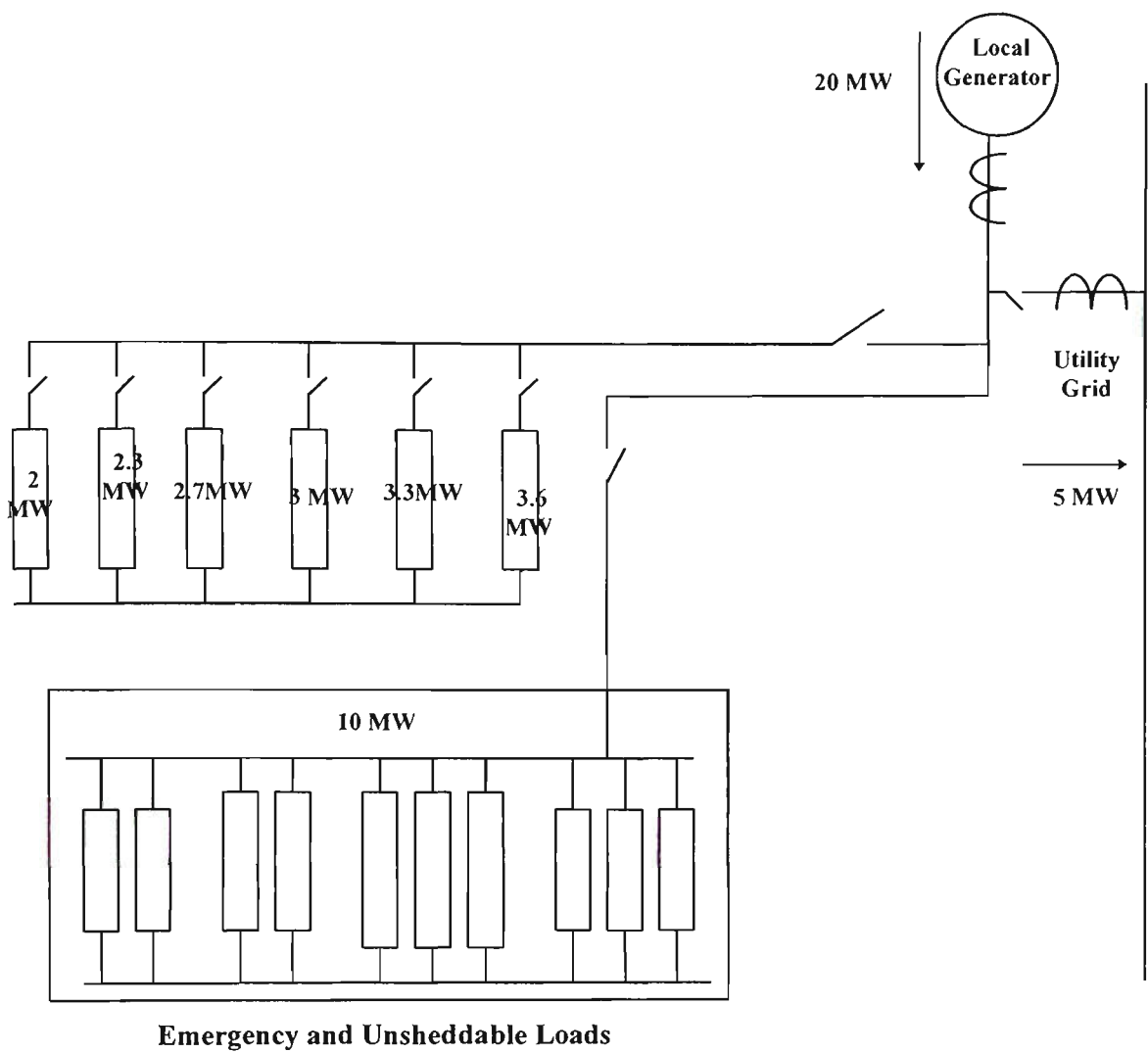
Figure 5.6 Load Shedding considerations in cases with constant Load Shedding Requirement during all time slots

$$\begin{aligned} &= 50 \quad - \quad 0 \\ &= 50 \text{ MW} \end{aligned}$$

- Total load demand varies from 55.5 MW to 50 MW.
- Emergency and unsheddable loads = 10 MW.
- 0 MW to 45.5 MW worth of loads are available for shedding, during entire time of islanding condition.
- 0 MW to 5.5 MW worth of loads need to be shed, during contracted hours.
- The maximum single load that could be shed is 5.5 MW.
- The minimum single load that could be shed is 0.4 MW.
- There are six (14) given loads (circuits) available for shedding.
- A small number of circuits can be shed during each time slot.
- In the given scenario, the loads available for shedding will be available to meet the shed requirement.

### 5.7.5 Load Shedding Considerations in Cases with few circuits available for Shedding

Figure 5.7 depicts a case with only a few circuits available for shedding.



**Figure 5.7    Load Shedding considerations in cases with few circuits available for Shedding**

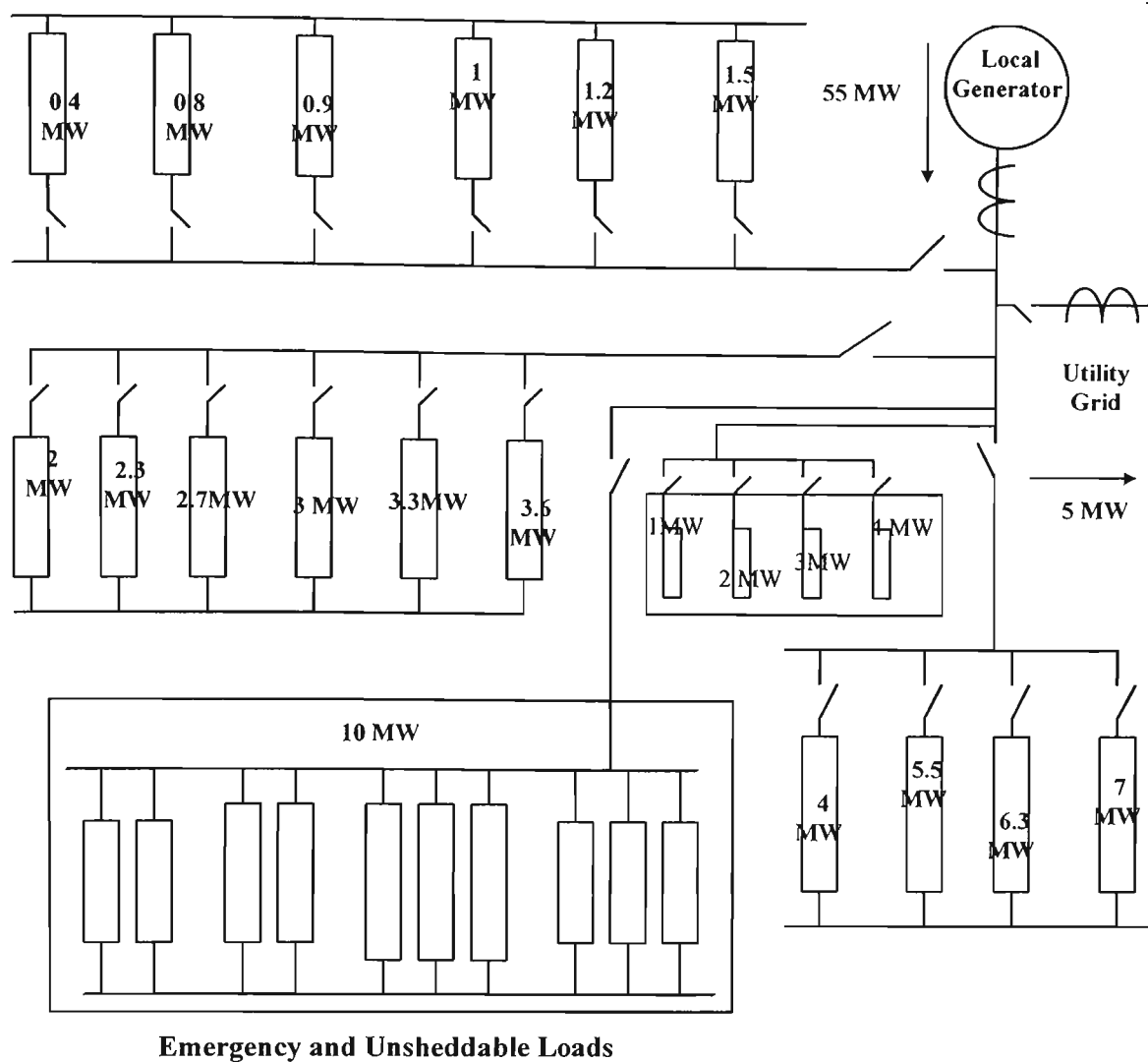
- Situation could arise typically either during exporting power, importing power or islanding condition.
- Considering that the local generation is constant at 20 MW.
- |                                     |   |         |
|-------------------------------------|---|---------|
| Total generation = local generation | - | exports |
| = 20                                | - | 5       |
| = 15 MW                             |   |         |

- Total load demand varies from 16.9 MW to 26.9 MW.
- Emergency and unsheddable loads = 10 MW.
- 0 MW to 16.9 MW worth of loads are available for shedding.
- 1.9 MW to 11.9 MW worth of loads need to be shed, during contracted hours.
- The maximum single load that could be shed is 3.6 MW.
- The minimum single load that could be shed is 2 MW.
- There are six (6) given loads (circuits) available for shedding.
- A fairly large number of circuits need to be shed during each time slot.
- In the given scenario, the loads available for shedding will be unavailable at more than 50% of the time slots, during the load shedding period.
- There may be certain times where all four (4) criteria mentioned in Chapter 5.5.1 will not be met, as the shed requirement is achieved.

#### **5.7.6 Load Shedding Considerations in Cases with a reasonably large number of circuits available for Shedding**

Figure 5.8 depicts a case with a reasonably large number of circuits available for shedding.

- Situation could arise typically either during exporting power, importing power or islanding condition.



**Figure 5.8 Load Shedding considerations in cases with large number of circuits available for Shedding**

- Considering that the local generation is constant at 50 MW.
- Total generation = local generation - exports  

$$= 55 - 5$$

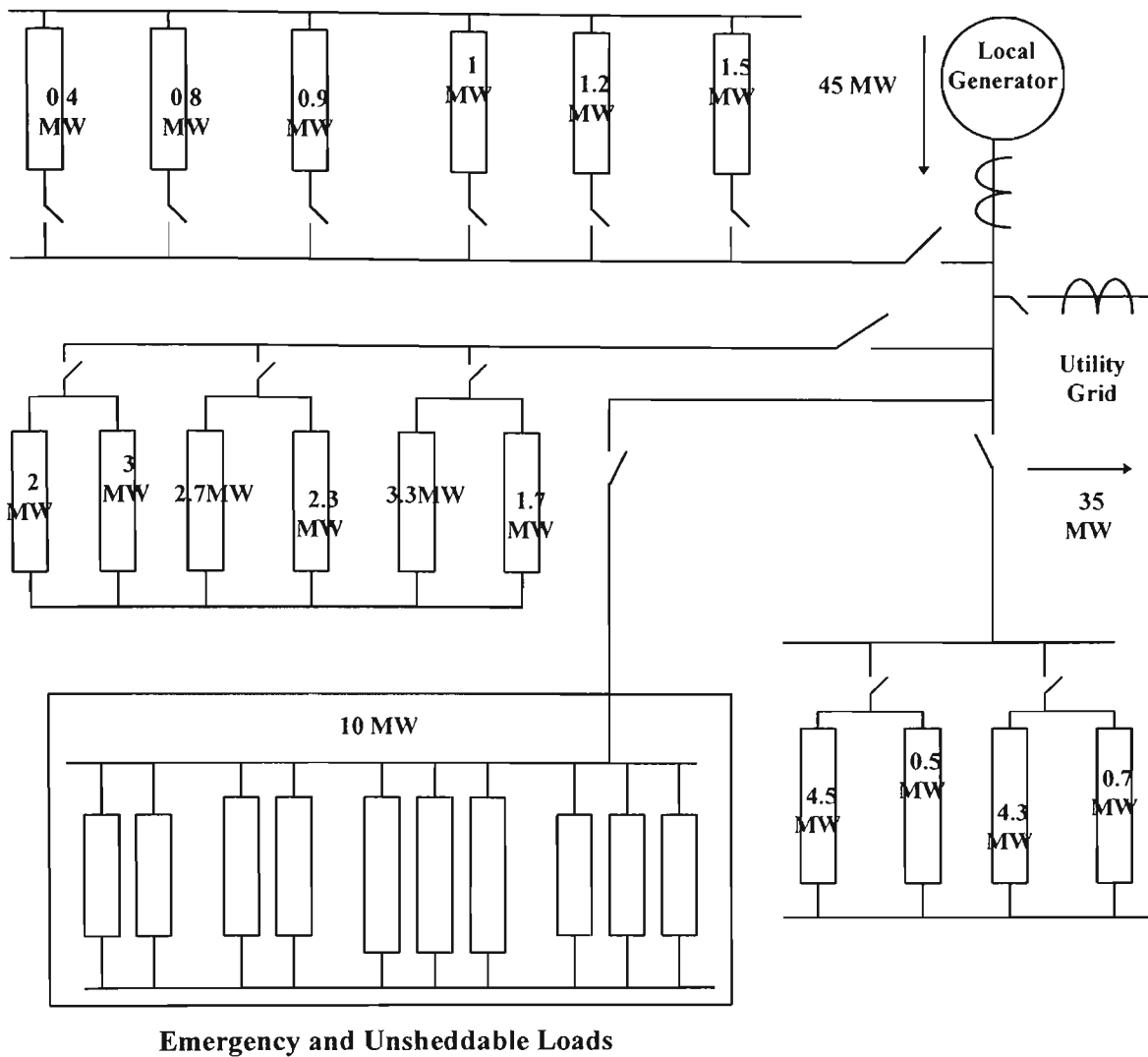
$$= 50 \text{ MW}$$
- Total load demand varies from 65.5 MW to 60 MW.
- Emergency and unsheddable loads = 10 MW.

- 55.5 MW to 50 MW worth of loads are available for shedding.
- 10 MW to 15.5 MW worth of loads need to be shed, during contracted hours.
- The maximum single load that could be shed is 7 MW.
- The minimum single load that could be shed is 0.4 MW.
- There are twenty (20) given loads (circuits) available for shedding.
- In the given scenario, the unavailability of a single load will be only for a few time slots.

**5.7.7 Load Shedding Considerations in Cases with a number of circuits being grouped for Shedding purposes**

Figure 5.9 depicts a case with a number of circuits being grouped for shedding purposes.

- Situation could arise typically either during exporting power, importing power or islanding condition.
- Considering that the local generation is constant at 45 MW.
- $$\begin{aligned} \text{Total generation} &= \text{local generation} && - && \text{exports} \\ &= && 45 && - && 35 \\ &= && 10 \text{ MW} \end{aligned}$$
- Total load demand varies from 30.8 MW to 40.8 MW.
- Emergency and unsheddable Loads = 10 MW.



**Figure 5.9 Load Shedding considerations in cases with circuits being grouped for shedding purposes**

- 0 MW to 30.8 MW worth of loads are available for shedding.
- 20.8 MW to 30.8 MW worth of loads need to be shed, during contracted hours.
- The maximum single load that could be shed is 5 MW.
- The minimum single load that could be shed is 0.4 MW.
- There are twenty (20) given loads (circuits) available for shedding.

- Loads have been grouped to shed load effectively, in that the number of circuit breakers that need to be turned on and off is minimised.

In the given scenario, the unavailability of a single load will be only for a few time slots.

## 5.8 Chapter Summary

The logical steps taken in the system development of load shedding aspects in an ICP have been described within this chapter. Insight into the issues encountered have been presented along with a suitable explanation of the solution found.

The lead up to and the development of the new algorithm load shedding strategy was described in detail in this chapter. The aims of the new algorithm load shedding strategy, circuit selection strategy as well as load shedding and restoration strategy have been examined.

The interaction of parameters such as *fuel inputs*, *local power* and *heat generation*, *power exports*, *power imports*, *total generation*, *load demand profile* have been analysed in determining the *load shedding requirement* as well as *load shedding and restoration strategies*.

The simulation focussed on modelling the load shedding and restoration responses to several generation and load demand opportunities, as pertinent to various ICP's requirements. Hence, the system development was for generic load shedding in Generic ICPs. However, the outcome of the software analysed for a particular scenario will produce specific load shedding options in a specific ICP.

The analysis, design and development of a new algorithm load shedding strategy with load shedding software was conducted in this chapter. The “academically popular” theories for local generation, load and load demand as well as sort and selection algorithms were enhanced and applied to the “industrial requirement” of maintaining generation/load balance by

providing the opportunity of load shedding. The outcome of the system design is an executable load shedding software file. Source code of software developed is in Appendix A.

## 6.0 Performance Analysis

Within the scope of this research, a new algorithm in an Industrial Cogeneration Plant was investigated. The shed size verses shed requirement were of prime interest. Different fuel levels, import/export levels, circuits available for shedding, load demands and shed requirements were considered in the analysis. The system complexity vis-a-vis software/hardware implemented results of a real time load shedding cogenerated system should be the subject of more detailed future research.

The new algorithm load shedding software was adapted to analyse important load shedding strategies of various ICPs. However, it is possible to also assess the load shedding strategies of distribution schemes.

Unlike the traditional method of load shedding approximate constant loads, the new algorithm method enables the application of a variety of parameters that could be controlled effectively to maintain generation/load balance.

The overall performance of the new algorithm load shedding strategy was verified with an IEE journal paper [40]. The new algorithm load shedding strategy was also tested on the load shedding scheme at the Shell Refinery.

Load Shedding applications in various scenarios were considered in Chapter 6.1.

Load Shedding applications with various fuel levels were investigated in Chapter 6.1.1.

Load Shedding applications with variable import/export levels were analysed in Chapter 6.1.2.

Load Shedding applications with variable load demand levels, circuit numbers and relatively higher shed requirements were considered in Chapter 6.1.3, 6.1.4, and 6.1.5 respectfully.

Chapter 6.2 focuses on verification of the new algorithm with a journal paper. Chapter 6.3 deals with a simulation of load shedding at the Shell Refinery.

The feasibility analysis of load shedding is presented in Chapter 6.4, followed by a chapter summary in Chapter 6.5.

## 6.1 Load shedding applications in various scenarios

In order to assess the effect of variables on load shedding, each variable was varied while keeping all other parameters constant. The load shedding procedure was observed for several diverse instances.

**In all simulations conducted throughout section 6.1 the ICP's generator details were as follows:**

Energy rate, 
$$F_i (P_{Gi}) = a'_i + b'_i P_{Gi} + c'_i P_{Gi}^2 \quad (MKCal/h)$$

where

$$a' = 111.11; \quad b' = 4; \quad c' = 0.044 \quad [61]$$

### 6.1.1.1 Load Shedding applications with variable Fuel Levels - 1

- **Non essential loads available for shedding = 35**
- **Those circuits in ascending order ( in MW ) :** 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

• LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.1.1 Varying Fuel Levels - 1

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal/ MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	420	8.4	49.9	0	49.9	10.1	20	-	10.5
30	55	415	8.4	49.3	0	49.3	5.7	16	20	5.5
45	58	395	8.4	46.8	0	46.8	11.2	19 5	16	10.9
60	50	410	8.4	48.7	0	48.7	1.3	4	19 5	1.0
75	53.5	350	8.5	41.1	0	41.1	12.4	21	4	12.0
90	59	375	8.5	44.3	0	44.3	14.7	23	21	14.5
105	51.5	358	8.5	42.2	0	42.2	9.3	18 3	23	8.8
120	55.5	400	8.4	47.5	0	47.5	8.0	17 6	18 3	8.0
135	58.4	385	8.4	45.6	0	45.6	12.8	15 14 1	17 6	12.5
150	53.5	415	8.4	49.3	0	49.3	4.2	13	15 14 11	4
165	50.5	400	8.4	47.5	0	47.5	3.0	10	13	2.9
180	55.5	405	8.4	48.1	0	48.1	7.4	12 9 2	10	7.0

Fuel levels were varied between 350 MKCal/hr to 420 MKCal/hr

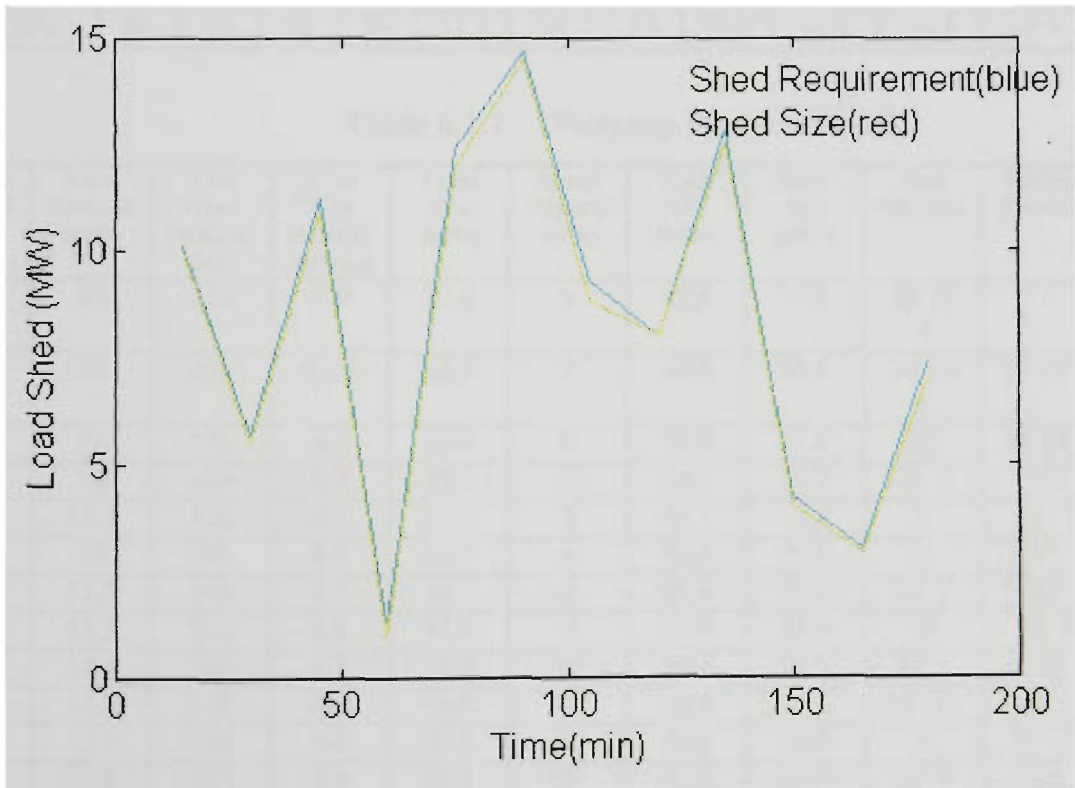


Figure 6.1 Comparison of Shed Requirement vs Shed Size For varying Fuel values between 350 and 420 MKCal/hr

**Observations:**

- Given no imports, both the local generation and the total generation varied from 41.1 to 49.9 MW.
- The shed requirement, varied from 1.3 MW to 14.7 MW.
- Graph of Figure 6.1 indicates that, the shed size closely follows the shed requirement.

**6.1.1.2 Load Shedding applications with variable Fuel Levels - 2**

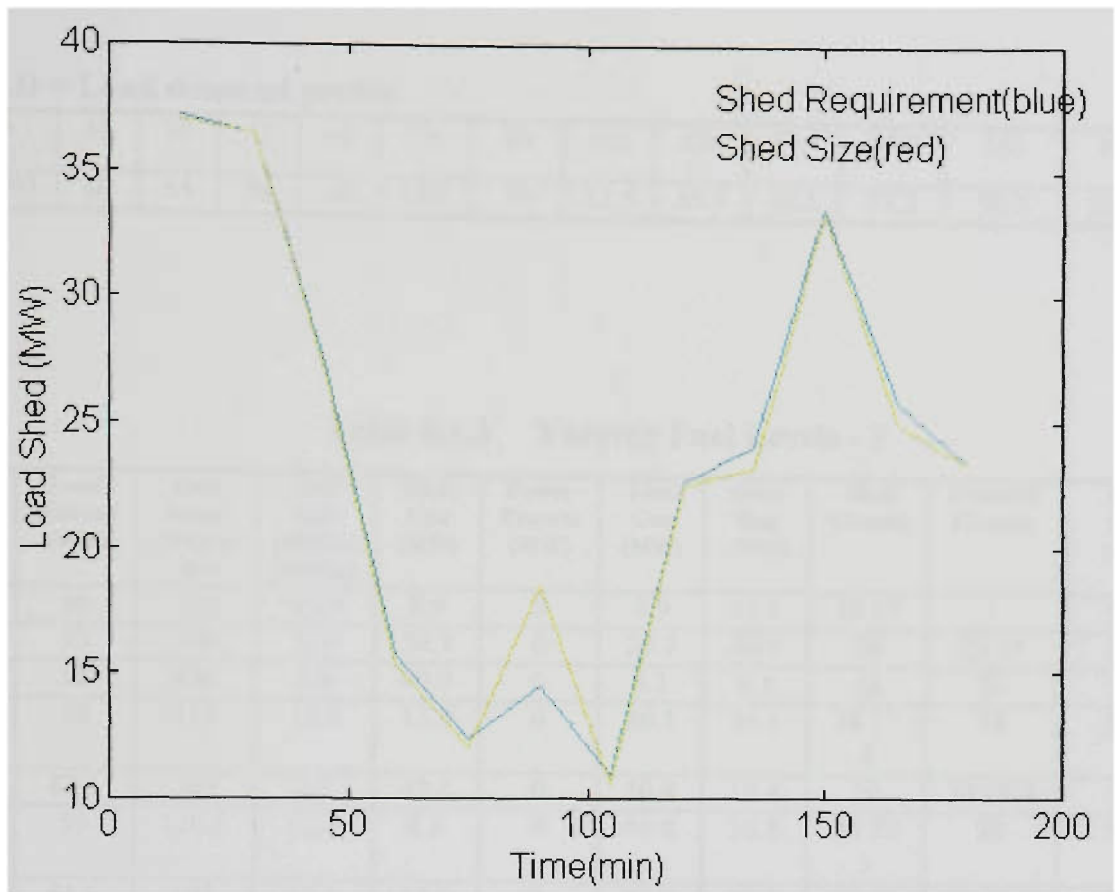
- Non essential loads available for shedding = 35
- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

**Table 6.1.2 Varying Fuel Levels - 2**

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	0	22.8	37.2	35 17 4	-	37
30	55	200	10.8	18.5	0	18.5	36.5	34 16 6	35 17 4	36.5
45	58	275	9.0	30.6	0	30.6	27.4	32	34 16 6	27.0
60	50	300	8.7	34.3	0	34.3	15.7	23 3	32	15.3
75	53.5	350	8.5	41.1	0	41.1	12.4	21	23 3	12.0
90	59	338	8.6	39.5	0	39.5	19.5	25	21	18.5
105	51.5	345	8.5	40.5	0	40.5	11.0	20 2	25	10.6
120	55.5	290	8.8	32.9	0	32.9	22.6	28	20 2	22.4
135	58.4	300	8.7	34.3	0	34.3	24.1	29 1	28	23.2
150	53.5	208	10.5	19.9	0	19.9	33.6	33 15	29 1	33.4
165	50.5	236	9.6	24.6	0	24.6	25.9	31	33 15	25.0
180	55.5	285	8.9	32.1	0	32.1	23.4	27 7	31	23.3

Fuel levels varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.2 Comparison of Shed Requirement vs Shed Size For Varying Fuel values between 200 and 350 MKCal/hr**

**Observations:**

- Given no imports, both the local generation and the total generation varied from 18.5 to 41.1 MW.
- The shed requirement, varied from 11.0 MW to 37.2 MW.
- Graph of Figure 6.2 indicates that, the shed size closely follows the shed requirement.

**6.1.1.3 Load Shedding applications with variable Fuel Levels - 3**

- **Non essential loads available for shedding = 35**
- **Those circuits in ascending order ( in MW ) :** 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

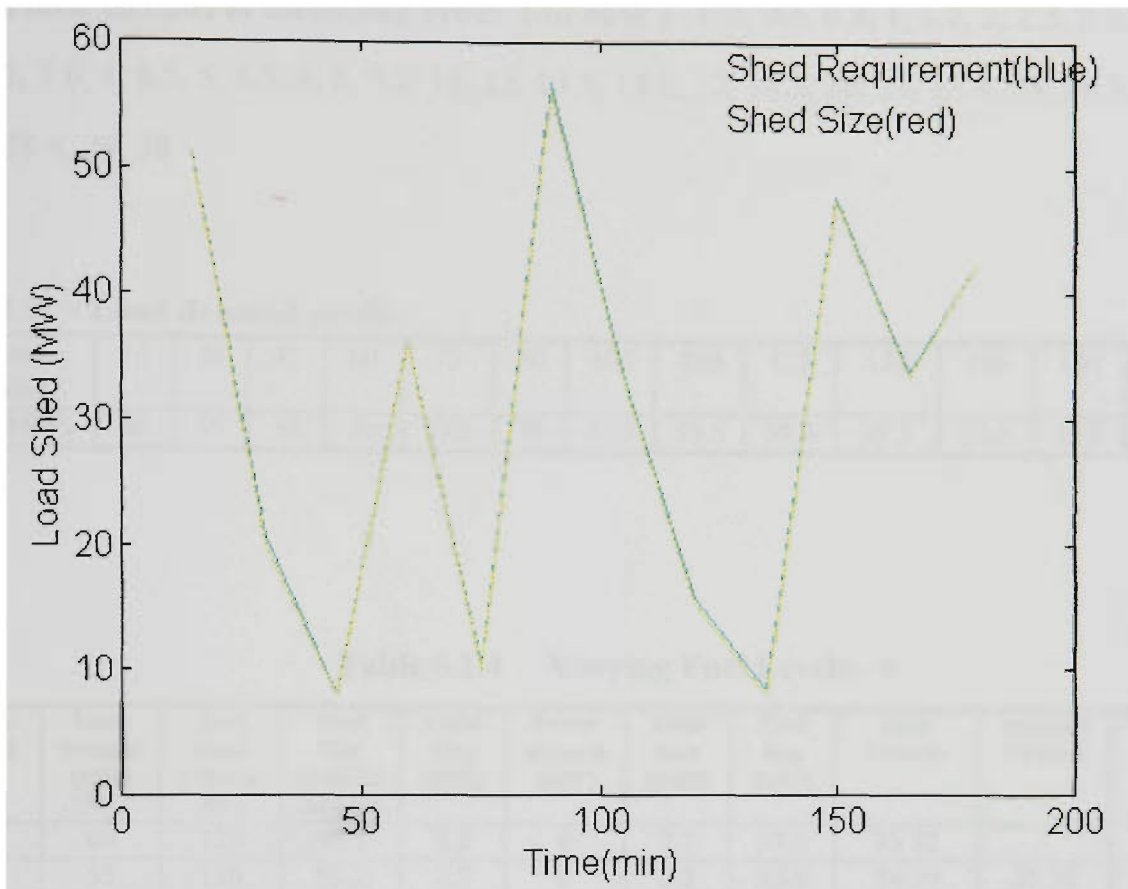
• **LD = Load demand profile**

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

**Table 6.1.3 Varying Fuel Levels - 3**

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	150	16.9	8.9	0	8.9	51.1	35 17	-	51.0
30	55	300	8.7	34.3	0	20.7	20.7	26	35 17	20.0
45	58	420	8.4	49.9	0	8.1	8.1	18	26	8.0
60	50	175	12.6	13.9	0	36.1	36.1	34 17 4	18	36.0
75	53.5	365	8.5	43.1	0	10.4	10.4	20	34 17 4	10.0
90	59	120.3	53.7	2.2	0	56.8	56.8	33 32 3	20	56.2
105	51.5	195	11.1	17.6	0	33.9	33.9	31 16 11	33 32 3	33.5
120	55.5	340	8.5	39.8	0	15.7	15.7	23 2	31 16 11	16.1
135	58.4	420	8.4	49.9	0	8.5	8.5	15 10	23 2	7.9
150	53.5	135	24.0	5.6	0	47.9	47.9	30 29	15 10	47.5
165	50.5	190	11.4	16.7	0	33.8	33.8	28 19 6	30 29	33.6
180	55.5	170	13.2	12.9	0	42.6	42.6	25 24 14 8	28 19 6	42.5

Fuel levels varied between 120 MKCal/hr to 420 MKCal/hr



**Figure 6.3 Comparison of Shed Requirement vs Shed Size For Varying Fuel values between 120 and 420 MKCal/hr**

**Observations:**

- Given no imports, both the local generation and the total generation varied from 2.2 to 49.9 MW.
- The shed requirement, varied from 8.1 MW to 56.8 MW.
- Graph of Figure 6.3 indicates that, the shed size closely follows the shed requirement.

**6.1.1.4 Load Shedding applications with variable Fuel Levels - 4**

- Non essential loads available for shedding = 35

- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

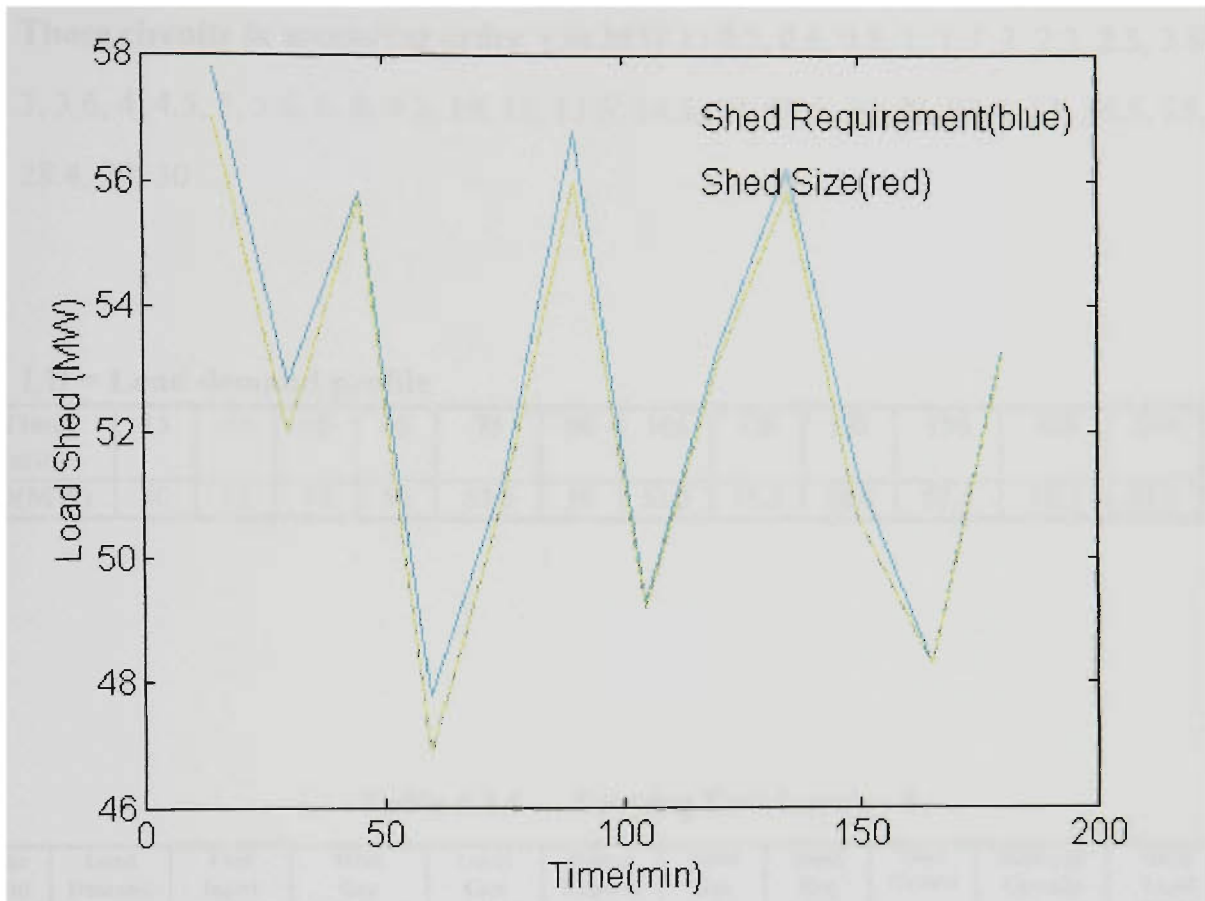
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.1.4 Varying Fuel Levels - 4

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	120	56.3	2.2	0	2.2	57.8	35 32	-	57.0
30	55	120	56.3	2.2	0	2.2	52.8	34 29	35 32	52.0
45	58	120	56.3	2.2	0	2.2	55.8	33 31 7	34 29	55.7
60	50	120	56.3	2.2	0	2.2	47.8	30 28	33 31 7	46.9
75	53.5	120	56.3	2.2	0	2.2	51.3	27 26 20	30 28	51.0
90	59	120	56.3	2.2	0	2.2	56.8	25 24 23 17	27 26 20	56.0
105	51.5	120	56.3	2.2	0	2.2	49.3	22 21 19 18 16 4	25 24 23 17	49.2
120	55.5	120	56.3	2.2	0	2.2	53.3	1 2 3 5 6 8 9 10 11 12 13 14 15 25 4	22 21 19 18 16 4	53.1
135	58.4	120	56.3	2.2	0	2.2	56.2	35 31 3	1 2 3 5 6 8 9 10 11 12 13 14 15 25 4	55.8
150	53.5	120	56.3	2.2	0	2.2	51.3	34 27 2	35 31 3	50.6
165	50.5	120	56.3	2.2	0	2.2	48.3	33 24 10	34 27 2	48.3
180	55.5	120	56.3	2.2	0	2.2	53.3	32 30 5	33 24 10	53.2

Fuel levels constant at 120 MKCal/hr



**Figure 6.4 Comparison of Shed Requirement vs Shed Size For Constant Fuel Levels of 120 MKCal/hr**

**Observations:**

- Given no imports, both the local generation and the total generation remained constant at 2.2 MW.
- The shed requirement, varied from 47.8 MW to 57.8 MW.
- Graph of Figure 6.4 indicates that, the shed size closely follows the shed requirement.

**6.1.1.5 Load Shedding applications with variable Fuel Levels - 5**

- **Non essential loads available for shedding = 35**

- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

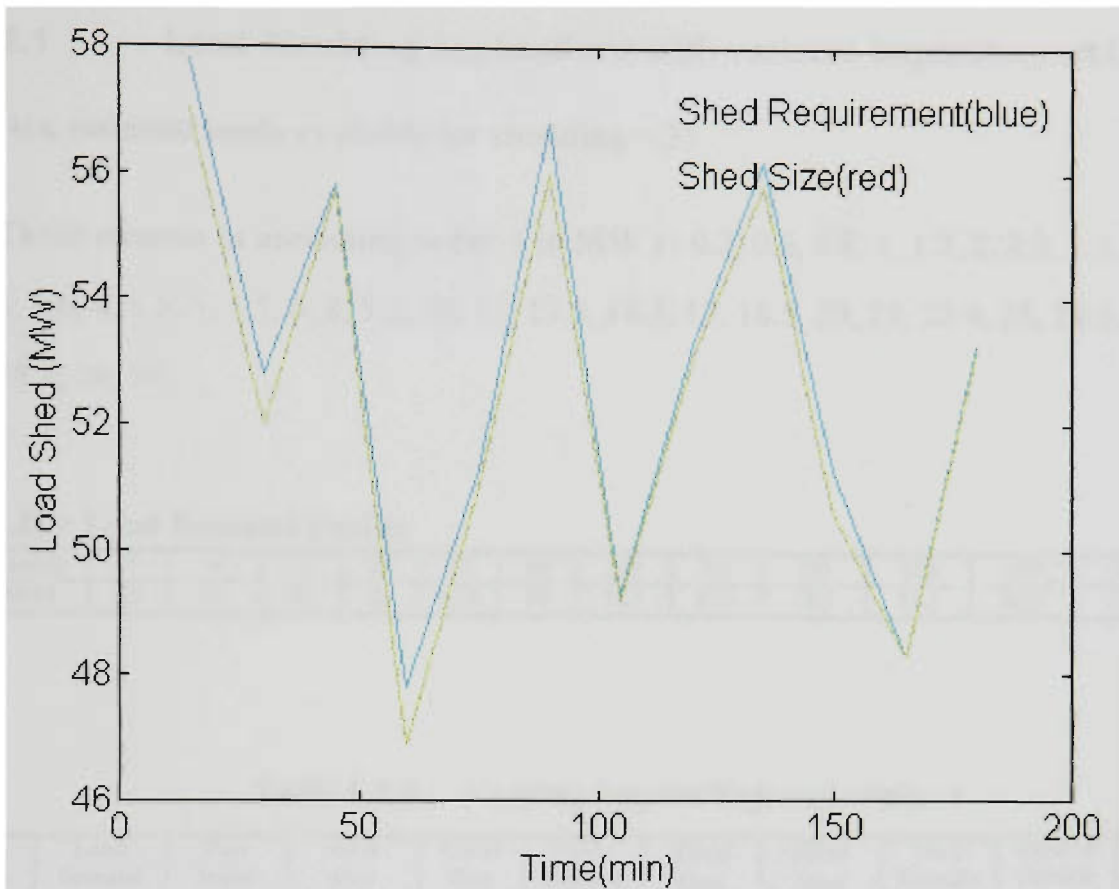
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.1.5 Varying Fuel Levels - 5

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal/ MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	420	8.4	49.9	0	49.9	10.1	20	-	10.0
30	55	420	8.4	49.9	0	49.9	6.1	15	20	5.0
45	58	420	8.4	49.9	0	49.9	8.1	18	15	8.0
60	50	420	8.4	49.9	0	49.9	0.1	1	18	0.2
75	53.5	420	8.4	49.9	0	49.9	3.6	12	1	3.6
90	59	420	8.4	49.9	0	49.9	9.1	17 11	12	9.0
105	51.5	420	8.4	49.9	0	49.9	1.6	4	17 11	1.0
120	55.5	420	8.4	49.9	0	49.9	5.6	16	4	5.5
135	58.4	420	8.4	49.9	0	49.9	8.5	14 13	16	8.5
150	53.5	420	8.4	49.9	0	49.9	3.6	10	14 13	2.9
165	50.5	420	8.4	49.9	0	49.9	0.6	2	10	0.6
180	55.5	420	8.4	49.9	0	49.9	5.6	9 8	2	6.3

Fuel levels constant at 420 MKCal/hr



**Figure 6.5 Comparison of Shed Requirement vs Shed Size For Constant Fuel Levels of 420 MKCal/hr**

**Observations:**

- Given no imports, both the local generation and the total generation remained constant at 49.9 MW.
- The shed requirement, varied from 0.1 MW to 10.1 MW.
- Graph of Figure 6.5 indicates that, the shed size closely follows the shed requirement.

### 6.1.2.1 Load Shedding applications with variable import/export Levels - 1

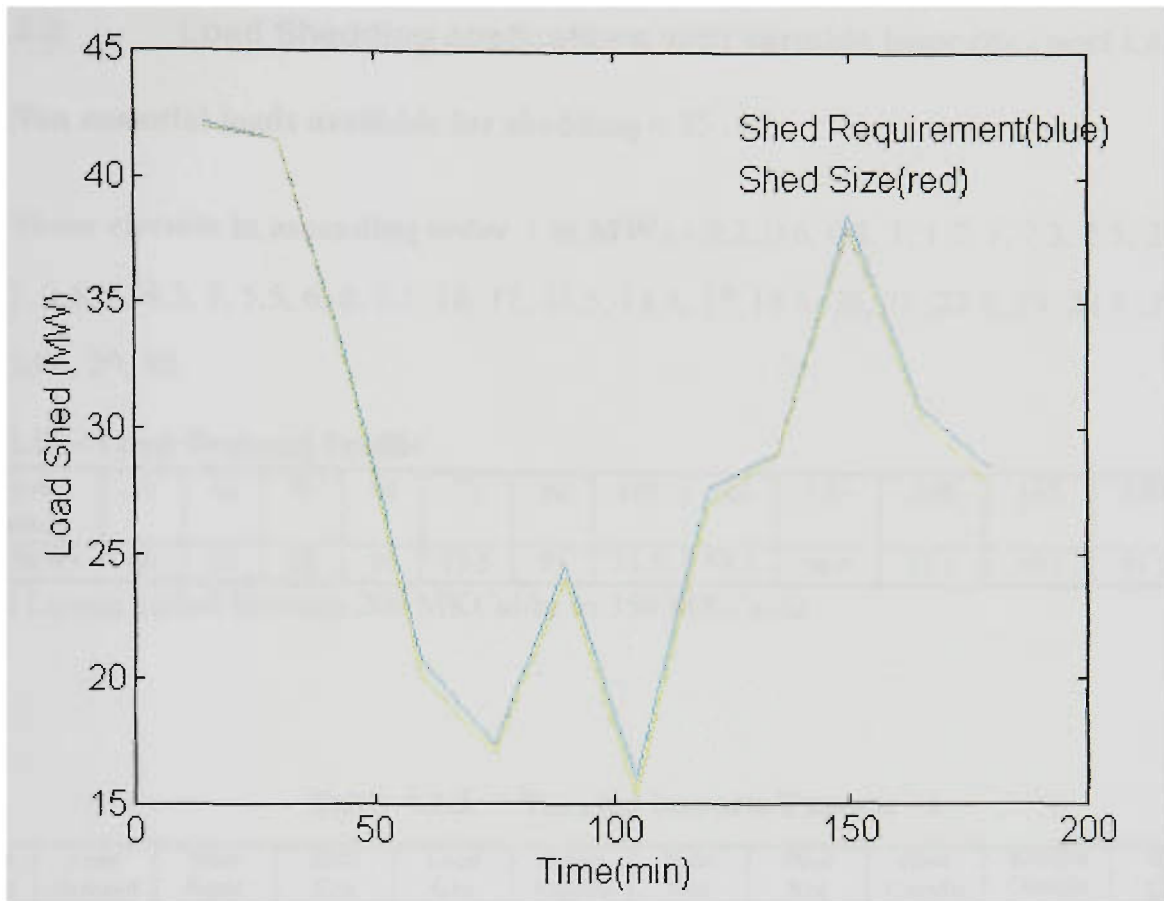
- Non essential loads available for shedding = 35
- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30
- LD = Load Demand Profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

**Table 6.2.1 Varying Import/Export Levels - 1**

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal/ MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	5	17.8	42.2	35 21	-	42.0
30	55	200	10.8	18.5	5	13.5	41.5	34 20 8	35 21	41.5
45	58	275	9.0	30.6	5	25.6	32.4	33 12	34 20 8	32.0
60	50	300	8.7	34.3	5	29.3	20.7	26	33 12	20.0
75	53.5	350	8.5	41.1	5	36.1	17.4	24	26	17.0
90	59	338	8.6	39.5	5	34.5	24.5	29 4	24	24.0
105	51.5	345	8.5	40.5	5	35.5	16.0	23 3	29 4	15.3
120	55.5	290	8.8	32.9	5	27.9	27.6	32	23 3	27.0
135	58.4	300	8.7	34.3	5	29.3	29.1	31 13	32	29.0
150	53.5	208	10.5	19.9	5	14.9	38.6	30 22	31 13	38.0
165	50.5	236	9.6	24.6	5	19.6	30.9	28 18	30 22	30.4
180	55.5	285	8.9	32.1	5	27.1	28.4	27 17 2	28 18	27.6

Fuel Levels were varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.6 Comparison of Shed Requirement vs Shed Size in periods of exporting 5 MW of Power.**

**Observations:**

- Given 5 MW worth of exports during the entire time period, the total generation varied from 14.9 MW to 36.1 MW.
- The Shed Requirement varied from 16.0 MW to 42.2 MW.
- Figure 6.6 indicated, that the Shed Size closely followed the Shed Requirement.

6.1.2.2 Load Shedding applications with variable import/export Levels - 2

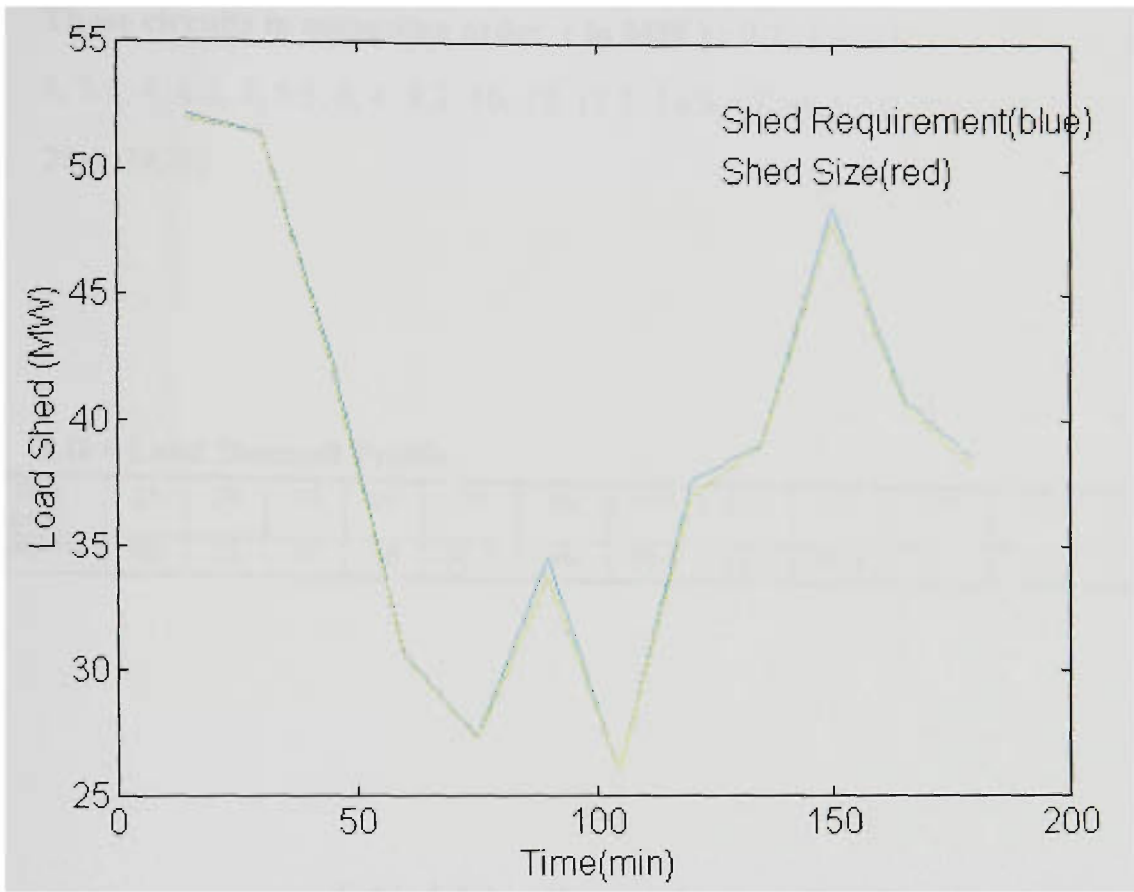
- Non essential loads available for shedding = 35
- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30
- LD = Load Demand Profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Fuel Levels varied between 200 MKCal/hr to 350 MKCal/hr

Table 6.2.2 Varying Imports/Exports - 2

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	15	7.8	52.2	35 27 4	-	52.0
30	55	200	10.8	18.5	15	3.5	51.5	34 28	35 27 4	51.4
45	58	275	9.0	30.6	15	15.6	42.4	33 22	34 28	41.9
60	50	300	8.7	34.3	15	19.3	30.7	32 12	33 22	30.6
75	53.5	350	8.5	41.1	15	26.1	27.4	31 7	32 12	27.3
90	59	338	8.6	39.5	15	24.5	34.5	30 19	31 7	33.7
105	51.5	345	8.5	40.5	15	25.5	26.0	29 11	30 19	26.0
120	55.5	290	8.8	32.9	15	17.9	37.6	26 24	29 11	37.0
135	58.4	300	8.7	34.3	15	19.3	39.1	25 23 17	26 24	39.0
150	53.5	208	10.5	19.9	15	4.9	48.6	21 20 18 16 15 14 10	25 23 17	47.9
165	50.5	236	9.6	24.6	15	9.6	40.9	1 2 3 5 6 8 9 13 31 4	21 20 18 16 15 14 10	40.6
180	55.5	285	8.9	32.1	15	17.1	38.4	35 18	1 2 3 5 6 8 9 13 31 4	38.0



**Figure 6.7 Comparison of Shed Requirement vs Shed Size in periods of exporting 15 MW of Power.**

**Observations:**

- Given 15 MW worth of exports during the entire time period, the total generation varied from 3.5 MW to 26.1 MW.
- The Shed Requirement varied from 26.0 MW to 52.2 MW.
- Figure 6.7 indicated, that the Shed Size closely followed the Shed Requirement.

**6.1.2.3 Load Shedding applications with variable import/export Levels - 3**

- **Non essential loads available for shedding = 35**

- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

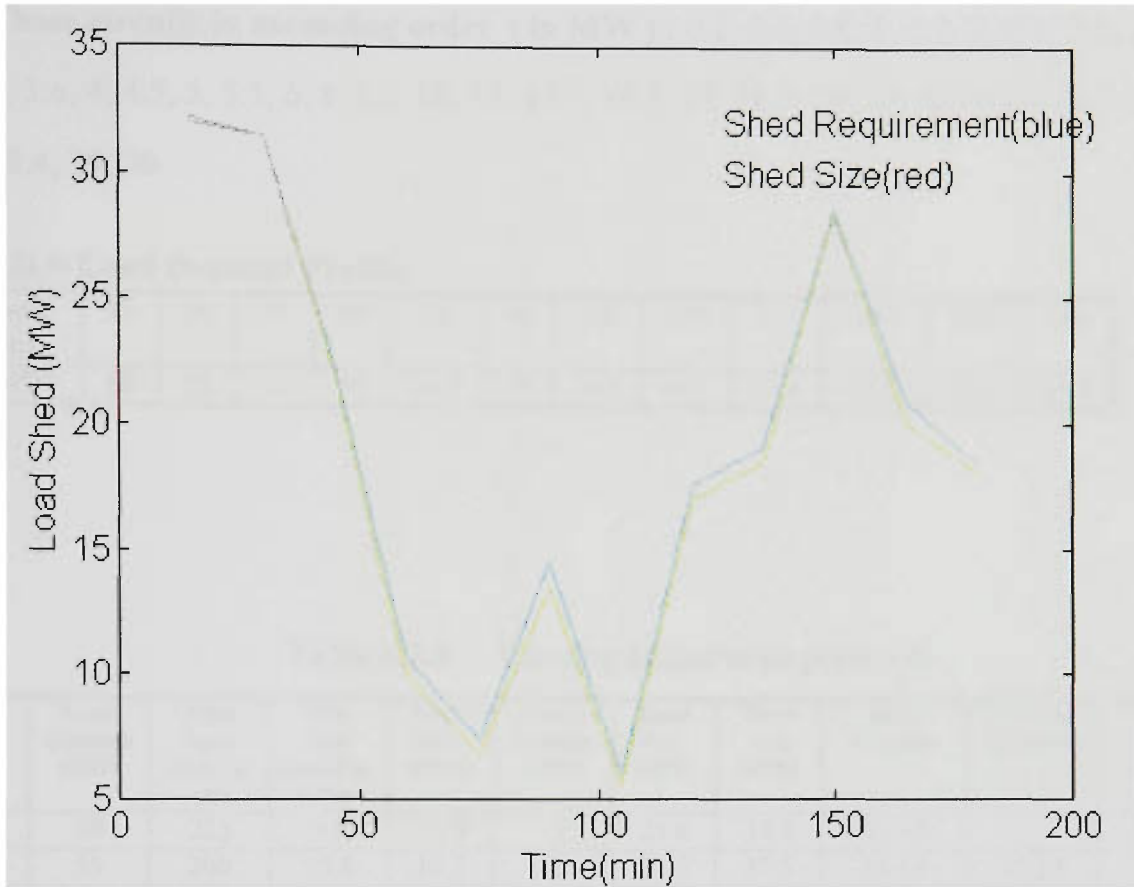
- **LD = Load Demand Profile**

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

**Table 6.2.3 Varying Imports/Exports - 3**

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	-5	27.8	32.2	35 6	-	32.0
30	55	200	10.8	18.5	-5	23.5	31.5	34 8	35 6	31.5
45	58	275	9.0	30.6	-5	35.6	22.4	27 4	34 8	22.0
60	50	300	8.7	34.3	-5	39.3	10.7	20	27 4	10.0
75	53.5	350	8.5	41.1	-5	46.1	7.4	17 3	20	6.8
90	59	338	8.6	39.5	-5	44.5	14.5	22	17 3	13.5
105	51.5	345	8.5	40.5	-5	45.5	6.0	16	22	5.5
120	55.5	290	8.8	32.9	-5	37.9	17.6	24	16	17.0
135	58.4	300	8.7	34.3	-5	39.3	19.1	25	24	18.5
150	53.5	208	10.5	19.9	-5	24.9	28.6	33	25	28.4
165	50.5	236	9.6	24.6	-5	29.6	20.9	26	33	20.0
180	55.5	285	8.9	32.1	-5	37.1	18.4	23 12	26	18.1

Fuel Levels varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.8 Comparison of Shed Requirement vs Shed Size in periods of importing 5 MW of Power.**

**Observations:**

- Given 5 MW worth of imports during the entire time period, the total generation varied from 23.5 MW to 46.1 MW.
- The Shed Requirement varied from 7.4 MW to 32.2 MW.
- Figure 6.8 indicated, that the Shed Size closely followed the Shed Requirement.

**6.1.2.4 Load Shedding applications with variable import/export Levels- 4**

- Non essential loads available for shedding = 35

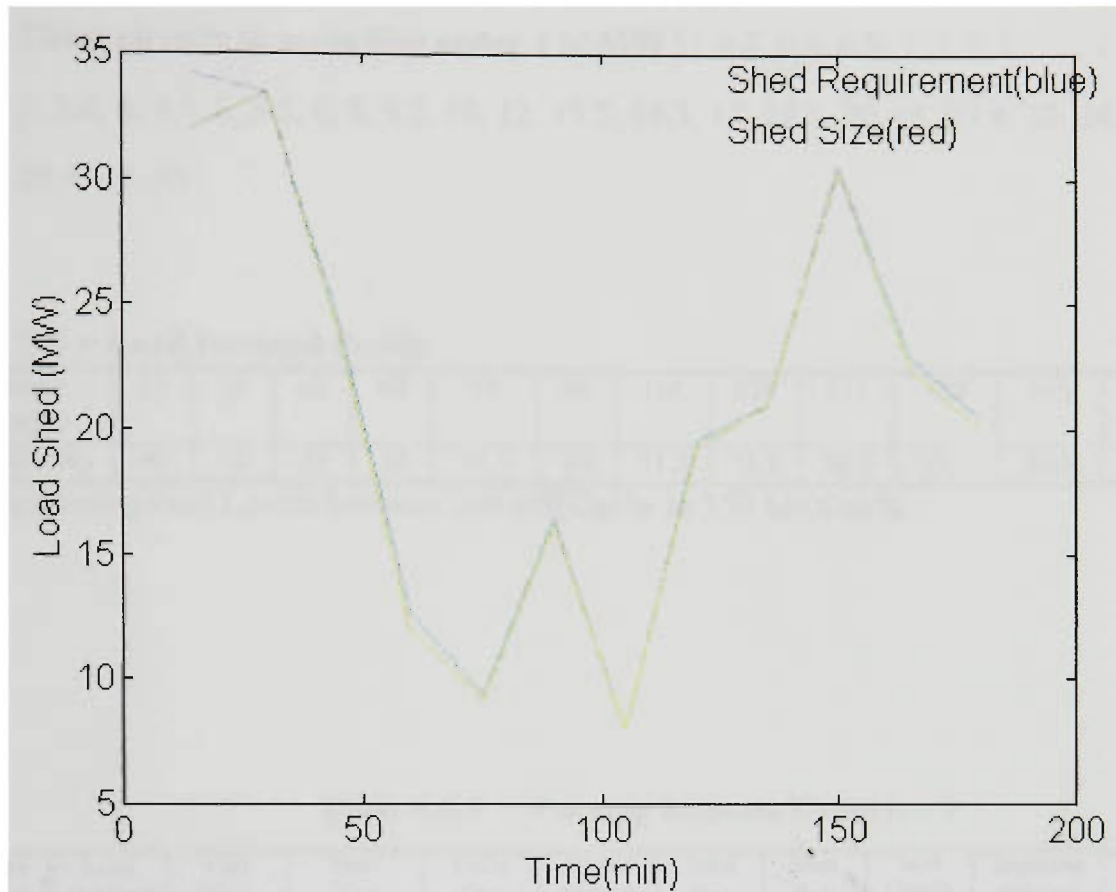
- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30
- LD = Load Demand Profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.2.4 Varying Imports/Exports - 4

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	-3	25.8	34.2	35 13	-	34.0
30	55	200	10.8	18.5	-3	21.5	33.5	34 14	35 13	33.5
45	58	275	9.0	30.6	-3	33.6	24.4	29 4	34 14	24.0
60	50	300	8.7	34.3	-3	37.3	12.7	21	29 4	12.0
75	53.5	350	8.5	41.1	-3	44.1	9.4	19	21	9.2
90	59	338	8.6	39.5	-3	42.5	16.5	23 5	19	16.2
105	51.5	345	8.5	40.5	-3	43.5	8.0	18	23 5	8.0
120	55.5	290	8.8	32.9	-3	35.9	19.6	25 3	18	19.3
135	58.4	300	8.7	34.3	-3	37.3	21.1	27	25 3	21.0
150	53.5	208	10.5	19.9	-3	22.9	30.6	33 6	27	30.4
165	50.5	236	9.6	24.6	-3	27.6	22.9	28	33 6	22.4
180	55.5	285	8.9	32.1	-3	35.1	20.4	26	28	20.0

Fuel Levels between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.9 Comparison of Shed Requirement vs Shed Size in periods of importing 3 MW of Power.**

#### **Observations:**

- Given 3 MW worth of imports during the entire time period, the total generation varied from 21.5 MW to 44.1 MW.
- The Shed Requirement varied from 8.0 MW to 34.2 MW.
- Figure 6.9 indicated, that the Shed Size closely followed the Shed Requirement.

#### **6.1.2.5 Load Shedding applications with variable import/export Levels - 5**

- **Non essential loads available for shedding = 35**

- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

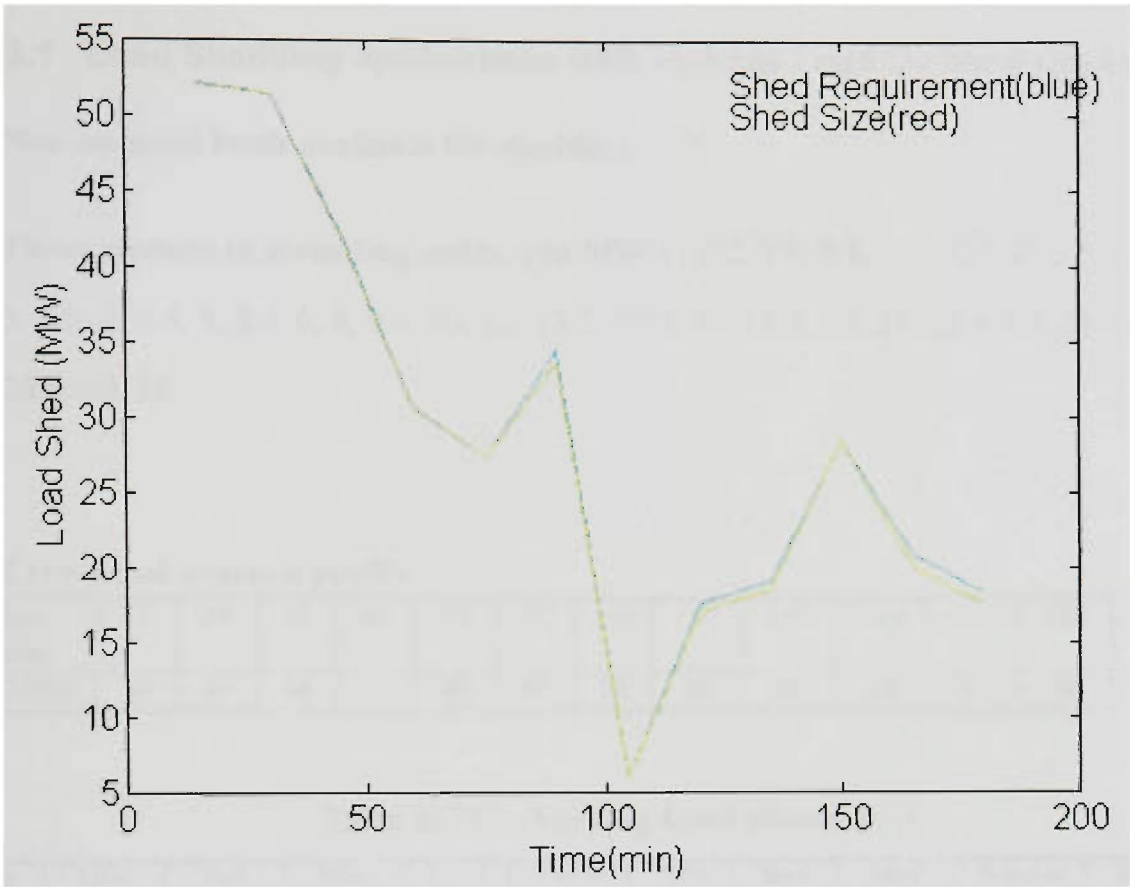
- LD = Load Demand Profile**

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Considering Fuel Levels between 200 MKCal/hr to 350 MKCal/hr

**Table 6.2.5 Varying Imports/Exports - 5**

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal/ MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	15	7.8	52.2	35 27 4	-	52.0
30	55	200	10.8	18.5	15	3.5	51.5	34 28	35 27 4	51.4
45	58	275	9.0	30.6	15	15.6	42.4	33 22	34 28	41.9
60	50	300	8.7	34.3	15	19.3	30.7	32 12	33 22	30.6
75	53.5	350	8.5	41.1	15	26.1	27.4	31 7	32 12	27.3
90	59	338	8.6	39.5	15	24.5	34.5	30 19	31 7	33.7
105	51.5	345	8.5	40.5	-5	45.5	6.0	17	30 19	6.0
120	55.5	290	8.8	32.9	-5	37.9	17.6	24	17	17.0
135	58.4	300	8.7	34.3	-5	34.3	19.1	25	24	18.5
150	53.5	208	10.5	19.9	-5	24.9	28.6	29 16	25	28.5
165	50.5	236	9.6	24.6	-5	29.6	20.9	26	29 16	20.0
180	55.5	285	8.9	32.1	-5	37.1	18.4	23 11	26	17.5



**Figure 6.10 Comparison of Shed Requirement vs Shed Size in periods of Exporting 15 MW of Power for an hour and importing 5 MW of Power for an hour.**

**Observations:**

- Given 15 MW worth of exports for 1.5 hours and 5 MW worth of imports for 1.5 hours, the total generation varied from 3.5 MW to 45.5 MW.
- The Shed Requirement varied from 6 MW to 52.2 MW.
- Figure 6.10 indicated, that the Shed Size closely followed the Shed Requirement.

6.1.3.1 Load Shedding applications with variable Load Demand Levels - 1

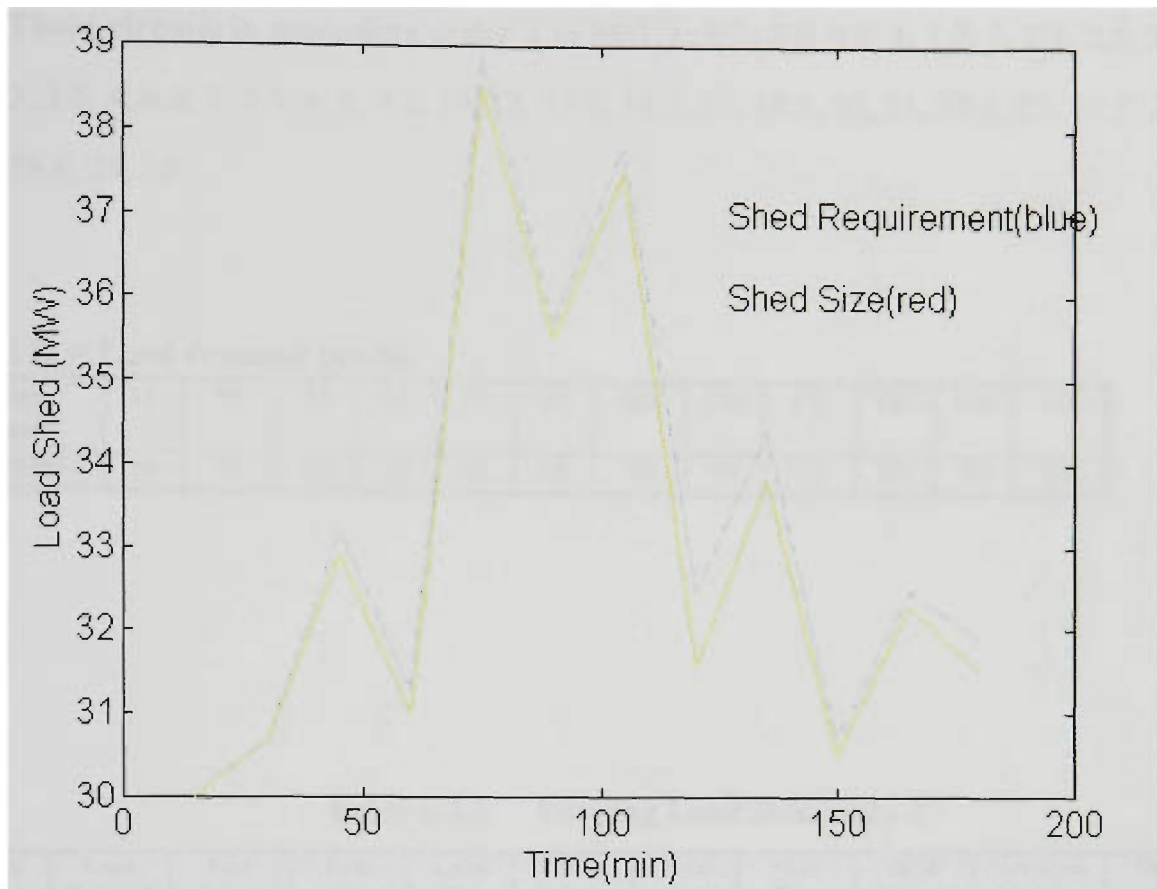
- Non essential loads available for shedding = 35
- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	80	80	80	80	80	80	80	80	80	80	80	80

Table 6.3.1 Varying Load Demand - 1

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	80	420	8.4	49.9	0	49.9	30.1	35	-	30.0
30	80	415	8.4	49.3	0	49.3	30.7	34 5	35	30.7
45	80	395	8.4	46.8	0	46.8	33.2	33 14	34 5	32.9
60	80	410	8.4	48.7	0	48.7	31.3	32 13	33 14	31.0
75	80	350	8.5	41.1	0	41.1	38.9	31 22	32 13	38.5
90	80	375	8.5	44.3	0	44.3	35.7	30 20 4	31 22	35.5
105	80	358	8.5	42.2	0	42.2	37.8	29 23 4	30 20 4	37.5
120	80	400	8.4	47.5	0	47.5	32.5	28 19	29 23	31.6
135	80	385	8.4	45.6	0	45.6	34.4	27 21 3	28 19	33.8
150	80	415	8.4	49.3	0	49.3	30.7	26 18 8	27 21 3	30.5
165	80	400	8.4	47.5	0	47.5	32.5	25 17 16 7	26 18 8	32.3
180	80	405	8.4	48.1	0	48.1	31.9	24 15 12 11 10	25 17 16 7	31.5

Considering fuel levels between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.11 Comparison of Shed Requirement vs Shed Size in periods of constant Load Demand of 80 MW.**

#### **Observations:**

- Total generation varied between 41.1 MW and 49.9 MW
- Given constant load demand of 80 MW, the shed requirement varied from 30.1 MW to 38.9 MW
- Figure 6.11 indicated, that the shed size closely followed the shed requirement.

#### **6.1.3.2 Load Shedding applications with variable Load Demand Levels - 2**

- **Non essential loads available for shedding = 35**

- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

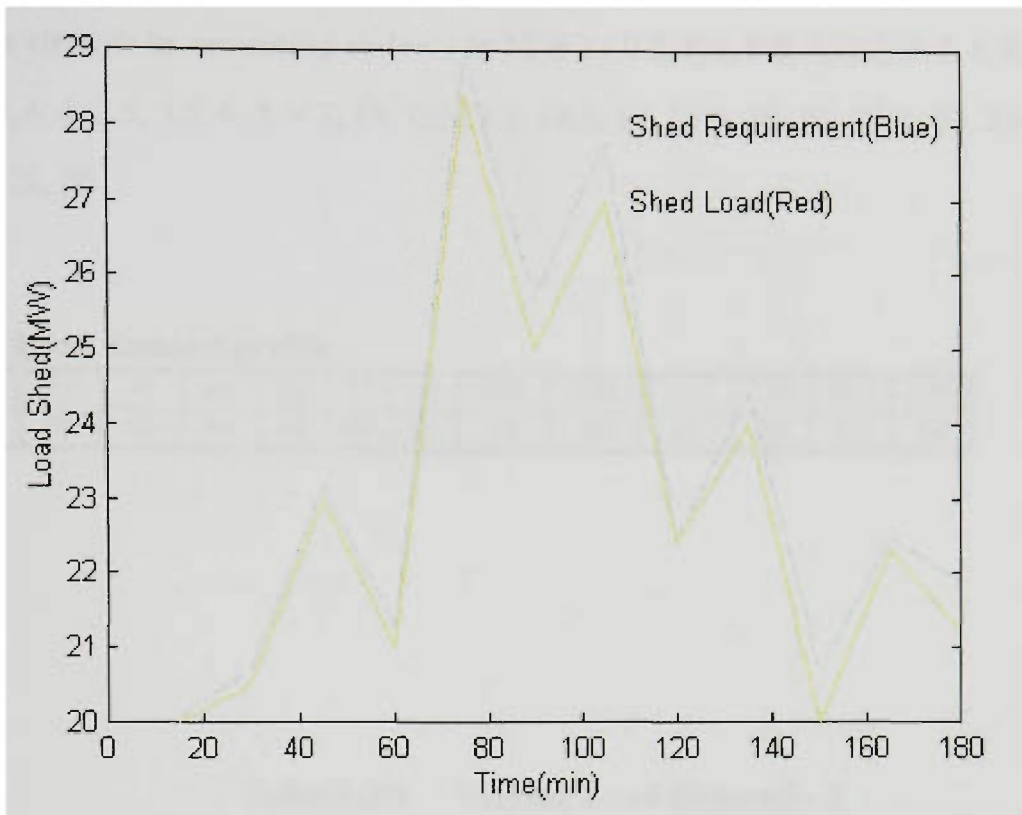
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	70	70	70	70	70	70	70	70	70	70	70	70

**Table 6.3.2 Varying Load Demand - 2**

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	70	420	8.4	49.9	0	49.9	20.1	26	-	20.0
30	70	415	8.4	49.3	0	49.3	20.7	25 6	26	20.5
45	70	395	8.4	46.8	0	46.8	23.2	29	25 6	23.0
60	70	410	8.4	48.7	0	48.7	21.3	27	29	21.0
75	70	350	8.5	41.1	0	41.1	28.9	33	27	28.4
90	70	375	8.5	44.3	0	44.3	25.7	31	33	25.0
105	70	358	8.5	42.2	0	42.2	27.8	32	31	27.0
120	70	400	8.4	47.5	0	47.5	22.5	28	32	22.4
135	70	385	8.4	45.6	0	45.6	24.4	24 17 4	28	24.0
150	70	415	8.4	49.3	0	49.3	20.7	23 16	24 17 4	20.0
165	70	400	8.4	47.5	0	47.5	22.5	22 18 3	23 16	22.3
180	70	405	8.4	48.1	0	48.1	21.9	21 19	22 18 3	21.2

Considering fuel levels between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.12 Comparison of Shed Requirement vs Shed Size in periods of constant Load Demand of 70 MW.**

**Observations:**

- Total generation varied between 41.1 MW and 49.9 MW
- Given constant load demand of 70 MW, the shed requirement varied from 20.1 MW to 28.9 MW
- Figure 6.12 indicated, that the shed size closely followed the shed requirement.

**6.1.3.3 Load Shedding applications with variable Load Demand Levels - 3**

- Non essential loads available for shedding = 35

- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

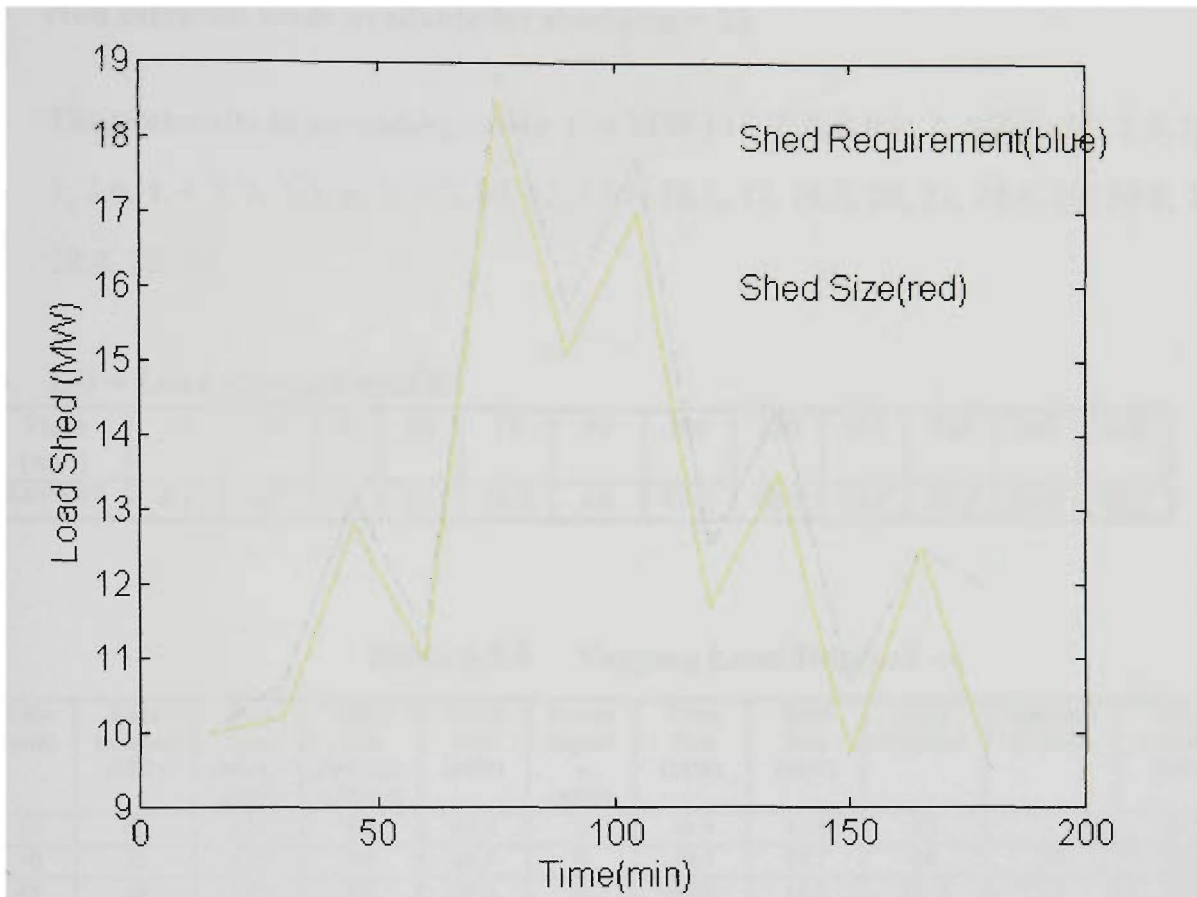
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	60	60	60	60	60	60	60	60	60	60	60

Table 6.3.3 Varying Load Demand - 3

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	420	8.4	49.9	0	49.9	10.1	20	-	10.0
30	60	415	8.4	49.3	0	49.3	10.7	19 4	20	10.2
45	60	395	8.4	46.8	0	46.8	13.2	21 3	19 4	12.8
60	60	410	8.4	48.7	0	48.7	11.3	18 11	21 3	11.0
75	60	350	8.5	41.1	0	41.1	18.9	25	18 11	18.5
90	60	375	8.5	44.3	0	44.3	15.7	23 2	25	15.1
105	60	358	8.5	42.2	0	42.2	17.8	24	23 2	17.0
120	60	400	8.4	47.5	0	47.5	12.5	17 16 1	24	11.7
135	60	385	8.4	45.6	0	45.6	14.4	22	17 16 1	13.5
150	60	415	8.4	49.3	0	49.3	10.7	15 14 1	22	9.7
165	60	400	8.4	47.5	0	47.5	12.5	13 12 10 6	15 14 1	12.5
180	60	405	8.4	48.1	0	48.1	11.9	9 8 7 5 1	13 12 10 6	9.5

Considering fuel levels between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.13 Comparison of Shed Requirement vs Shed Size in periods of constant Load Demand of 60 MW.**

**Observations:**

- Total generation varied between 41.1 MW and 49.9 MW
- Given constant load demand of 60 MW, the shed requirement varied from 10.1 MW to 18.9 MW
- Figure 6.13 indicated, that the shed size closely followed the shed requirement.

6.1.3.4 Load Shedding applications with variable Load Demand Levels - 4

- Non essential loads available for shedding = 35
- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	65	60	63	65	58.5	64	66.5	60.5	63.4	58.5	55.5	60.5

Table 6.3.4 Varying Load Demand - 4

Time (min)	Load Demand (MW)	Fuel Input (MKCal/Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Export s (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	420	8.4	49.9	0	49.9	15.1	23	-	14.5
30	55	415	8.4	49.3	0	49.3	10.7	20	23	10.0
45	58	395	8.4	46.8	0	46.8	16.2	22 8	20	16.0
60	50	410	8.4	48.7	0	48.7	29.3	26 19	22 8	29.2
75	53.5	350	8.5	41.1	0	41.1	17.4	24	26 19	17.0
90	59	375	8.5	44.3	0	44.3	19.7	25 4	24	19.5
105	51.5	358	8.5	42.2	0	42.2	24.3	21 18 13	25 4	24.0
120	55.5	400	8.4	47.5	0	47.5	13.0	17 16 3	21 18 13	12.3
135	58.4	385	8.4	45.6	0	45.6	17.8	15 14 12 11 5	17 16 3	17.8
150	53.5	415	8.4	49.3	0	49.3	9.2	10 9 7 2	15 14 12 11 5	8.6
165	50.5	400	8.4	47.5	0	47.5	8.0	1 6 16	10 9 7 2	7.7
180	55.5	405	8.4	48.1	0	48.1	12.4	21	1 6 16	12.0

Considering fuel levels between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.14 Comparison of Shed Requirement vs Shed Size in periods of variable Load Demand between 55.5 to 66.5 MW**

**Observations:**

- Total generation varied between 41.1 MW and 49.9 MW
- Given a variable load demand between 55.5 MW and 66.5 MW, the shed requirement varied between 8 MW and 29.3 MW
- Figure 6.14 indicated, that the shed size closely followed the shed requirement.

**6.1.3.5 Load Shedding applications with variable Load Demand Levels - 5**

- Non essential loads available for shedding = 35

- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

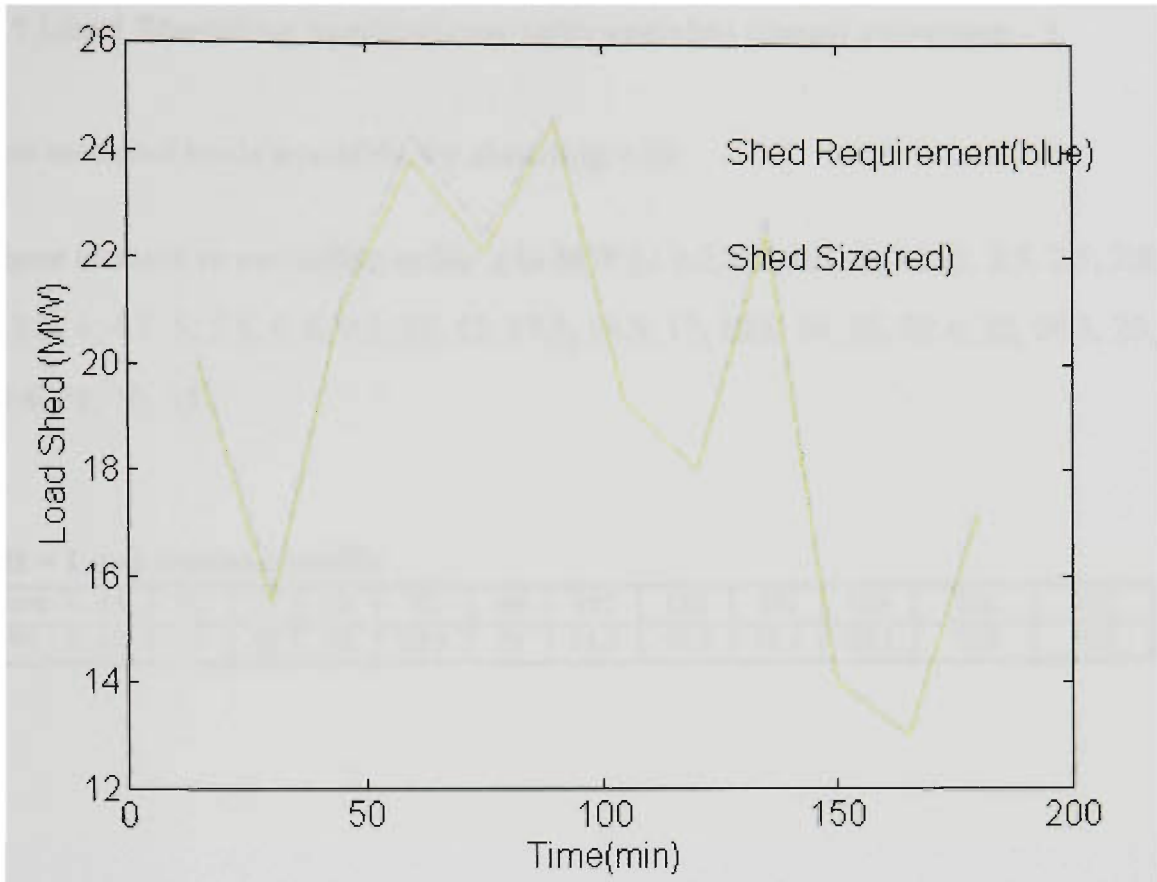
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	70	65	68	60	63.5	69	61.5	65.5	68.4	63.5	60.5	65.5

**Table 6.3.5 Varying Load Demand - 5**

Time (min)	Load Demand (MW)	Fuel Input (MKCal/Hr)	Heat Gen (MKCal/MW hr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	70	420	8.4	49.9	0	49.9	20.1	26	-	20.0
30	65	415	8.4	49.3	0	49.3	15.7	23 4	26	15.5
45	68	395	8.4	46.8	0	46.8	21.2	27	23 4	21.0
60	60	310	8.7	35.7	0	35.7	24.3	29 3	27	23.8
75	63.5	350	8.5	41.1	0	41.1	22.4	25 12	29 3	22.1
90	69	375	8.5	44.3	0	44.3	24.7	30	25 12	24.5
105	61.5	358	8.4	42.2	0	42.2	19.3	24 17	30	19.3
120	65.5	400	8.4	47.5	0	47.5	18.0	22 14	24 17	18.0
135	68.4	385	8.4	45.6	0	45.6	22.8	28	22 14	22.4
150	63.5	415	8.4	49.3	0	49.3	14.2	21 6	28	14.0
165	60.5	400	8.4	47.5	0	47.5	13.0	20 11	21 6	13.0
180	65.5	405	8.4	48.1	0	48.1	17.4	19 18	20 11	17.2

Considering fuel levels between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.15 Comparison of Shed Requirement vs Shed Size in periods of variable Load Demand between 60 to 70 MW.**

**Observations:**

- Total generation varied between 41.1 MW and 49.9 MW
- Given a variable load demand between 60 MW and 70 MW, the shed requirement varied between 13 MW and 24.7 MW
- Figure 6.15 indicated, that the shed size closely followed the shed requirement.

### 6.1.4.1 Load Shedding applications with variable circuit numbers - 1

- Non essential loads available for shedding = 36
- Those circuits in ascending order ( in MW ) : 0.2, 0.6, 0.8, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30, 35
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.4.1 Varying Circuits Available For Shedding - 1

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	0	22.8	37.2	36 6	-	37.0
30	55	200	10.8	18.5	0	18.5	36.5	35 17	36 6	36.0
45	58	275	9.0	30.6	0	30.6	27.4	32	35 17	27.0
60	50	300	8.7	34.3	0	34.3	15.7	23 4	32	15.5
75	53.5	350	8.5	41.1	0	41.1	12.4	21	23 4	12.0
90	59	338	8.6	39.5	0	39.5	19.5	25	21	18.5
105	51.5	345	8.5	40.5	0	40.5	11.0	20 3	25	10.8
120	55.5	290	8.8	32.9	0	32.9	22.6	28	20 3	22.4
135	58.4	300	8.7	34.3	0	34.3	24.1	29 2	28	23.6
150	53.5	208	10.5	19.9	0	19.9	33.6	34 14	29 2	33.5
165	50.5	236	9.6	24.6	0	24.6	25.9	31	34 14	25.0
180	55.5	285	8.9	32.1	0	32.1	23.4	27 7	31	23.3

Fuel levels varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.16 Comparison of Shed Requirement vs Shed Size with 36 circuits available for shedding.**

#### **Observations:**

- Shed requirement varied between 11 MW and 37.2 MW.
- 36 circuits were available for shedding.
- Circuit values varied from 0.2 MW to 35 MW.
- Figure 6.16, indicated that the shed size closely followed the shed requirement.

#### **6.1.4.2 Load Shedding applications with variable circuit numbers -2**

- **Non essential loads available for shedding = 32**

- Those circuits in ascending order ( in MW ) : 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.4.2 Varying Circuits Available For Shedding - 2

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	0	22.8	37.2	32 14 1	-	37.0
30	55	200	10.8	18.5	0	18.5	36.5	31 13 3	32 14 1	36.5
45	58	275	9.0	30.6	0	30.6	27.4	29	31 13 3	27.0
60	50	300	8.7	34.3	0	34.3	15.7	20 2	29	16.2
75	53.5	350	8.5	41.1	0	41.1	12.4	18	20 2	12.0
90	59	338	8.6	39.5	0	39.5	19.5	22	18	18.5
105	51.5	345	8.5	40.5	0	40.5	11.0	17 1	22	11.0
120	55.5	290	8.8	32.9	0	32.9	22.6	25	17 1	22.4
135	58.4	300	8.7	34.3	0	34.3	24.1	26 1	25	24.0
150	53.5	208	10.5	19.9	0	19.9	33.6	30 12	26 1	33.4
165	50.5	236	9.6	24.6	0	24.6	25.9	28	30 12	25.0
180	55.5	285	8.9	32.1	0	32.1	23.4	24 4	28	23.3

Fuel levels varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.17 Comparison of Shed Requirement vs Shed Size with 32 circuits available for shedding**

**Observations:**

- Shed requirement varied between 11 MW and 37.2 MW.
- 32 circuits were available for shedding.
- Circuit values varied from 1 MW to 30 MW.
- Figure 6.17, indicated that the shed size closely followed the shed requirement.

**6.1.4.3 Load Shedding applications with variable circuit numbers - 3**

- **Non essential loads available for shedding = 26**

- Those circuits in ascending order ( in MW ) : 1, 2, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 24.5, 25, 27, 28.4, 30

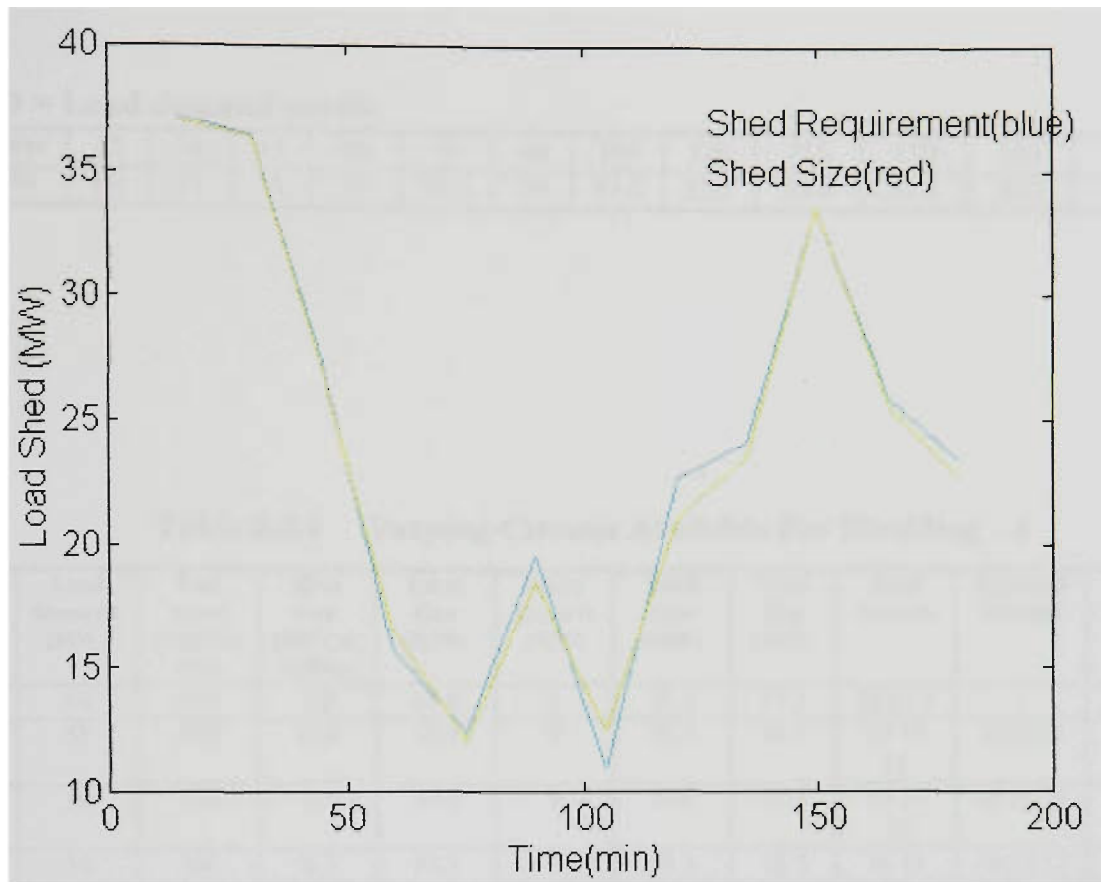
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

**Table 6.4.3 Varying Circuits Available For Shedding - 3**

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	0	22.8	37.2	26 12 1	-	37.0
30	55	200	10.8	18.5	0	18.5	36.5	25 13	26 12 1	36.4
45	58	275	9.0	30.6	0	30.6	27.4	24	25 13	27.0
60	50	300	8.7	34.3	0	34.3	15.7	18 2	24	16.5
75	53.5	350	8.5	41.1	0	41.1	12.4	16	18 2	12.0
90	59	338	8.6	39.5	0	39.5	19.5	20	16	18.5
105	51.5	345	8.5	40.5	0	40.5	11.0	15 3	20	12.5
120	55.5	290	8.8	32.9	0	32.9	22.6	21 1	15 3	21.0
135	58.4	300	8.7	34.3	0	34.3	24.1	19 11 1	21 1	23.5
150	53.5	208	10.5	19.9	0	19.9	33.6	23 10 7	19 11 1	33.6
165	50.5	236	9.6	24.6	0	24.6	25.9	22 1	23 10 7	25.5
180	55.5	285	8.9	32.1	0	32.1	23.4	17 14	22 1	22.7

Fuel levels varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.18 Comparison of Shed Requirement vs Shed Size with 26 circuits available for shedding**

**Observations:**

- Shed requirement varied between 11 MW and 37.2 MW.
- 26 circuits were available for shedding.
- Circuit values varied from 1 MW to 30 MW.
- Figure 6.18, indicated that the shed size closely followed the shed requirement.

**6.1.4.4 Load Shedding applications with variable circuit numbers - 4**

- **Non essential loads available for shedding = 22**
- **Those circuits in ascending order ( in MW ) : 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5**

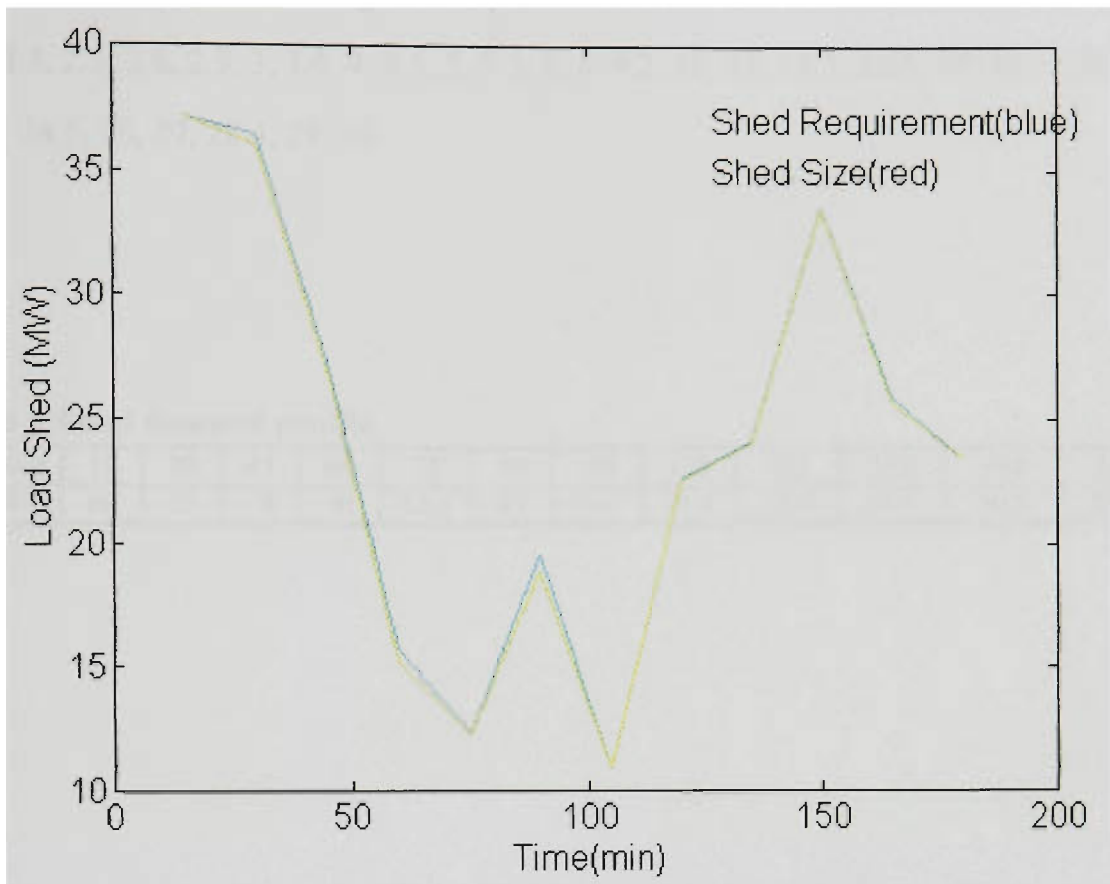
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.4.4 Varying Circuits Available For Shedding - 4

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	0	22.8	37.2	22 21 2	-	37.2
30	55	200	10.8	18.5	0	18.5	36.5	20 19 15	22 21 2	36.0
45	58	275	9.0	30.6	0	30.6	27.4	18 17 12	20 19 15	27.0
60	50	300	8.7	34.3	0	34.3	15.7	16 14	18 17 12	15.2
75	53.5	350	8.5	41.1	0	41.1	12.4	13 11 4	16 14	12.3
90	59	338	8.6	39.5	0	39.5	19.5	10 9 8 7 6 5	13 11 4	18.8
105	51.5	345	8.5	40.5	0	40.5	11.0	1 3 15	10 9 8 7 6 5	11.0
120	55.5	290	8.8	32.9	0	32.9	22.6	22 10	1 3 15	22.5
135	58.4	300	8.7	34.3	0	34.3	24.1	21 14 1	22 10	24.0
150	53.5	208	10.5	19.9	0	19.9	33.6	20 19 13	21 14 1	33.5
165	50.5	236	9.6	24.6	0	24.6	25.9	18 17 9	20 19 13	25.6
180	55.5	285	8.9	32.1	0	32.1	23.4	16 12 11 8 2	18 17 9	23.4

Fuel levels varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.19 Comparison of Shed Requirement vs Shed Size with 22 circuits available for shedding**

#### **Observations:**

- Shed requirement varied between 11 MW and 37.2 MW.
- 22 circuits were available for shedding.
- Circuit values varied from 1 MW to 18.5 MW.
- Figure 6.19, indicated that the shed size closely followed the shed requirement.

#### **6.1.4.5 Load Shedding applications with variable circuit numbers - 5**

- **Non essential loads available for shedding = 40**

- Those circuits in ascending order ( in MW ) : 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 0.9, 1, 1.7, 2, 2.3, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 21, 22.4, 23, 24.5, 25, 27, 28.4, 29, 30

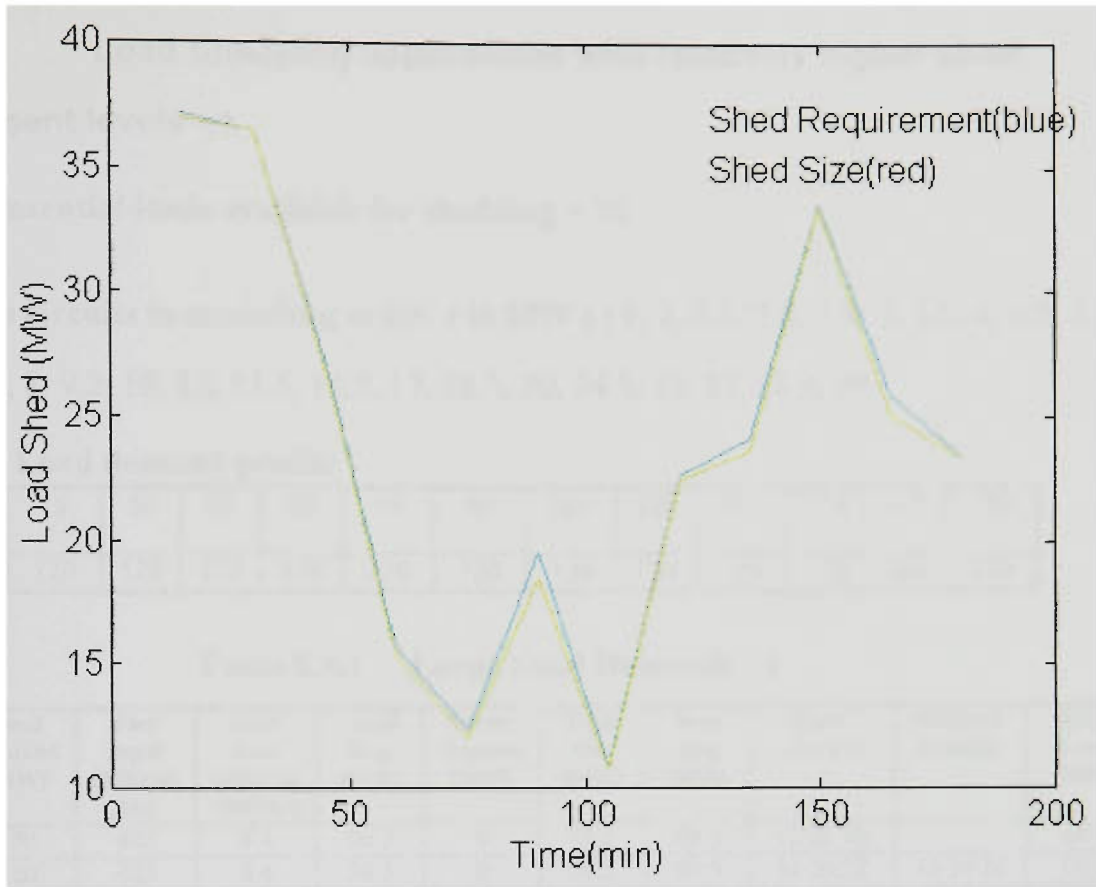
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	60	55	58	50	53.5	59	51.5	55.5	58.4	53.5	50.5	55.5

Table 6.4.5 Varying Circuits Available For Shedding - 5

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	225	9.9	22.8	0	22.8	37.2	40 22 9	-	37.2
30	55	200	10.8	18.5	0	18.5	36.5	39 21 11	40 22 9	36.5
45	58	275	9.0	30.6	0	30.6	27.4	37	39 21 11	27.0
60	50	300	8.7	34.3	0	34.3	15.7	28 8	37	15.4
75	53.5	350	8.5	41.1	0	41.1	12.4	26	28 8	12.0
90	59	338	8.6	39.5	0	39.5	19.5	30	26	18.5
105	51.5	345	8.5	40.5	0	40.5	11.0	25 7	30	10.8
120	55.5	290	8.8	32.9	0	32.9	22.6	33	25 7	22.4
135	58.4	300	8.7	34.3	0	34.3	24.1	34 6	33	23.6
150	53.5	208	10.5	19.9	0	19.9	33.6	38 20	34 6	33.4
165	50.5	236	9.6	24.6	0	24.6	25.9	36	38 20	25.0
180	55.5	285	8.9	32.1	0	32.1	23.4	32 12	36	23.3

Fuel levels varied between 200 MKCal/hr to 350 MKCal/hr



**Figure 6.20 Comparison of Shed Requirement vs Shed Size with 40 circuits available for shedding**

**Observations:**

- Shed requirement varied between 11 MW and 37.2 MW.
- 40 circuits were available for shedding.
- Circuit values varied from 0.1 MW to 30 MW.
- Figure 6.20, indicated that the shed size closely followed the shed requirement.

6.1.5.1 Load Shedding applications with relatively higher shed requirement levels - 1

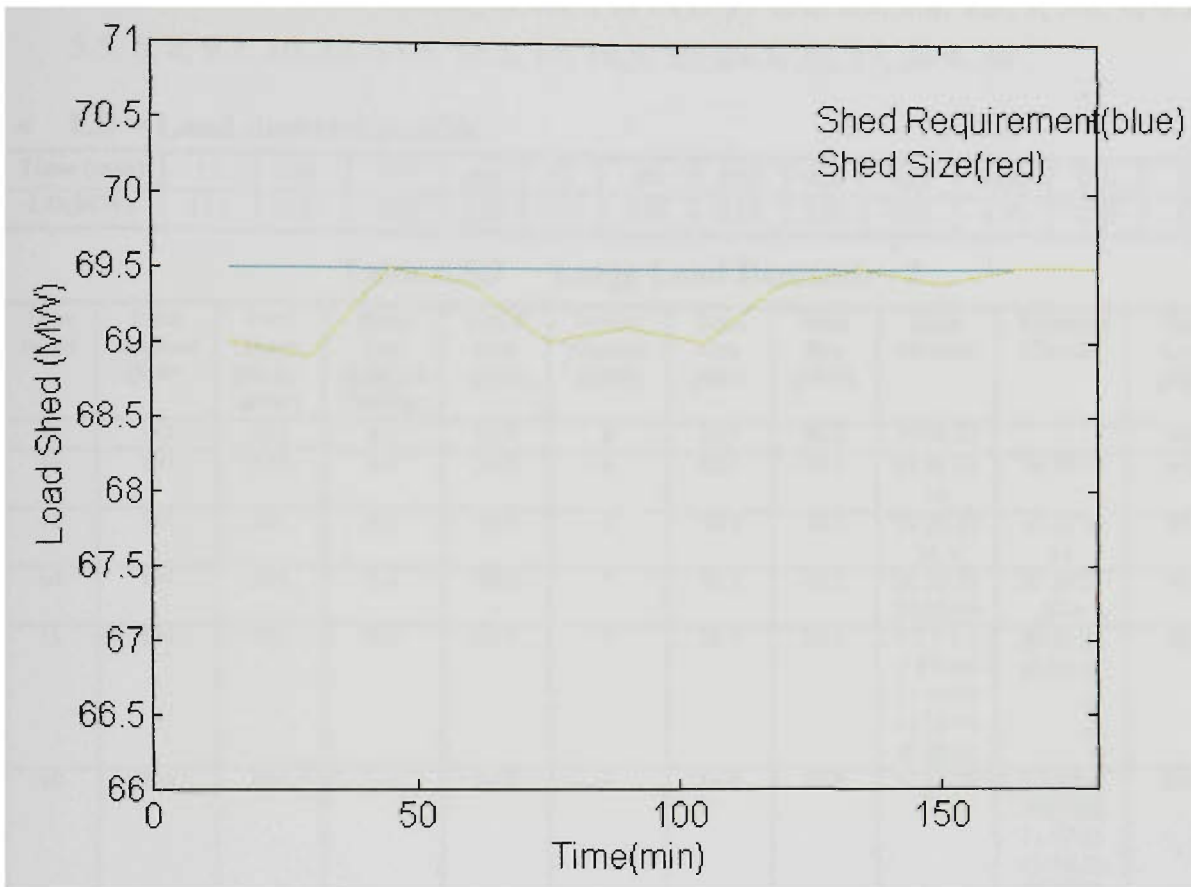
- Non essential loads available for shedding = 26
- Those circuits in ascending order ( in MW ) : 1, 2, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 24.5, 25, 27, 28.4, 30
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	120	120	120	120	120	120	120	120	120	120	120	120

Table 6.5.1 Large Load Demands - 1

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	120	425	8.4	50.5	0	50.5	69.5	35 34 20	-	69.0
30	120	425	8.4	50.5	0	50.5	69.5	33 32 22	35 34 20	68.9
45	120	425	8.4	50.5	0	50.5	69.5	31 30 26	33 32 22	69.5
60	120	425	8.4	50.5	0	50.5	69.5	29 28 27 11	31 30 26	69.4
75	120	425	8.4	50.5	0	50.5	69.5	25 24 23 21 17 4	29 28 27 11	69.0
90	120	425	8.4	50.5	0	50.5	69.5	1 2 3 5 6 7 8 9 10 12 13 14 15 16 18 19 22	25 24 23 21 17 4	69.1
105	120	425	8.4	50.5	0	50.5	69.5	35 34 20	1 2 3 5 6 7 8 9 10 12 13 14 15 16 18 19 22	69.0
120	120	425	8.4	50.5	0	50.5	69.5	33 32 21 6	35 34 20	69.4
135	120	425	8.4	50.5	0	50.5	69.5	31 30 26	33 32 21 6	69.5
150	120	425	8.4	50.5	0	50.5	69.5	29 28 27 11	31 30 26	69.4
165	120	425	8.4	50.5	0	50.5	69.5	25 24 23 19 18 7	29 28 27 11	69.5
180	120	425	8.4	50.5	0	50.5	69.5	1 2 3 4 5 8 9 10 12 13 14	25 24 23 19 18 7	69.5

Fuel levels constant at 425 MKCal/hr



**Figure 6.21 Comparison of Shed Requirement vs Shed Size with a 120 MW Load Demand**

**Observations:**

- Fuel input was kept to a fixed 425 MKCal/hr.
- Total generation remained constant at 50.5 MW.
- Load demand was 120 MW right through the entire time.
- Shed requirement was 69.5 MW right through the entire load shedding period.
- Figure 6.21 indicated, that the shed size closely followed the shed requirement.

**6.1.5.2 Load Shedding applications with relatively higher shed requirement levels - 2**

- Non essential loads available for shedding = 26

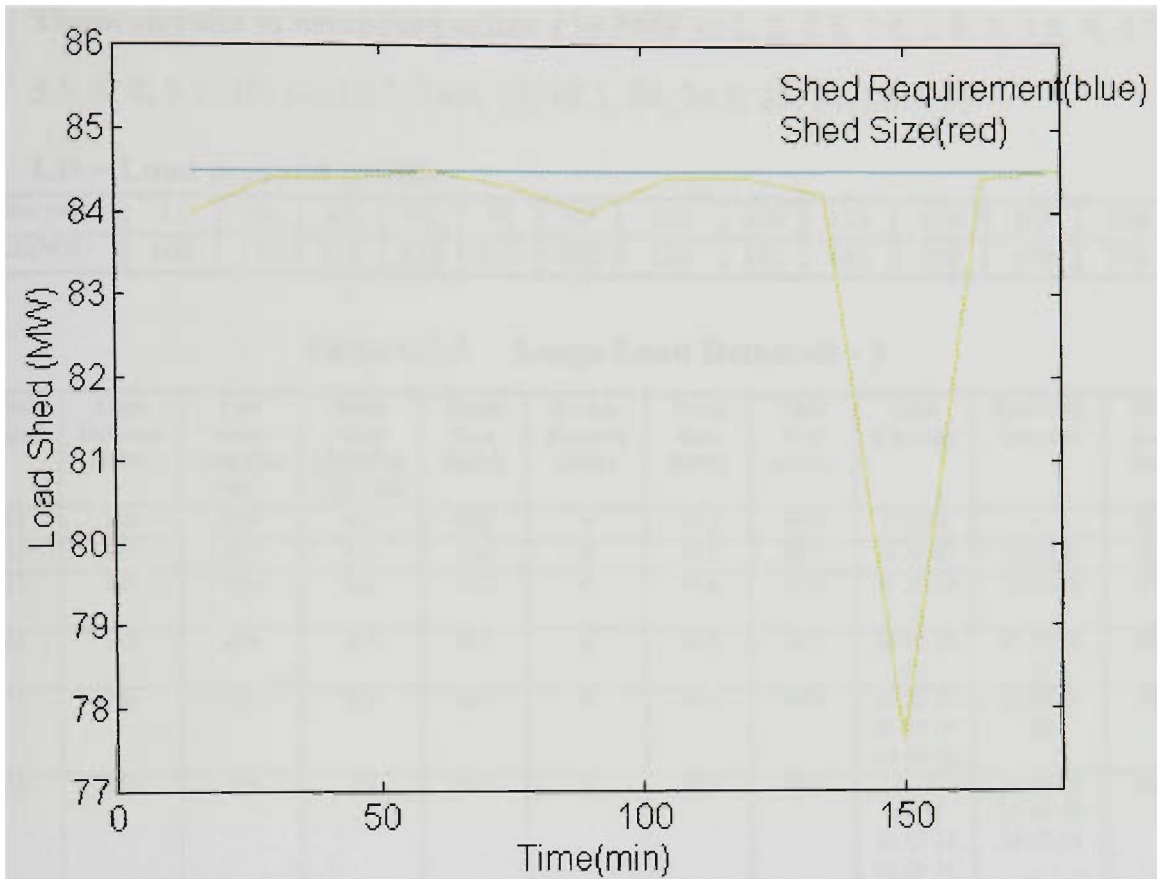
- Those circuits in ascending order ( in MW ) : 1, 2, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 24.5, 25, 27, 28.4, 30
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	135	135	135	135	135	135	135	135	135	135	135	135

Table 6.5.2 Large Load Demands - 2

Time (min)	Load Demand (MW)	Fuel Input (MKCal/Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	135	425	8.4	50.5	0	50.5	84.5	35 34 31	-	84.0
30	135	425	8.4	50.5	0	50.5	84.5	33 32 30 14	35 34 31	84.4
45	135	425	8.4	50.5	0	50.5	84.5	29 28 27 24 4	33 32 30 14	84.4
60	135	425	8.4	50.5	0	50.5	84.5	26 25 23 22 21 17	29 28 27 24 4	84.5
75	135	425	8.4	50.5	0	50.5	84.5	1 2 3 5 6 7 8 9 10 11 12 13 15 16 18 19 20 25	26 25 23 22 21 17	84.3
90	135	425	8.4	50.5	0	50.5	84.5	35 34 31	1 2 3 5 6 7 8 9 10 11 12 13 15 16 18 19 20 25	84.0
105	135	425	8.4	50.5	0	50.5	84.5	33 32 30 14	35 34 31	84.4
120	135	425	8.4	50.5	0	50.5	84.5	29 28 27 24 4	33 32 30 14	84.4
135	135	425	8.4	50.5	0	50.5	84.5	26 23 22 21 20 19 15	29 28 27 24 4	84.2
150	135	425	8.4	50.5	0	50.5	84.5	1 2 3 5 6 7 8 9 10	26 23 22 21 20 19 15	77.6
165	135	425	8.4	50.5	0	50.5	84.5	34 33 32	1 2 3 5 6 7 8 9 10	84.4
180	135	425	8.4	50.5	0	50.5	84.5	31 30 29 21	34 33 32	84.5

Fuel levels constant at 425 MKCal/hr



**Figure 6.22 Comparison of Shed Requirement vs Shed Size with a 135 MW Load Demand**

**Observations:**

- Fuel input was kept to a fixed 425 MKCal / hr.
- Total generation remained constant at 50.5 MW.
- Load demand was 135 MW right through the entire time.
- Shed requirement was 84.5 MW right through the entire load shedding period.
- Figure 6.22 indicated, that the shed size closely followed the shed requirement.

**6.1.5.3 Load Shedding applications with relatively higher shed requirement levels - 3**

- **Non essential loads available for shedding = 26**

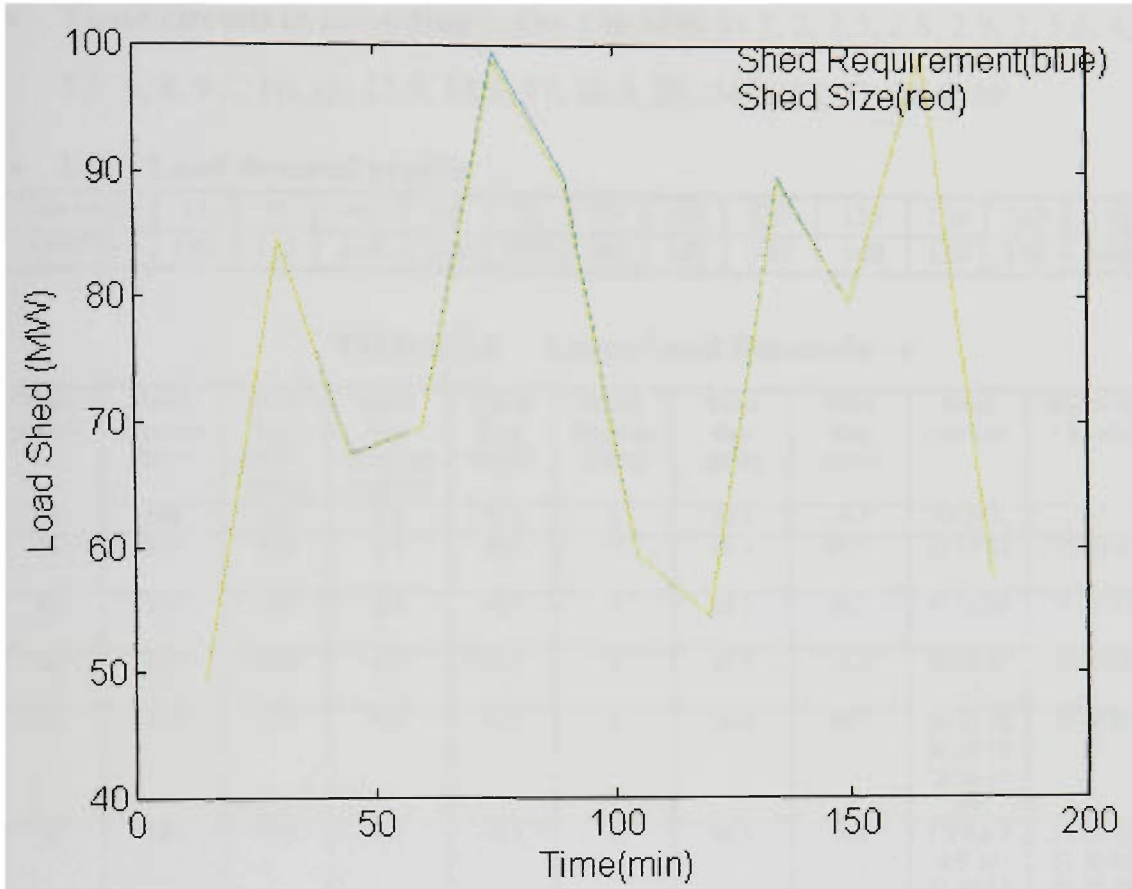
- Those circuits in ascending order ( in MW ) : 1, 2, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 24.5, 25, 27, 28.4, 30
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	100	135	118	120	150	140	110	105	140	130	150	108

Table 6.5.3 Large Load Demands - 3

Time (min)	Load Demand (MW)	Fuel Input (MKCal /Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	100	425	8.4	50.5	0	50.5	49.5	35 25 4	-	49.5
30	135	425	8.4	50.5	0	50.5	84.5	34 33 32	35 25 4	84.4
45	118	425	8.4	50.5	0	50.5	67.5	31 30 24 3	34 33 32	67.3
60	120	425	8.4	50.5	0	50.5	69.5	29 28 27 10	31 30 24 3	69.4
75	150	425	8.4	50.5	0	50.5	99.5	26 23 22 21 20 19 18 17 16	29 28 27 10	98.7
90	140	425	8.4	50.5	0	50.5	89.5	1 2 5 6 7 8 9 11 12 13 14 15 35 31	26 23 22 21 20 19 18 17 16	88.8
105	110	425	8.4	50.5	0	50.5	59.5	34 33 6	1 2 5 6 7 8 9 11 12 13 14 15 35 31	59.4
120	105	425	8.4	50.5	0	50.5	54.5	32 30 10	34 33 6	54.5
135	140	425	8.4	50.5	0	50.5	89.5	29 28 27 26 9	32 30 10	89.3
150	130	425	8.4	50.5	0	50.5	79.5	25 24 23 22 21 12	29 28 27 26 9	79.5
165	150	425	8.4	50.5	0	50.5	99.5	1 2 3 4 5 7 8 11 13 14 15 16 17 18 19 20 35 12	25 24 23 22 21 12	99.4
180	108	425	8.4	50.5	0	50.5	57.5	34 33	1 2 3 4 5 7 8 11 13 14 15 16 17 18 19 20 35 12	57.4

Fuel levels constant at 425 MKCal/hr



**Figure 6.23 Comparison of Shed Requirement vs Shed Size for a variable Load Demand between 100 - 150 MW**

**Observations:**

- Fuel input was kept to a fixed 425 MKCal/hr.
- Total generation remained constant at 50.5 MW.
- Load demand was varied between 100 MW and 150 MW.
- Shed requirement varied between 49.5 MW and 99.5 MW.
- Figure 6.23 indicated, that the shed size closely followed the shed requirement.

**6.1.5.4 Load Shedding applications with relatively higher shed requirement levels - 4**

- Non essential loads available for shedding = 26

- Those circuits in ascending order ( in MW ) : 1, 2, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 24.5, 25, 27, 28.4, 30

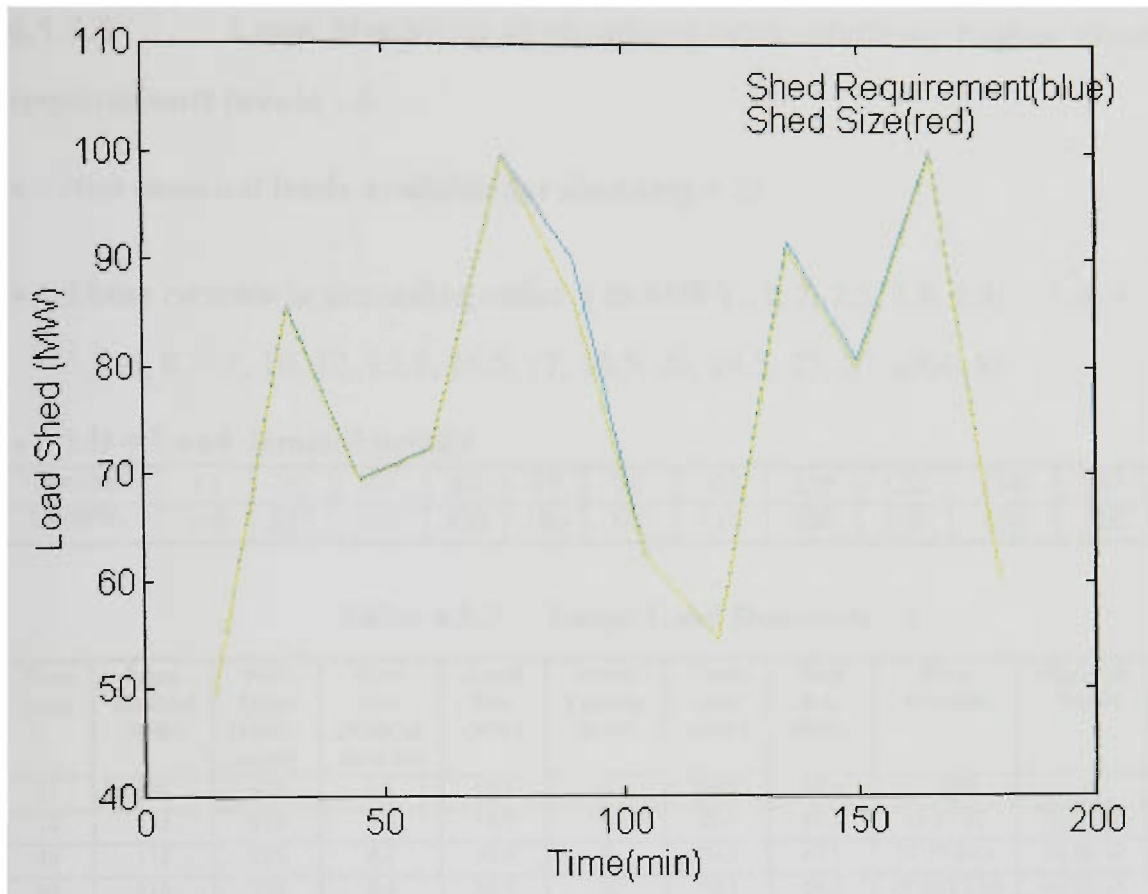
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	100	135	118	120	150	140	110	105	140	130	150	108

Table 6.5.4 Large Load Demands - 4

Time (min)	Load Demand (MW)	Fuel Input (MKCal/Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	100	425	8.4	50.5	0	50.5	49.5	35 25 4	-	49.5
30	135	415	8.4	49.3	0	49.3	85.7	34 33 32 3	35 25 4	85.2
45	118	407	8.4	48.3	0	48.3	69.7	31 30 26	34 33 32 3	69.5
60	120	400	8.4	47.5	0	47.5	72.5	29 28 27 17	31 30 26	72.4
75	150	423	8.4	50.2	0	50.2	99.8	24 23 22 21 20 19 18 16 15 14	29 28 27 17	99.2
90	140	420	8.4	49.9	0	49.9	90.1	1 2 5 6 7 8 9 10 11 12 13 35 34	24 23 22 21 20 19 18 16 15 14	86.3
105	110	400	8.4	47.5	0	47.5	62.5	33 32 17 4	1 2 5 6 7 8 9 10 11 12 13 35 34	62.4
120	105	425	8.4	50.5	0	50.5	54.5	31 30 15	33 32 17 4	54.5
135	140	407	8.4	48.3	0	48.3	91.7	29 28 27 26 14	31 30 15	90.9
150	130	415	8.4	49.3	0	49.3	80.7	25 24 23 22 21 13	29 28 27 26 14	80.0
165	150	420	8.4	49.9	0	49.9	100.1	1 10 11 12 16 18 19 20 35 22	25 24 23 22 21 13	99.8
180	108	405	8.4	48.1	0	48.1	59.9	34 33 8	1 10 11 12 16 18 19 20 35 22	59.9

Fuel levels between 400 and 425 MKCal/hr



**Figure 6.24 Comparison of Shed Requirement vs Shed Size for a variable Fuel input between 400 and 425 MKCal/Hr and a Variable Load Demand between 100 and 150 MW.**

**Observations:**

- Fuel input varied from 400 to 425 MKCal / hr.
- Total generation varied from 47.5 MW to 50.5 MW.
- Load demand was varied between 100 MW and 150 MW.
- Shed requirement varied between 49.5 MW and 100.1 MW.
- Figure 6.24 indicated, that the shed size closely followed the shed requirement.

6.1.5.5 Load Shedding applications with relatively higher shed requirement levels - 5

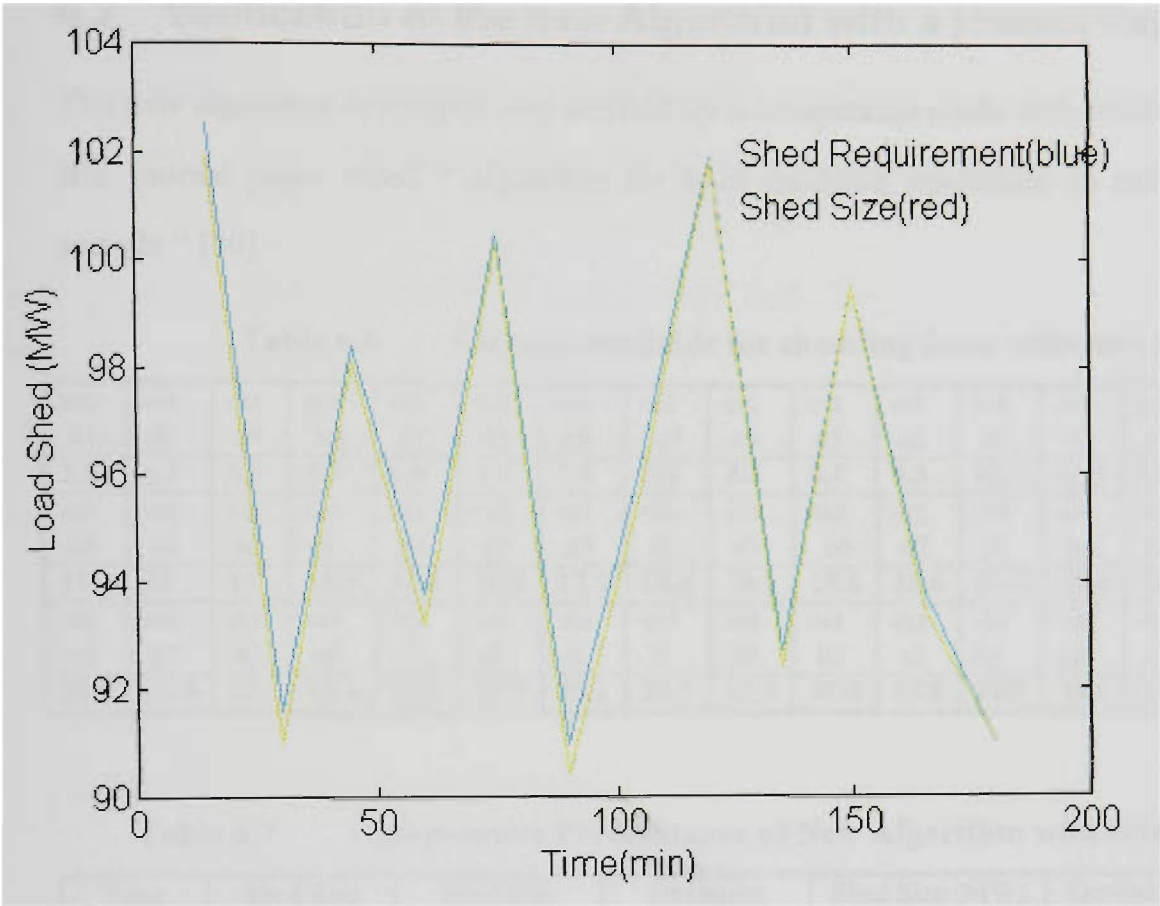
- Non essential loads available for shedding = 26
- Those circuits in ascending order ( in MW ) : 1, 2, 2.5, 2.8, 2.9, 3, 3.6, 4, 4.5, 5, 5.5, 6, 8, 9.2, 10, 12, 13.5, 14.5, 17, 18.5, 20, 24.5, 25, 27, 28.4, 30
- LD = Load demand profile

Time (min)	15	30	45	60	75	90	105	120	135	150	165	180
LD(MW)	100	135	118	120	150	140	110	105	140	130	150	108

Table 6.5.5 Large Load Demands - 5

Time (min)	Load Demand (MW)	Fuel Input (MKCal/Hr)	Heat Gen (MKCal /MWhr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	100	425	8.4	50.5	0	50.5	49.5	35 25 4	-	49.5
30	135	425	8.4	50.5	0	50.5	84.5	34 33 32	35 25 4	84.4
45	118	425	8.4	50.5	0	50.5	67.5	31 30 24 3	34 33 32	67.3
60	120	425	8.4	50.5	0	50.5	69.5	29 28 27 10	31 30 24 3	69.4
75	150	425	8.4	50.5	0	50.5	99.5	26 23 22 21 20 19 18 17 16	29 28 27 10	98.7
90	140	425	8.4	50.5	0	50.5	89.5	1 2 5 6 7 8 9 11 12 13 14 15 35 31	26 23 22 21 20 19 18 17 16	88.8
105	110	425	8.4	50.5	0	50.5	59.5	34 33 6	1 2 5 6 7 8 9 11 12 13 14 15 35 31	59.4
120	105	425	8.4	50.5	0	50.5	54.5	32 30 10	34 33 6	54.5
135	140	425	8.4	50.5	0	50.5	89.5	29 28 27 26 9	32 30 10	89.3
150	130	425	8.4	50.5	0	50.5	79.5	25 24 23 22 21 12	29 28 27 26 9	79.5
165	150	425	8.4	50.5	0	50.5	99.5	1 2 3 4 5 7 8 11 13 14 15 16 17 18 19 20 35 12	25 24 23 22 21 12	99.4
180	108	425	8.4	50.5	0	50.5	57.5	34 33	1 2 3 4 5 7 8 11 13 14 15 16 17 18 19 20 35 12	57.4

Fuel levels constant at 425 MKCal/hr



**Figure 6.25 Comparison of Shed Requirement vs Shed Size for a Variable Fuel input between 400 and 500 MKCal/Hr and a Constant Load Demand of 150 MW.**

**Observations:**

- Fuel input varied from 400 to 500 MKCal / hr.
- Total generation varied from 47.5 MW to 59 MW.
- Load demand was kept constant at 150 MW.
- Shed requirement varied between 91 MW to 102.5 MW.
- Figure 6.25 indicated, that the shed size closely followed the shed requirement.

6.2 Verification of the new Algorithm with a journal Paper

The new algorithm developed was verified by a comparison made with results obtained in an IEE journal paper titled “ algorithm for load shedding operations in reduced generation periods “ [40].

Table 6.6      Circuits available for shedding from reference [40]

cct d1	cct i6	cct d4	cct K6	cct d3	cct d5	cct e8	cct e7	cct c5	cct e5	cct e2	cct i8	cct e6	cct i5	cct k4	cct k5
3.5	5.3	5.7	5.7	6.6	6.6	7.1	8.4	8.4	8.8	9.3	11.3	11.9	12.4	13.7	15.0
cct k8	cct h2	cct a5	cct e4	cct g4	cct g5	cct g3	cct i1	cct e3	cct a6	cct d2	cct i4	cct h6	cct h3	cct b3	cct b2
15	15	15	15.9	16.8	16.8	17.2	18.1	18.1	18.6	18.6	19.4	19.4	20.3	21.1	21.2
cct b4	cct k7	cct b1	cct a8	cct i2	cct a3	cct i9	cct i7	cct a7	cct h5	cct a2	cct h4	cct c2	cct c7		
22.5	22.5	23	23.4	23.4	25.2	25.2	26.5	27.0	27.0	27.8	28.7	33.6	35.4		

Table 6.7      Comparative Performance of New Algorithm with reference [40]

Time	Shed Req (MW)	Shed Size (MW) <i>Journal paper</i>	Deviation (MW) <i>Journal paper</i>	Shed Size (MW) New Algorithm	Deviation (MW) New Algorithm
6.00	29.6	32.6	<u>3.0</u>	28.7	<u>0.9</u>
6.15	35.3	47.3	<u>12.0</u>	37.1	<u>1.8</u>
6.30	40.7	51.9	<u>11.2</u>	40.7	<u>0</u>
6.45	6.3	18.7	<u>12.4</u>	5.7	<u>0.6</u>
7.00	34.4	37.0	<u>2.6</u>	34.4	<u>0</u>
7.15	0	0	<u>0</u>	0	<u>0</u>
7.30	0	0	<u>0</u>	0	<u>0</u>
7.45	24.2	31.0	<u>6.8</u>	23.4	<u>0.8</u>
8.00	0	0	<u>0</u>	0	<u>0</u>
8.15	0	0	<u>0</u>	0	<u>0</u>
8.30	22.4	33.50	<u>11.1</u>	26.9	<u>4.5</u>
8.45	0	0	<u>0</u>	0	<u>0</u>

The IEE journal paper referenced was obviously developed with a different strategic plan, that is noteworthy in itself. However, results obtained from Table 6.7 indicate that the shed size of the new algorithm was closer to the shed requirement than that of the IEE journal paper during the entire load shedding period. Given a similar range of circuits to shed from as indicated in Table 6.6, the validity of the new algorithm was hence confirmed with the comparative performance of results obtained.

6.3 Simulation of load shedding at the Shell Refinery

The new algorithm load shedding strategy software was also tested on a Victorian cogeneration plant. The Shell Refinery was chosen for this purpose.

Plant specifications of Geelong Refinery, Shell Australia

- Local gen - varies from 10 - 24 MW.
- Maximum load demand - 40 MW. (electrical consumer load)
- ( A number of distribution boards consisting of circuits from 0.5 MW to 14 MW )
- Normally import 16 -30 MW of power.

In case of loss of mains

Load Shed down into a 16 MW island

- A) Load utilisation - Step down from 40 MW - 24 MW
- B) If necessary all production units will shut down - step down from 24 MW to 10 MW
- C) Essential Loads that will remain operational, ie emergency facilities
- D) Emergency diesel generator and battery backup

Simulation Figures

- Number of circuits available for shedding - 25 ( 0.5 MW to 14 MW )
- \* Suitable load shedding methodology required for step down from 40 MW to 24 MW.
- ( Maximum shed size = 16 MW)

Table 6.8 Circuits available for Load shedding (MW) in Shell Refinery Plant

cct 1	cct 2	cct 3	cct 4	cct 5	cct 6	cct 7	cct 8	cct 9	cct 10	cct 11	cct 12	cct 13	cct 14	cct 15	cct 16
0.5	1	1.5	2	3.4	4	4.3	5.4	6.7	7.2	7.9	8.3	10	10.5	11	12.8
cct 17	cct 18	cct 19	cct 20	cct 21	cct 22	cct 23	cct 24	cct 25							
13	14	14.5	16.7	17.5	18	20	23	25							

**Table 6.9      Load shedding procedure for a step down of 16 MW for 3 hours  
at the Shell Refinery Plant**

Time	15 min	30 min	45 min	60 min	75 min	90 min	105 min	120 min	135 min	150 min	165 min	180 min
Shed Req(MW)	16	16	16	16	16	16	16	16	16	16	16	16
Shed circuits	19,3	18,4	17,2, 1	16,5	15,7	14,8	13,6, 1	12,10	11,9, 1	20	21	22
Restored circuits	----	19,3	18,4	17,2 ,1	16,5	15,7	14,8	13,6,1	12,10	11,9, 1	20	21
Shed Load(MW)	15.9	16	14.5	16.2	15.3	15.9	14.5	15.5	15.1	16.7	17.5	18
Number Of All Sheds	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.9 illustrates the load shedding procedure utilising the new algorithm developed, for a step down of 16 MW for 3 hours at the Shell Refinery plant.

From the 25 circuits of Table 6.8 available for shedding during a period of three hours:

- 1) The shed size was close as possible to the shed requirement of 16 MW, given the loads available for shedding at each time slot.
- 2) All circuits shed during a particular time slot were restored before load shedding began for the subsequent time slot.
- 3) The number of circuits shed at a particular time slot varied from 1 to 3 and in adherence to a minimum number of circuits being shed.
- 4) The number of times all circuits had been shed indicated 0, confirming that no circuit was shed twice before all circuits were shed once.

Results shown in Table 6.9 clearly indicate how the four strategic criteria of the new algorithm has been implemented.

**6.4      Feasibility Analysis Of Load Shedding**

This section deals with the feasibility analysis of the load shedding option in contrast to the other options available for an ICP to maintain generation/load balance.

### 6.4.1 Scenarios Presenting The Option Of Load Shedding In Cogeneration Plants.

#### (1) Scenario 1 :

ICPs may require to have a suitable load shedding scheme so that the contracted power is supplied to Utility during peak hours.

$$\text{if } (G_t = G_{loc} - P_{exp}) < \text{Maximum Load Demand}$$

**Application example:** ICP exports contracted quantity ( i.e exports 5 MW of power) to the Utility grid, during three (3) hours of uninterrupted operation.

( Sc )1: Option A: With available fuel for cogeneration, how should non essential load be shed to operate at load/generation balance?

( Sc )1: Option B: How much fuel input is required to operate at load/generation balance without shedding load?

#### (2) Scenario 2:

During faults at Utility side, the ICP's feeders connected to the Utility substation might be switched off.

$$\text{if } (G_t = G_{loc}) < \text{Maximum Load Demand}$$

**Application example :** Cogenerator sustains its own load ( i.e no exports or imports) during islanding of ICP, from Utility grid.

( Sc )2: Option A: With available fuel for cogeneration, how should non essential load be shed to operate at generation/load balance?

( Sc )2: Option B: How much fuel input is required to operate at load/generation balance without shedding load?

**(3) Scenario 3 :**

Industries, which generate electricity in order to meet part of its requirement, are allowed to draw a fixed amount of electricity from Utility during peak hours.

$$\text{if } (Gt = Gloc + Pimp) < \text{Maximum Load Demand}$$

**Application example :** Operation of ICP, while importing power from Utility grid.

( Sc )3: Option A: With available fuel for cogeneration, how should non essential load be shed to operate at load/generation balance?

( Sc )3 : Option B: How much fuel input is required to operate at load/generation balance without shedding load or varying amount of imported power?

( Sc )3: Option C: How much power imports are required to operate at load/generation balance without shedding load or varying the amount of fuel input.

**6.4.2 Data Set**

- Non essential loads available for shedding = 30

Those circuits in ascending order (in MW) : 1, 1.1, 1.7, 2, 2.4, 2.7, 3.0, 3.2, 3.7, 4.0, 4.4, 4.9, 5.2, 6.6, 6.8, 7.5, 8.0, 8.5, 9.7, 10.2, 12, 12.8, 13, 15, 17, 17.7, 18.5, 19, 20, 25

- Maximum demand profile during three (3) hours corresponding to 15 minute time slots.

15 min: 60 MW	30 min: 55 MW	45 min: 57 MW	60 min: 56 MW
75 min: 60 MW	90 min: 55 MW	105 min: 63 MW	120 min: 60 MW
135 min: 55 MW	150 min: 62.5 MW	165 min: 60.5 MW	180 min : 63 MW

• Generator details

Capacity of cogenerator's generator = 100 MW

Generator constants

$a = 111.11, \quad b = 4, \quad c = 0.044$

Heat rate,  $H(P_g) = ( 111.11 / P_g ) + 4.44 + ( 0.0444 * P_g )$  MKCal / Mwahr. [61]

Fuel input rate,  $F(P_g) = 111.11 + ( 4.44 * P_g ) + ( 0.0444 * (P_g) * (P_g) )$  MKCal/hr. [61]

Cogenerated power,  $P_g = F(P_g) / H (P_g)$  MW [61]

6.4.3.1 Analysis Of Results For Scenario 1

Comparing Tables 6.10 and Tables 6.11 it is evident that, without load shedding to restore generation/load balance, the additional fuel volume incurred *during the contracted hours of exporting power* were even up to ( 40%) during some time periods.

Table 6.10 Cogenerating with available fuel and load shedding during contracted hours of exporting power

Time Slot (min)	Load Demand (MW)	Fuel Input (MKCal/hr)	Heat Gen (MKCal/M W hr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	410	8.4	48.7	-5	43.7	16.3	24 2		16.1
30	55	425	8.4	50.5	-5	45.5	9.5	18 1	24 2	9.5
45	57	430	8.4	51.5	-5	46.1	10.9	20	18 1	10.2
60	56	412	8.4	48.9	-5	43.9	12.1	21	20	12.0
75	60	450	8.4	53.4	-5	48.4	11.6	19 3	21	11.4
90	55	375	8.5	44.3	-5	39.3	15.7	23 5	19 3	15.4
105	63	430	8.4	51.1	-5	46.1	16.9	22 10	23 5	16.8
120	60	380	8.4	45.0	-5	40.0	20.0	29	22 10	20.0
135	55	370	8.5	43.7	-5	38.7	16.3	17 16	29	15.5
150	62.5	390	8.4	46.2	-5	41.2	21.3	28 4	17 16	21.0
165	60.5	400	8.4	47.5	-5	42.5	18.0	26	28 4	17.7
180	63	420	8.4	49.9	-5	44.9	18.1	25 1	26	18.0

Table 6.11 Cogenerating with additional fuel during contracted hours of exporting power

Time Slot (min)	Load Demand (MW)	Fuel Input (MKCal/hr)	Heat Gen (MKCal/M Whr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	550.8	8.6	64.4	-5	59.4	-	-	-	-
30	55	508.5	8.5	59.9	-5	54.9	-	-	-	-
45	57	525.4	8.5	61.7	-5	56.7	-	-	-	-
60	56	516.9	8.5	60.8	-5	55.8	-	-	-	-
75	60	550.8	8.6	64.4	-5	59.4	-	-	-	-
90	55	508.5	8.5	59.9	-5	54.9	-	-	-	-
105	63	576.3	8.6	67.0	-5	62.0	-	-	-	-
120	60	550.8	8.6	64.4	-5	59.0	-	-	-	-
135	55	508.5	8.5	59.9	-5	54.9	-	-	-	-
150	62.5	572.0	8.5	66.5	-5	61.5	-	-	-	-
165	60.5	555.1	8.6	64.8	-5	59.8	-	-	-	-
180	63	576.3	8.6	67.0	-5	52.0	-	-	-	-

6.4.3.2 Analysis Of Results For Scenario 2

Comparing Tables 6.12 and Tables 6.13 it is evident that, without load shedding to restore generation/load balance, the additional fuel volume incurred *during the contracted hours of exporting power* were even up to ( 34%) during some time periods.

Table 6.12 Cogenerating with available fuel and load shedding during period when ICP sustains its own load

Time Slot (min)	Load Demand (MW)	Fuel Input (MKCal/hr)	Heat Gen (MKCal/M Whr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	410	8.4	48.7	0	48.7	11.3	20 2		11.3
30	55	425	8.4	50.5	0	50.5	4.5	11	20 2	4.4
45	57	430	8.4	51.5	0	51.5	5.9	13	11	5.2
60	56	412	8.4	48.9	0	48.9	7.1	15	13	6.8
75	60	450	8.4	53.4	0	53.4	6.6	14	15	6.6
90	55	375	8.5	44.3	0	44.3	10.7	19	14	9.7
105	63	430	8.4	51.1	0	51.1	11.9	18 8	19	11.7
120	60	380	8.4	45.0	0	45.0	15.0	24	18 8	15.0
135	55	370	8.5	43.7	0	43.7	11.3	17 7	24	11.0
150	62.5	390	8.4	46.2	0	46.2	16.3	23 6	17 7	15.7
165	60.5	400	8.4	47.5	0	47.5	13.0	22	23 6	12.8
180	63	420	8.4	49.9	0	49.9	13.1	21 1	22	13.0

Table 6.13 Cogenerating with additional fuel during period when ICP sustains its own load

Time Slot (min)	Load Demand (MW)	Fuel Input (MKCal/hr)	Heat Gen (MKCal/M Whr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	508.5	8.4	59.9	0	59.9	-	-	-	-
30	55	462.96	8.4	54.9	0	54.9	-	-	-	-
45	57	483	8.4	57.1	0	57.1	-	-	-	-
60	56	474.6	8.4	56.2	0	56.2	-	-	-	-
75	60	508.5	8.4	59.9	0	59.9	-	-	-	-
90	55	466	8.5	55.2	0	55.2	-	-	-	-
105	63	533.9	8.4	62.6	0	62.6	-	-	-	-
120	60	508.5	8.4	59.9	0	59.9	-	-	-	-
135	55	466.1	8.5	55.2	0	55.2	-	-	-	-
150	62.5	529.6	8.4	62.1	0	62.1	-	-	-	-
165	60.5	512.7	8.4	60.3	0	60.3	-	-	-	-
180	63	533.9	8.4	62.6	0	62.6	-	-	-	-

6.4.3.3 Analysis Of Results For Scenario 3

Comparing Tables 6.14 and Tables 6.15 it is evident that, without load shedding to restore generation/load balance, the additional fuel volume incurred *during the contracted hours of exporting power* were even up to ( 25%) during some time periods.

Table 6.14 Cogenerating with available fuel and load shedding during period when ICP imports power from Utility grid.

Time Slot (min)	Load Demand (MW)	Fuel Input (MKCal/hr)	Heat Gen (MKCal/M Whr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	410	8.4	48.7	-4	52.7	7.3	15		6.8
30	55	425	8.4	50.5	-4	54.5	0.5	1	15	1.0
45	57	430	8.4	51.5	-4	55.5	1.5	3	1	1.7
60	56	412	8.4	48.9	-4	52.9	3.1	7	3	3.0
75	60	450	8.4	53.4	-4	57.4	2.6	5	7	2.4
90	55	375	8.5	44.3	-4	48.3	6.7	14	5	6.6
105	63	430	8.4	51.1	-4	55.1	7.9	16	14	7.5
120	60	380	8.4	45.0	-4	49.0	11.0	20	16	10.2
135	55	370	8.5	43.7	-4	47.7	7.3	13 4	20	7.2
150	62.5	390	8.4	46.2	-4	50.2	12.3	21 4	13 4	12.0
165	60.5	400	8.4	47.5	-4	51.5	9.0	18	21 4	8.5
180	63	420	8.4	49.9	-4	53.9	9.1	17 2	18	9.1

**Table 6.15      Cogenerating with additional fuel during period when ICP imports power from Utility grid.**

Time Slot (min)	Load Demand (MW)	Fuel Input (MKCal/hr)	Heat Gen (MKCal/M Whr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	466.1	8.4	55.2	-5	60.2	-	-	-	-
30	55	423.7	8.4	50.3	-5	55.3	-	-	-	-
45	57	440.7	8.4	52.3	-5	57.3	-	-	-	-
60	56	432.2	8.4	51.3	-5	56.3	-	-	-	-
75	60	466.1	8.4	55.2	-5	60.2	-	-	-	-
90	55	423.7	8.4	50.3	-5	55.3	-	-	-	-
105	63	491.5	8.5	58.0	-5	63.0	-	-	-	-
120	60	466.1	8.4	55.2	-5	60.2	-	-	-	-
135	55	423.7	8.4	50.3	-5	55.3	-	-	-	-
150	62.5	487.3	8.5	57.6	-5	62.6	-	-	-	-
165	60.5	470.4	8.4	55.7	-5	60.7	-	-	-	-
180	63	491.5	8.5	58.0	-5	63.0	-	-	-	-

Comparing Tables 6.14 and Tables 6.16 it is evident that, without load shedding to restore generation/load balance, the additional imported power required to maintain generation/load balance were at times more than double the regular amount of imported power.

**Table 6.16      Cogenerating with available fuel and stepping up imports at a period where ICP imports power from Utility grid.**

Time Slot (min)	Load Demand (MW)	Fuel Input (MKCal/hr)	Heat Gen (MKCal/M Whr)	Local Gen (MW)	Power Exports (MW)	Total Gen (MW)	Shed Req (MW)	Shed Circuits	Restored Circuits	Shed Load (MW)
15	60	410	8.4	48.7	-11.3	60	-	-	-	-
30	55	425	8.4	50.5	-4.5	55	-	-	-	-
45	57	430	8.4	51.5	-6.9	57	-	-	-	-
60	56	412	8.4	48.9	-7.1	56	-	-	-	-
75	60	450	8.4	53.4	-6.6	60	-	-	-	-
90	55	375	8.5	44.3	-0.7	55	-	-	-	-
105	63	430	8.4	51.1	-11.9	63	-	-	-	-
120	60	380	8.4	45.0	-15	60	-	-	-	-
135	55	370	8.5	43.7	-11.3	55	-	-	-	-
150	62.5	390	8.4	46.2	-16.3	62.5	-	-	-	-
165	60.5	400	8.4	47.5	-12.7	60.5	-	-	-	-
180	63	420	8.4	49.9	-13.1	63	-	-	-	-

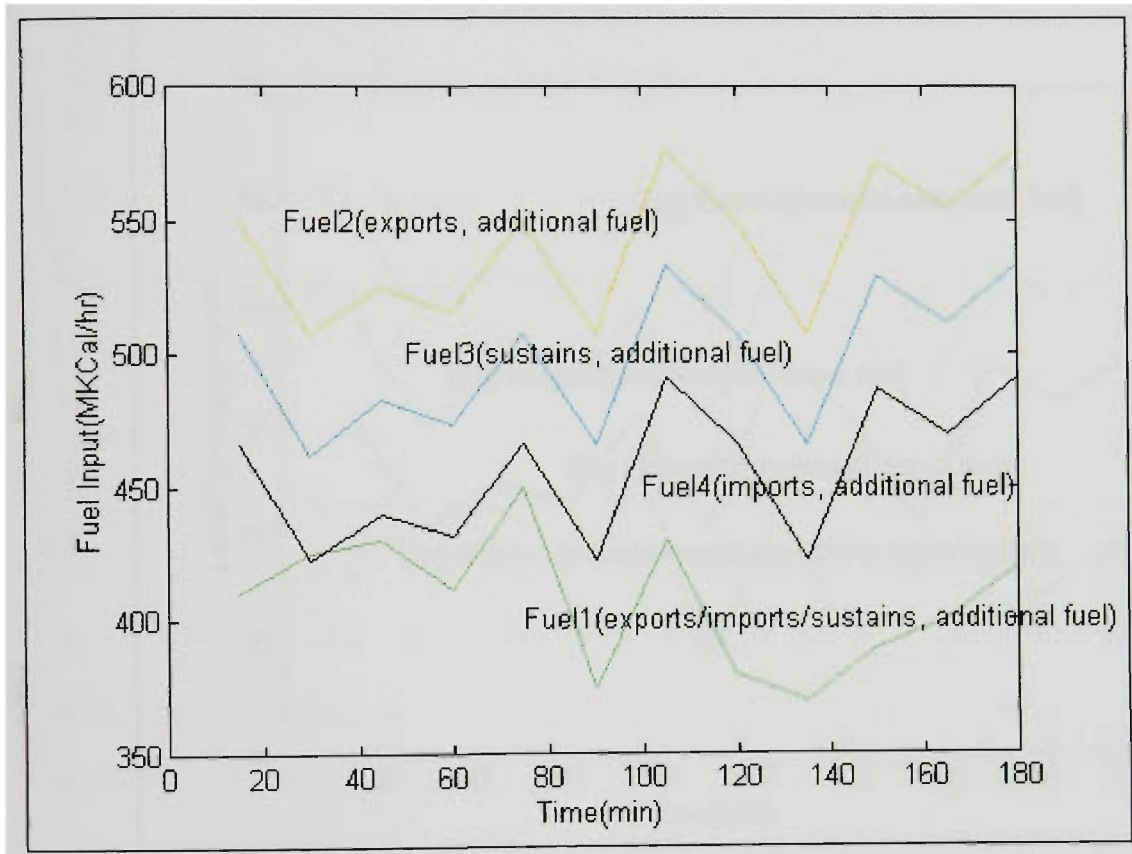
The fuel increments for different scenarios were compared with the case involving available fuel inputs when the ICP exports, imports and sustains its own load, Section 6.4.4.

The cogenerated power for different scenarios were compared with the case involving available fuel inputs when the ICP exports, imports and sustains its own load, Section 6.4.5.

#### 6.4.4 Graphical Analysis Of Fuel Costs In Scenarios Considered.

From Figure 6.26, it is evident that:

- Without load shedding to restore generation/load balance, the additional fuel cost incurred *during the contracted hours of exporting power* were even up to ( 40%) during some time periods.



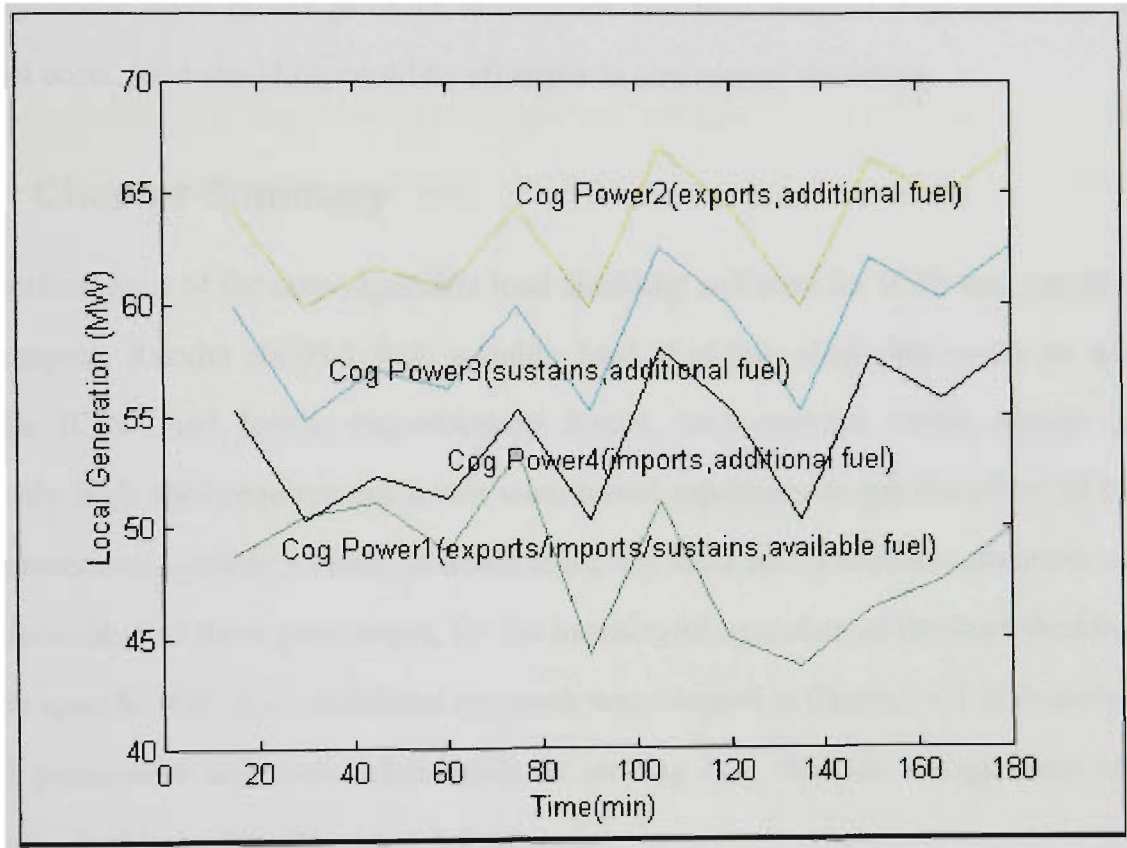
**Figure 6.26 Fuel Volume Required to achieve Generation/Load balance vs Fuel Volume**

- Without load shedding to restore generation/load balance, the additional fuel cost incurred *during periods when cogenerator sustained its own load* were even up to ( 34%) during some time periods.
- Without load shedding to restore generation/load balance, the additional fuel cost incurred *during periods when cogenerator imported power from the Utility* were even up to ( 25%) during some time periods.

### 6.4.5 Graphical Analysis Of Power Generated In Scenarios Considered

From Figure 6.27, it is evident that:

- Without load shedding to restore generation/load balance, the additional fuel cost incurred *during the contracted hours of exporting power* which was up to ( 40%) was utilised to *cogenerate up to (40%) of additional power* and *up to 2.5% of additional heat*.



**Figure 6.27 Cogenerated Power with Additional Fuel vs Cogenerated Power with Available Fuel**

- Without load shedding to restore generation/load balance, the additional fuel cost incurred *during periods when cogenerator sustained its own load* which was up to ( 34%) was utilised to *cogenerate up to (34%) of additional power* and *up to 1.2% of additional heat*.
- Without load shedding to restore generation/load balance, the additional fuel cost incurred *during periods when cogenerator imported power from the Utility* which was up to ( 25%) was utilised to *cogenerate up to (25%) of additional power* and *up to 1% of additional heat*.

- Without load shedding to restore generation/load balance, the additional fuel cost incurred *during periods when cogenerator imported power from the Utility* which was up to (25%) was utilised to *cogenerate up to (25%) of additional power* and *up to 1% of additional heat*.
- Even if plenty of additional heat is generated, that could be re utilised very efficiently to cogenerate more power in order to meet the full load demand with relatively less initial fuel costs, load shedding could be effective in emergency situations.

## 6.5 Chapter Summary

The performance of the new algorithm load shedding software for ICPs was presented within this chapter. Results showed that, suitable load shedding strategies could be adapted for specific ICPs. Fuel levels, import/export levels, load demand levels, circuit groupings, relatively high shed requirement levels were tested separately to see the effect of each of the aforementioned variable's effect in determining the shed size. Particular attention was paid to the relationship of these parameters, for the meaningful operation of the load shedding scheme in each specific ICP. A consolidated approach was adopted in Chapter 6.1 in examining all the useful parameters and their relationship in making sure that the design aims of the new algorithm highlighted in Chapter 5.5.1 were met.

The following conclusions were made from the results obtained in the feasibility analysis of Load Shedding, Chapter 6.4 :

- A general and efficient new algorithm for load shedding and restoring circuits during periods when power demand is more than supply was developed.
- The new algorithm approach provided suitable load shedding strategies from primarily a planning perspective.
- In scenario 1 cited in Chapter 6.4.1, using the new algorithm load shedding strategy to restore generation/load balance, an additional fuel cost of up to (40%) incurred was saved

*during the contracted hours of the cogenerator exporting power* with available fuel inputs. However, in general load should not be shed to economise on fuel cost.

- In scenario 2 cited in Chapter 6.4.1, using the new algorithm load shedding strategy to restore generation/load balance an additional fuel cost of up to **(34%)** incurred was saved *during periods when cogenerator sustained its own load* with available fuel inputs.
- In scenario 3 cited in Chapter 6.4.1, using the new algorithm load shedding strategy to restore generation/load balance an additional fuel cost of up to **(25%)** incurred was saved *during periods when cogenerator imported power from the Utility* with available fuel inputs.
- The case for load shedding will be unfavourable if the cost of having unemergency loads unavailable supersedes the cost of importing power from the Utility in order to meet the shed requirement. This is unlikely, unless the Utility subsidises the cost of imported power or if setting up a load shedding scheme in a cogeneration plant is too costly.
- However since the percentage increase of additional reusable heat generated in the cogenerating plant with additional fuel is in the order of 1 to 2.5%, the case for cogenerating and load shedding hangs favourably in the balance with the case for selling cogenerated power at a higher rate to the Utility and importing power at a lower rate from the Utility, from an energy management perspective.
- A suitable less costly load shedding scheme, complements the functionality of a cogeneration plant.

Simulation results were confirmed to conform to world's best practice, via successful comparative performance analysis made in reference [40]. With the application of the new algorithm load shedding strategy it was possible to exploit a variety of operating standpoints of various ICPs, and answer questions such as is load shedding viable?, when should load be shed?, and how should load be shed?, in each given scenario.

## 7.0 Conclusions

The scope and objectives of this research have been successfully completed.

Role of cogeneration, commercial viability cost and performance and protection principles were broadly investigated in Chapter 2. This was followed by an analysis into renewable energy connection of generator to the power system and assessing implications and solving issues of concern in the interconnection of an ICP to the Utility's distribution system, in Chapter 3. The need for load shedding as well as the requirement for effective load shedding strategies in ICPs were introduced in Chapter 3.

The limitations and assumptions defined in Chapter 4, were necessary to allow reasonable results to be obtained within the specified time and resource constraints. The proposed system configuration involved a large number of variables, and the development strategy carefully orchestrated so as to focus only on key aspects with direct performance benefits.

In Chapter 5, the simulation platforms used, scenarios of load shedding discussed as well as the circuit selection, shedding and restoration strategy were analysed first in view of the project requirements. Diverse load shedding scenarios were constructed and Matlab graphical representations were utilised to investigate the impact of controllable system parameters.

The objective performance analysis of Chapter 6 presented the successful results of load shedding instances of ICPs operating at various system conditions. The new algorithm load shedding software was developed in order to study the independent effect of one variable, while keeping all other variables constant. The impact that each of the variables *fuel levels*, *import/export levels*, *variable load demands*, *circuit numbers* and *relatively higher shed requirement levels* would make on *shed requirement* vs *shed size* was investigated.

Heat and power are the life-blood of any industry; essential for the operation of everything from the lowly light bulb and radiator to the most complex process technology. Obtaining these vital commodities at the lowest cost is traditionally the duty of management. With the

privatisation of the electricity supply industry and institutional changes there is now an opportunity of reducing overall costs of energy supply by using cogeneration technology [1].

Load shedding provides a useful alternative for ICPs that are contracted to supply power during peak hours and/or non peak hours. With the adoption of load shedding a private generator has the added incentive to cope during times when fuel cost is high and operate effectively during islanding condition. Therefore the focus, evaluation and development of this project are to fulfil the justifiable demand of cogenerator's dream of managing an ICP with suitable load shedding schemes to operate during diverse scenarios.

Utility power grids have generation capabilities in the very high range. These grids appear to be infinite in size compared to cogenerators. When an ICP operates in parallel with a Utility grid, the Utility acts as an infinite bus bar with almost constant frequency and controlled voltage. Hence, the load shedding requirements, can not be sensed by normal dropping of frequency [46 - 49].

The option of load shedding is applicable only if the ICP's load demand exceeds its total generation. The load/generation imbalance needs to be detected, for load shedding purposes.

The most significant contribution of this research was the development of the new algorithm circuit selection, shed and restoration strategy that would:

- Match *shed size* as close as possible to *shed requirement*.
- Ensure *number of circuits shed* to be minimum.
- *Restore circuits shed* in a time slot during subsequent time slot.
- Maintain *periodicity of circuits shed*.

The logical steps into the system development of load shedding in an ICP have been described in Chapter 5. The simulation platforms in Chapter 5.1 facilitated the initial simulations in cogeneration.

The new algorithm load shedding strategy was introduced in Chapter 5.2. Scenarios in load shedding were analysed in Chapter 5.3.

Chapter 5.4 focussed on an existing load shedding strategy from reference [40]. Aims of the new algorithm load shedding strategy were described in Chapter 5.5. The software development methodology, capability, function and programming methodology were described in Chapter 5.6.

Various considerations in load shedding were presented in Chapter 5.7.

Several scenarios were considered with a full exploitation of the new algorithm load shedding software. In Chapter 6, the performance analysis described the various investigations in load shedding that has been made possible.

Observing results obtained in entire Chapter 6.1.1, it was evident that as the fuel input became less, the cogenerated power became less too. This in turn translated to a higher total of loads being shed corresponding to lesser fuel input.

Visualising results obtained in entire Chapter 6.1.2 it was noticeable how as the amount of power exports increased, that the total number of loads that were shed during the entire load shedding period increased too.

Results obtained in Chapter 6.1.3 showed how an averagely higher load demand that effectively caused a higher load/generation imbalance effected a larger number of loads to be shed.

Results derived in Chapter 6.1.4 indicated that with a well grouped pool of circuits available for shedding, that an ICP had a better opportunity of making sure that the shed size closely matched the shed requirement.

Observation of results in Chapter 6.1.5 indicated that to cope up with relatively higher shed requirement levels a larger pool of circuits which when grouped could match shed requirement levels, should be available for shedding purposes.

The new algorithm developed was verified in respect to its validity and effectiveness via performance comparisons made with an IEE journal paper [40], in Chapter 6.2. Comparative performance of results indicated that the new algorithm load shedding strategy achieved *shed sizes* closer to the *shed requirement* than that of reference [40].

The load shedding strategy that was developed was also tested on the Shell Refinery load shedding event as described in Chapter 6.3, and found to be operating favourably.

Investigations of Chapter 6.4, showed that the case for load shedding will be unfavourable if the cost of having unemergency loads unavailable supersedes the cost of importing power from the Utility in order to meet the shed requirement.

Investigations of Chapter 6.4, however demonstrated that a suitable less costly load shedding scheme, complemented the functionality of an ICP.

In summary the application of load shedding techniques enabled a variety of parameters to be evaluated across a platform of different ICP network configurations, in the study of cogeneration and load shedding. The assumptions made within Chapter 4 highlight the scope for further research into the specific aspects of the analysis.

## 7.1 Outcome of the thesis

In order to ensure quality of service is maintained in the end product load shedding software, a number of issues were considered, as highlighted in **Chapter 4.6**. The performance analysis was explored from different perspectives.

The outcome of the thesis could be summarised as follows:

- (1) The source code of the software tool developed for planners of ICPs, has been included in Appendix A. The load shedding software that was developed, has been demonstrated to representatives of the ERDC.
- (2) Reliability and efficiency incorporated in the algorithm development of load shedding software was verified with IEE journal paper [40] as discussed Chapter 6.2. The load shedding algorithm developed brought about a performance improvement of *shed requirement* vs *shed size*.
- (3) The operation of load shedding was tested on a variety of data relating to different ICPs as described in Chapter 5.7. Various cases were studied, which assisted in the algorithm development.
- (4) Power engineering students should be able to use the software tool to study the effect of various system control parameters of load shedding as presented in Chapter 6.1. The effect of five control variables was analysed as to the independent effect each variable may have in determining *shed requirement* vs *shed size*.
- (5) The software developed has been used as a design tool, in the load shedding analysis of the Shell Australia refinery as shown in Chapter 6.3. Results discussed, indicated one design strategy. Many such design strategies could be evaluated, with the load shedding software that was developed.

## 7.2 Quality of load shedding

The quality of load shedding aimed at in **Chapter 4.7**, was realised as follows:

- (1) Load shedding results were acceptable according to world's best practise with successful comparison of results with a Utility application described in Chapter 6.2.
- (2) The software tool developed was user friendly as well as interactive. Software development outcomes and programming methodology has been described in Chapter 5.6.

(3) The software enabled the user to carry out a feasibility analysis of load shedding as described in Chapter 6.4. Load shedding was investigated together with alternative options of using additional fuel or importing access power to meet generation/load balance of ICPs.

(4) The load shedding software developed was tested on an industry, with the Shell Refinery application discussed in Chapter 6.3. Load shedding possibilities were considered, in the event of mains loss.

(5) The system control parameters of load shedding were analysed as described in Chapter 6.1. The variable effect of *fuel* on shed requirement vs shed size have been graphed from *Figures 6.1 to Figures 6.5*. The variable effect of *import/export levels* on shed requirement vs shed size have been graphed from *Figures 6.6 to Figures 6.10*. The variable effect of *load demand levels* on shed requirement vs shed size have been graphed from *Figures 6.11 to Figures 6.15*. The variable effect of *circuits available for shedding* on shed requirement vs shed size have been graphed from *Figures 6.16 to Figures 6.20*. The variable effect of *relatively high load demand levels* on shed requirement vs shed size have been graphed from *Figures 6.21 to Figures 6.25*.

(6) The load shedding algorithm developed, enabled the user to analyse the trade off between load shedding and additional fuel costs as described in Chapter 6.4.4 and graphed in Figure 6.26.

### 7.3 Application of load shedding on a local industrial application.

Within system design in Chapter 5.7 the following load shedding considerations were made as raised in **Chapter 4.8**, during the process of algorithm development.

The system parameters were defined to cater for cases such as:

(1) More load and less generation as described in Chapter 5.7.1.

(2) Both large loads and large generation amounts as described in Chapter 5.7.2.

- (3) Both less loads and less generation amounts as described in Chapter 5.7.3.
- (4) Constant load shedding requirements in each time slot as described in Chapter 5.7.4.
- (5) When only a few circuits are available for shedding as described in Chapter 5.7.5.
- (6) A reasonably large number of circuits are available for shedding as described in Chapter 5.7.6.
- (7) A number of circuits are being grouped for shedding purposes as described in Chapter 5.7.7.

## **7.4 Issues of concern from an ICP operator's standpoint**

Issues of concern from an ICP operator's standpoint, raised in **Chapter 4.9**, were addressed as follows:

- (1) The load shedding scheme considered in Chapter 6.4 successfully offset additional fuel costs of 40%, 34% and 25% for ICPs exporting, sustaining its own load and importing power. Therefore, a load shedding scheme can substitute for additional fuel costs when ICP is exporting, sustaining its own load and importing power.
- (2) When load shedding was implemented with variable fuel levels as described in Chapter 6.1.1, it was observed that the load shedding strategy best catered for fuel levels between 120 and 420 MK Cal/hr.
- (3) When load shedding was implemented with variable import/export levels as described in Chapter 6.1.2, it was observed that the load shedding strategy best catered for power exports of 15 MW.
- (4) When load shedding was implemented for variable load demand levels as described in Chapter 6.1.3, it was observed that the load shedding strategy was most effective when load demand levels were between 60 MW to 70 MW.

(5) When load shedding was implemented for variable circuit numbers as described in Chapter 6.1.4, it was observed that the load shedding strategy was most effective when twenty two circuits were available for shedding.

(6) In cases with high shed requirements as described in Chapter 6.1.5, there needs to be a number of circuit groups that could closely match the shed requirement of the ICP.

(7) With the selection of suitable parameters for each scenario, the new algorithm load shedding strategy could facilitate the operation of ICPs.

## **7.5 Issues of concern from the Utility's standpoint.**

Issues of concern from the Utility's standpoint raised in **Chapter 4.10**, have been analysed as follows:

(1) The Utility distributor can engage the services of a particular ICP to purchase power, if that ICP has the capacity to sustain its own load demand, as well as show that it can export the contracted amount of power without compromising load/generation balance.

(2) The Utility's distributor can potentially purchase power from any one of the ICPs that could uncompromisingly supply the contracted amount of power.

(3) "Buy back rates" offered by Utility distributor to ICP, should take into consideration all the costs incurred by the ICP to produce that contracted power. As it has been shown in Chapter 6.4 of the thesis, a load shedding cogeneration scheme could save on additional fuel costs. A reasonable profit margin should be offered as an incentive for ICPs.

(4) If a load shedding ICP can pass the software test of "exporting contracted power" while maintaining generation/load balance, then that ICP becomes a potential customer of the Utility distributor.

(5) Results obtained in Chapter 6.4 indicate that the shedding of unemergency loads is a viable alternative for ICPs to operate successfully, compared to going for additional fuel.

(6) The main costs from the industry's perspective is setting up a "cogeneration scheme" and a "load shedding scheme". The operating efficiency of a cogeneration plant is greater than a generation house. *Additional fuel costs of ICPs could be saved by effective load shedding as shown in this research thesis.* Although a generation house produces "bulk power" cost is incurred to transport power produced from a generation house. All these factors need to be considered as well as supply and demand characteristics of electricity in different regions during a lengthy period of time.

## 7.6 In which cases are load shedding viable ?

The following issues raised in **Chapter 4.11**, have been realised in the performance analysis as follows:

- (1) During contracted hours of exporting power, a saving of 40% in additional fuel costs was brought about for ICPs by load shedding, as described in Chapter 6.4.4.
- (2) During periods when an ICP is sustaining its own load, a saving of 34% in additional fuel costs was brought about for ICPs by load shedding, as described in Chapter 6.4.4.
- (3) During periods when an ICP imports power from the Utility, a saving of 25% in additional fuel costs was brought about for ICPs by load shedding, as described in Chapter 6.4.4.
- (4) The case for load shedding will be unfavourable if the cost of having unemergency loads unavailable supersedes the cost of importing power from the Utility in order to meet the shed requirement, as discussed in Chapter 6.5.
- (5) As shown in Chapter 6.4, load shedding in ICPs offsets additional fuel costs and hence complements energy management.
- (6) Viability of load shedding in an ICP with less fuel input, would depend on the combined contribution of the amount of available fuel input and the capacity of loads available for shedding, as described in Chapter 6.1.1.

- (7) A load shedding scheme can manage when an ICP is contracted to export large amounts of power, if that load shedding scheme can group a number of unemergency loads and shed them periodically without compromising generation/load balance, as described in Chapter 6.1.2.
- (8) A load shedding scheme can manage when load demand levels are high, if that load shedding scheme can group a number of unemergency loads and shed them periodically without compromising generation/load balance, as described in Chapter 6.1.3.
- (9) Having a large pool of loads available for shedding makes no difference in the load shedding mechanism becoming more efficient, as described in Chapter 6.1.4. In Chapter 6.1.4 it was shown how the least number of circuits in a pool, better grouped to meet shed requirement periodically, can make the load shedding mechanism more efficient.
- (10) The load shedding scheme of an ICP would be able to manage during high shed requirement levels as described in Chapter 6.5, if that load shedding scheme can group a number of unemergency loads and shed them periodically without compromising generation/load balance.

## **7.7 Recommendations for further research**

Future work could focus on a few different issues of importance, depending on specific applications and are as follows.

Different priorities of loads could be assigned and the shedding of loads could be conducted ensuring that the priority levels are maintained, not compromising the aims of the new algorithm.

Another feature that could be researched is the practical implementation of a load shedding scheme, where the load shedding feature is software implemented to drive the circuit breakers of the loads on and off appropriately for shedding and restoration purposes. Coupled with appropriate governor control load/generation balance can be ensured.

The performance analysis conducted in Chapter 6 was for ICPs. In the future, further simulations could be conducted on Utility distributors integrated to various ICPs. The new algorithm software developed could be enhanced also to investigate how power pooling arrangements could be organised between Utility distributors and ICPs.

The work carried out within this research suggest that for ICPs, that a performance improvement can be brought about by appropriate trade off between fuel input, loads shed, and power exported to Utility grid. Design data relating to load shedding of ICPs have been obtained in this thesis. More investigations on the installing and commissioning of load shedding in ICPs can be conducted, in the future. Various scenarios could be studied and the implementation of a load shedding scheme utilising combination of both hardware and software are scope for further research.

Other renewables such as solar power could be researched. A key role for solar power is in areas far from the big Utilities and the grids. Remote power being supplied to isolated communities, farms, mine sites and communication systems. They often require kilowatt supplies rather than megawatt sources and these are ideal parameters for solar electric generation [62].

Photo voltaic cells are another renewable that could be researched. In the past, commercial use of photo voltaic cells has been restricted largely to remote area applications where conventional electricity was expensive. However, 1997 marks a year of transition where the major application of the cells has changed to become generation of residential electricity in urban areas already supplied by the conventional grid [63].

Wind energy is a clean source of renewable energy that could be researched further. Plans are already underway to build new wind farms in Australia [64].

Industries, academics and postgraduate researchers would be encouraged to pursue further research in renewables with the commitment made by the Australian Commonwealth

Government in November 1997, “to make a substantial investment in the development of renewable energy technologies” [65].

## **Appendix A    Source Code**

**Note:** The information presented in this Appendix is the source code. The concepts and design considerations involving the subroutines and drivers shown in the code here have been described in Chapter 5, System design.

**program LD\_SHED;**

uses

Crt, Dos;

const

```

    CR      = #13;           { Carriage Return key }
    BS      = #8;            { Back Space key  }
    ESC     = #27;           { ESCape key  }
    GROUP   = 'COGENERATION GROUP';      { GROUP NAME }
    VER     = '2.0';          { version number }
    DTIME   = 500;            { delay time for sound, window growing etc... }
    MaxC    = 75;             { Maximum number of circuits }

```

Type Arr1 = Array[1..MaxC] of real;

Arr2 = Array[1..12] of real;

ArrI1 = Array[1..MaxC] of integer;

ArrI2 = Array[1..12] of integer;

Type setup = Array[1..MaxC] of boolean;

var Ct:Arr1;

Req,SSarray:Arr2;

LDem,Gen,Fuel,Heat,Gloc,Pim,Pex:Arr2;

NoShed,Sarray,Rarray:ArrI1;

NoASarray:ArrI2;

CancelShed,Taken:setup;

writefile,infile,shedfile,shedRes: text;

I,Slot,P,Q:integer;

int,NoAllShed:integer;

AllShed,Complete:boolean;

ch,ch1:char;

toss:integer;

numL:integer;

choiceC,choiceS:char;

re,TotShed,SS,MShedSz,UnshedSz:real;

Gcap,a,b,c:real;

**procedure Wait;**

{ This procedure waits for &lt;ESC&gt; to be pressed }

var

Ch: Char;

begin

TextColor(White+Blink);

Write('Press &lt;ESC&gt; to exit.');

repeat

Ch:=readkey;

until Ch IN [ESC];

end;

**procedure Beep (Tone: Integer);**

{ This procedure provides different kinds of beeping tones }

begin { Beep }

case Tone of

0: begin { Invalid keypress tone }

Sound(100); Delay (DTIME\*2);

NoSound;

end;

1: begin { "Press any key to..." tone }

Sound(400); Delay (DTIME);

Sound(800); Delay (DTIME);

NoSound;

end;

2: begin { "Answer NO to query" tone }

Sound(800); Delay (DTIME);

Sound(400); Delay (DTIME);

NoSound;

end;

3: begin { "Are you sure?" tone }

Sound(400); Delay (DTIME);

Sound(600); Delay (DTIME);

Sound(800); Delay (DTIME);

NoSound;

end;

end;

end; { Beep }

**procedure Flash\_Msg(X1,Y1,X2,Y2: Integer; BColor, TColor: Byte;Text: String);**

{ This procedure flashes a message on the screen }

var

Ch: Char;

begin { Flash\_Msg }

Window(X1, Y1, X2, Y2);

TextBackground(BColor); ClrScr;

TextColor(TColor + Blink);

Write(Text);

Ch:= ReadKey;

end; { Flash\_Msg }

**procedure Divider(Length, Ch: Integer);**

{ This procedure displays a line to divide text }

var

Count: Integer;

begin { Divider }

Write(' ');

for Count:= 1 to Length do

Write(Chr(Ch));

WriteLn;

end; { Divider }

**procedure Wipe\_Up(X1, Y1, X2, Y2: Integer; Color: Byte);**

{ This procedure displays a window by growing it horizontally then vertically }

var

a1, a2, b1, b2, length, height, i: Integer;

```

begin { Wipe_Up }
  length:= x2-x1;
  height:= y2-y1;
  a1:= x1 + (length div 2);           { top left middle x coordinate }
  b1:= y1 + (height div 2);           { top left middle y coordinate }
  a2:= a1 + 1;                        { bottom right middle x coordinate }
  b2:= b1 + 1;                        { bottom right middle y coordinate }

```

```

for i:= 1 to (length div 2) do         { half the length }
begin
  Window(a1,b1,a2,b1);
  TextBackground(Color); ClrScr;
  dec(a1);                             { grow left }
  inc(a2);                             { grow right }
  delay(DTIME div 15);
  sound(i*sqr(20));                   { sound effects }
end;
for i:= 1 to (height div 2) do         { half the height }
begin
  Window(x1,b1,x2,b2);
  TextBackground(Color); ClrScr;
  dec(b1);                             { grow up }
  inc(b2);                             { grow down }
  delay(DTIME div 5);
  sound(i*sqr(20));                   (*200*) { sound effects }
end;
nosound;
end; { Wipe_Up }

```

**procedure Win\_Box(X1, Y1, X2, Y2: Integer; Color: Byte; Title: String);**

{ This procedure displays a window box and it's shadow }

var

i, length, height: Integer;

begin { Win\_Box }

Window(X1,Y1,X2,Y1); { title box }

TextBackground(LightGray); ClrScr;

TextColor(Color);

Write(Title);

if (X2 < 79) AND (Y2 < 25) then { check if over screen boundaries }

begin

TextBackground(Black); { shadow }

{TextColor(LightGray);}

window(1,1,80,25);

length:= 2;

height:= 1;

repeat

GoToXY(X2+1, Y1+height);

for i:= 1 to length do

Write(Chr(176));

Inc(height);

until height= (Y2-Y1) + 2;

GoToXY(X1+2, Y2+1);

for i:= 1 to X2-X1 do

Write(Chr(176));

end;

Window(X1,Y1+1,X2,Y2); { body }

TextBackground(Color); ClrScr;

end; { Win\_Box }

```

procedure Highlight(X1,Y1,X2,Y2: Integer; Text: String; N,Ch: Char);
{ This procedure highlights an item on the menu }
begin { Highlight }
  Window(X1,Y1,X2,Y2);
  TextBackground(Magenta); ClrScr;           { highlight color }
  TextColor(LightGray);
  GoToXY(2,1); Write(Text);
  TextColor(White);
  GoToXY(3,1); Write(N);
  GoToXY(7,1); Write(Ch);
end; { Highlight }

```

```

{*****
*           VIEW PROCEDURE           *
*****}

```

```

procedure View;
{ This procedure enables the user to view textfiles }
var
  FileName: String[40];
  quit: Boolean;
  FileView : Text;
  Character: Char;
begin { View }
  Wipe_Up(6,16,74,19,Blue);
  Win_Box(6,16,74,19,Blue,
    ' [p]           Filename Selection');
  TextColor(Yellow);
  WriteLn;
  Write(' Enter filename to view: ');      { prompt for path & filename }
  Window(31,18,73,18);
  TextBackground(Green); ClrScr;
  TextColor(White);
  readln(FileName);
  if FileName<>" then                      { if filename is given }
  begin
    assign(FileView,FileName);
    {$I-}
    reset(FileView);
    {$I+}
    if IOResult<>0 then                    { check if filename given is valid }
    begin
      Wipe_Up(6,15,74,23,Red);
      Win_Box(6,15,74,23,Red,
        ' [p]           Error');
      Beep(3);
      TextColor(Yellow);WriteLn;
      WriteLn(' ERROR: File not found in current/specified path. ');
      TextColor(White);
      WriteLn(' SOLUTION: Choose "[4] Directory listing" from',
        ' the Main Menu');
      WriteLn(' and get the correct path and filename of');
      WriteLn(' the file you wish to view. ');
      TextColor(Green);
      Flash_Msg(18,22,62,22, Green, White,

```

```

' < Press any key to return to Main Menu >');
end
else                                     { if filename given is valid }
begin
  quit:=false;                           { set to not quit }
  Wipe_Up(1,1,80,25,Blue);
  Win_Box(1,1,80,25,Blue,
  ' [p]          View a file [']);
  TextColor(Blue);
  Window(38,1,80,1); TextBackground(LightGray); ClrScr;
  Write(Filename,'];
  Window(2,3,79,24); TextBackground(Blue);
  while NOT quit AND NOT Eof(FileView) DO
  begin                                  { while not quit or end of file }
    clrscr;
    TextColor(White);
    while (NOT Eof(FileView)) AND (wherey<21) DO
    begin                                { while not end of file and screenful }
      Read(FileView,character);
      Write(character);                  { display on screen }
    end;
    TextColor(LightGray);
    if Eof(FileView) then                 { if end of file }
    begin                                  { display on screen }
      WriteLn;
      WriteLn('ÄÄÄÄÄÄÄÄ END OF FILE ÄÄÄÄÄÄÄÄ');
      Beep(1);
      Write('< Press any key to return to Main Menu >');
    end;
    else
    begin
      WriteLn;
      Write('ÄÄ More ÄÄ          ["Q" quits]');
    end;
    Character:= UpCase(ReadKey);
    if Character='Q' then                  { if 'Q' is pressed then exit }
    quit:= TRUE;
  end;
  Close(FileView);                        { close the file being viewed }
end;
end; { View }

{*****
*          DIR  PROCEDURE          *
*****}

procedure Dir;
{ This procedure lists the files in a user specified directory or the
  default directory }
var
  DirInfo: SearchRec; { variable of type SearchRec used to scan directories }
  Count,j,i,x1,x2,y1,y2: Integer;
  Total: Longint;
  sz: String[7];      { variable to hold size of files }
  Ch: String[1];
  P: PathStr;          { path string }
  s,D: DirStr;          { directory string }
  N: NameStr;           { filename string }

```

```

E: ExtStr;                                { extension string }

begin { Dir }
  GetDir(0,s);                             { get current directory of (0) default drive }
  Wipe_Up(6,16,74,19,Magenta);
  Win_Box(6,16,74,19,Magenta,
    '[p] Path & Filename Selection');
  TextColor(Yellow);
  WriteLn;
  Write(' Enter path & filename: ');        { prompt for path & filename }
  Window(30,18,73,18);
  TextBackground(Green); ClrScr;
  TextColor(White);

  if Length(s) = 3 then                    { check if root directory }
    Delete(s,3,1);                        { remove '\' char }
  TextBackground(Cyan);
  GotoXY(2,1); Write(s,'\*.');           { default drive & directory + all files }
  GotoXY(2,1);

  P:="";
  Ch:= Readkey;                           { read first character entered }
  if Ch = CR then
    P:= s + '\*. *';                     { if <Enter> key, use default directory }
  if (Ch=BS) then
    Delete(P,(Length(P)-1),2);            { if <Backspace>, delete char }
  if Ch = ESC then
    exit                                  { if <Esc>, exit }
  else
    begin
      P:= P + Ch;                        { put first character to path string }
      TextBackground(Green); ClrScr;
      GoToXY(2,1); Write(Ch);
      while (Ch <> CR) AND (Ch <> ESC) do { while not <Enter> and not <Esc> }
      begin
        Ch:=Readkey;
        P:= P + Ch;
        if (Ch=BS) then                  { check if <Backspace> }
          Delete(P,(Length(P)-1),2);
          Write(Ch);
        end;
        Delete(P,Length(P),1);           { delete last char in path var }
        Ch:= Copy (P,Length(P),1);       { get new last char }
        if (Ch = ':') OR (Ch = '\') then  { if chars are these then }
          P:= P + '*.*';                 { path is root directory, all archives }
        end;
        if Ch = ESC then exit;            { <Esc> ? }

        i:= 3; j:= 1;                    { Init_Tx output coordinates }
        x1:=2; y1:=2; x2:=78; y2:=23;    { Init_Tx window coordinates }
        Count:= 0; Total:= 0;

        Wipe_Up(x1,y1,x2,y2, Magenta);
        Win_Box(x1,y1,x2,y2, Magenta,
          '[p] Directory Listing');

        TextColor(White+blink);
        GoToXY(3,2); Write(' Reading ');

```

```

TextColor(White); Write(P, ' ...');
FindFirst(P, Archive, DirInfo); { search path given for archive files }
while DosError <> 18 do          { DosError 18 = no more files }
begin
    Total:= (DirInfo.Size) + Total;          { add file sizes }
    inc(Count);                             { count files read }
    FindNext(DirInfo);                      { search for next files }
end;

ClrScr;
Window(x1,y2-2,x2,y2);
TextBackground(Magenta); ClrScr;
TextColor(Yellow);
GoToXY(2,1); Divider(73,196);
TextColor(Cyan);                          { hide cursor }
Window(x1,y1+2,x2,y1+5);                  { window for path & file information }
TextBackground(Magenta); ClrScr;
TextColor(Yellow);
GoToXY(2,1); Write(' Path & Filename: ');
GoToXY(48,2); Write('Total Bytes Free: ');
GoToXY(48,1); Write('Total Bytes Used: ');
GoToXY(2,2); Write('  Total Files: ');
GoToXY(2,3); Divider(73,196);
TextColor(White);
GoToXY(20,1); Write(P);                    { path and filename }
GoToXY(66,2); Write(diskfree(0));           { free disk space }
GoToXY(66,1); Write(Total);                 { total bytes used by files }
GoToXY(20,2); Write(Count);                 { number of files }

Window(x1,y1+5,x2,y2);                     { window for list of files }
TextBackground(Magenta); ClrScr;
FindFirst(P, Archive, DirInfo);
while DosError = 0 do                       { DosError 0 = No Error }
begin
    FSplit(DirInfo.Name, D, N, E); { split filename to dir, name and ext }
    GoToXY(i,j); Write(N);             { output filename }
    GoToXY(i+8,j); Write(E);           { output extension }
    Str(DirInfo.Size,sz);               { convert file size(longint) to string }
    if Length(sz) <> 7 then
    repeat
        sz := ' ' + sz;
    until Length(sz) = 7;               { right justify output }
    GoToXY(i+13,j); Write(sz);          { display file size }
    GoToXY(i+22,j); Write('±');         { display column border }

    FindNext(DirInfo);
    inc(j);
    if j = ((y2-y1)-6) then             { if reached max. row }
    begin                                { set output coordinate to next column }
        i:=i+25;
        j:=1;
    end;

    if ((i = 78) and (j = 1)) and (Count > 42) then { if screen full }
    begin                                { set output coordinate to first column }
        i:= 3;
        j:= 1;
        Window(x1,y2-2,x2,y2);          { window for action message }

```

```

    TextBackground(Magenta);ClrScr;
    TextColor(Yellow);
    GoToXY(2,1); Divider(73,196);
    TextColor(Cyan);                { wait for keypress }
    Flash_Msg(29,22,48,22, LightCyan, White, '  ÄÄ More ÄÄ');
    TextColor(White);
    Window(x1,y1+5,x2,y2);    { go back to windows for list of files }
    TextBackground(Magenta);ClrScr;
end;
end;

Window(x1,y2-2,x2,y2);          { window for action message }
TextBackground(Magenta);ClrScr;
TextColor(Yellow);
GoToXY(2,1); Divider(73,196);
TextColor(Cyan);
Delay(DTIME*2);
Beep(1);
Flash_Msg(18,22,62,22, LightCyan, White,
' < Press any key to return to Main Menu >');
end; { Dir }

{ *****
*          ABOUT PROCEDURE          *
***** }

procedure About;
{ This procedure displays information about the authors of the program }
begin { About }
    Wipe_Up(14,5,66,21, LightCyan);
    Win_Box(14,5,66,21, LightCyan, ' [p]          About');
    TextColor(Black); WriteLn;
    WriteLn('          Load Shedding Software');
    WriteLn;
    WriteLn('          Version ', VER);
    WriteLn;
    WriteLn('          Copyright (c) 1996 by');
    WriteLn;
    WriteLn('          p',GROUP, 'p');
    WriteLn;
    Divider(51, 196);
    TextColor(Blue);
    TextColor(Black); Divider(51, 196);
    TextColor(Green);
    Flash_Msg(21,20,59,20, Green, White,
'          < Press any key to continue >');
end; { About }

Procedure LS_Help;
{ This procedure displays help information about the program }
begin { BSC_Help }
    Wipe_Up(14,5,66,21, LightGreen);
    Win_Box(14,5,66,21, LightGreen, ' [p]          Help');
    Window(15,7,65,20);
    TextColor(Black);
    WriteLn;
    WriteLn('- To specify CAPACITY OF LOADS choose 1 and enter');
    WriteLn(' Number & Capacity of Loads. ');
    WriteLn('- To specify MAXIMUM DEMAND choose 2 and enter');

```

```

WriteLn(' Maximum Demand for the 3 hrs at given times. ');
WriteLn('- To specify FUEL INPUT RATES choose 3 and enter ');
WriteLn('- To view LOAD SHEDDING PROCEDURE choose 4 and ');
WriteLn(' enter. ');
WriteLn('- To see about HELP SCREEN choose 5. ');
WriteLn('- To QUIT or SHELL to dos choose 6. ');
Flash_Msg(21,20,59,20, LightCyan, White, '      < Press any key > ');
end; { BSC_Help }

```

```

{*****
*          DOS_SHELL PROCEDURE          *
*****}

```

```

procedure Dos_Shell;
{$M 8192,0,0}           { 8 kbytes OF stack }
{ execute dos command without quitting program }
var
  Command: ComStr;
  s: DirStr;
begin
  Wipe_Up(1,1,80,25, Black);
  TextColor(LightRed); WriteLn('°±² Shelled to DOS ±°°');
  SwapVectors;
  Exec(GetEnv('COMSPEC'), '/C' + 'ver');      { display DOS version }
  SwapVectors;
  TextColor(LightGray);
  repeat
    GetDir(0,s);           { get current directory }
    Write('Type ');
    TextColor(White); Write('"exit" ');
    TextColor(LightGray); WriteLn('to return to Main Menu... ');
    Write(s,> ');          { prompt with directory name ie. $p$g }
    ReadLn(Command);       { read user command }
    if Command <> 'exit' then
      begin
        Command := '/C ' + Command;
        SwapVectors;
        Exec(GetEnv('COMSPEC'), Command);    { execute DOS command }
        SwapVectors;
        if DosError <> 0 then
          WriteLn('Could not execute COMMAND.COM');
        end;
        WriteLn;
      until command = 'exit';      { go back to program }
  End; { Dos_Shell }

```

```

procedure Goodbye;
{ This procedure quits the program and returns to the operating system }
var
  Color: Byte;
  i: Integer;
begin { Goodbye }
  Wipe_Up(1,1,80,25, Black);
  TextMode(CO80);           { sets text mode to normal }
  ClrScr;
  for i:= 1 to 8 do
    begin
      if (i = 1) or (i = 8) then Color:= Black;
      if (i = 2) or (i = 7) then Color:= DarkGray;
    
```

```

if (i = 3) or (i = 6) then Color:= LightGray;
if (i = 4) or (i = 5) then Color:= White;
TextColor(Color);
GoToXY(25,11); WriteLn('Thanks for using  LOAD SHEDDING Software ');
GoToXY(30,12); WriteLn('of ',GROUP);
GoToXY(32,13); WriteLn('Copyright (C) 1996');
if Color = White then Delay(2500)
else Delay(500);
end;
Halt;                                { stop program }
end; { Goodbye }

```

```

{*****
*           QUIT PROCEDURE           *
*****}

```

#### **procedure Quit;**

```

{ This procedure verifies the user for choosing Quit in the main menu }
var Answer: Char;
begin { Quit }
  Wipe_Up(10,16,70,19,Red);
  Win_Box(10,16,70,19,Red,' [p]           Quit');
  TextColor(Yellow);
  GoToXY(6,2); Write('Do you want to quit or');
  GoToXY(42,2); Write('[');
  GoToXY(43,2); Write('y');
  GoToXY(44,2); Write('/');
  GoToXY(45,2); Write('n');
  GoToXY(46,2); Write('/');
  GoToXY(48,2); Write(']?:');
  TextColor(LightGreen);
  GoToXY(29,2); Write('shell to DOS');
  GoToXY(47,2); Write('d');
  TextColor(White);

  Window(61,18,63,18);
  TextBackground(Cyan); ClrScr;
  Beep(3);
  repeat
    Answer:= UpCase(Readkey);      { Read user's keyboard response }
    if Answer = 'Y' then           { if yes then quit program }
      Goodbye
    else if Answer = 'D' then       { if dos shell then shell out }
      begin
        TextColor(LightGray);
        Dos_Shell
      end
    else if Answer IN ['N',ESC] then { if no then return to main menu }
      Beep(2)
    else
      Beep(0);
  until Answer IN ['Y','N','D',ESC]; { repeat until valid key }
end; { Quit }

```

#### **procedure Desktop;**

```

{ This procedure displays the background desktop and the top and bottom bars }
var
  count: Integer;

```

```

begin { Desktop }
  { Background pattern }
  Window(1,1,80,25);
  TextBackground(LightGray);
  TextColor(Blue);
  GoToXY(1,2);
  for count:= 1 to 1840 do
    Write(Chr(176));
  { Top Bar }
  Window(1,1,80,1);
  TextBackground(LightGray); ClrScr;
  TextColor(Black);
  GoToXY(2,1); Write('[p]');
  GoToXY(21,1); Write('Load Shedding Software');
  TextColor(DarkGray);
  GotoXy(44,1); Write('[Version ', VER, ']');
  { Bottom Bar }
  Window(1,25,80,25); ClrScr;
  TextColor(DarkGray);
  GoToXY(2,1); Write('Copyright (c) 1996');
  TextColor(Red);
  GoToXY(61,2); Write('p ',GROUP, ' Software p');
end; { Desktop }

```

#### **procedure Main\_Menu;**

{ This procedure displays the main menu of the program }

```

begin { Main_Menu }
  Win_Box(14,3,66,13,Blue, ' [p]          Main Menu');
  TextColor(LightGray);
  GoToXY(4,2); Write('[ ] apacity of Loads');
  GoToXY(4,4); Write('[ ] aximum Load Demand');
  GoToXY(4,6); Write('[ ] uel input rates');
  GoToXY(29,2); Write('[ ] iew Load Shedding');
  GoToXY(29,4); Write('[ ] elp/About');
  GoToXY(29,6); Write('[ ] uit/DOS shell');
  TextColor(White);
  GoToXY(5,2); Write('1'); GoToXY(9,2); Write('C');
  GoToXY(5,4); Write('2'); GoToXY(9,4); Write('M');
  GoToXY(5,6); Write('3'); GoToXY(9,6); Write('F');
  GoToXY(30,2); Write('4'); GoToXY(34,2); Write('V');
  GoToXY(30,4); Write('5'); GoToXY(34,4); Write('H');
  GoToXY(30,6); Write('6'); GoToXY(34,6); Write('Q');
  GoToXY(2,8); Divider(49, 196);
  GoToXY(18,9); Write('Selection: ');
  Window(42,12,44,12); TextBackground(Cyan); ClrScr;
end; { Main_Menu }

```

#### **Procedure SelectCapacity ( Var ct:Arr1; Var TotShed: real;**

**Var NumL:integer; Var writefile:text);**

Var x1, y1, x2, y2, k :integer;

ch:char;

begin

x1:=2; y1:=2; x2:=78; y2:=23; { Init\_Tx window coordinates }

Wipe\_Up(x1,y1,x2,y2, Magenta);

Win\_Box(x1,y1,x2,y2, LightRed{Magenta},

' [p] Selection of Load Capacity');

```

Repeat
  Window(3,3,65,6);
  TextBackground(Red); ClrScr;
  TextColor(White);
  Gotoxy(1,1); Writeln('Enter number of loads available for shedding ');
  Gotoxy(1,3); Write('Total Loads = '); Read(numL);
  if numL in ([1..75]) then
    else
      Beep(0);
Until (numL>0) and (numL<=75);

```

```

for k:=1 to 75 do
  ct[k]:=0;

```

```

Assign(writefile,'Loads.dat ');
rewrite(writefile);

```

```

For I:=1 to numL do
begin
  Repeat
    Window(3,7,65,10);
    TextBackground(Red); ClrScr;
    TextColor(White);
    Gotoxy(3,8);
    Writeln('Enter Load in MWs (Ascending Order) ');
    Gotoxy(3,9);
    Write('Circuit['I,'] = '); Read(ct[I]);

    if trunc(ct[I]) in ([0..250]) then
      begin
        TotShed:=TotShed + ct[I]
      end
    else
      Beep(0);

```

```

  Until (ct[I]>=0) and (ct[I]<=250);
  write(writefile,ct[I],');
end;
write(writefile,1000);

```

```

  TextColor(Green);
  Flash_Msg(18,22,62,22, Green, White,
    ' < Press any key to return to Main Menu >');
close(writefile);
end;

```

```

Procedure ReadFile(Var TotShed:real; Var ct:Arr1; Var NumL:integer;
  Var infile:text; Var writefile:text);
begin
  Assign(infile,'Loads.dat ');
  reset(infile);

```

```

I:=1;
Repeat
  read(infile,re);

  if (re<>1000) then
    begin
      Ct[I]:= re;
      TotShed:= TotShed + Ct[I];
      I:= I + 1;
    end;

  Until (re=1000);
  numL:=I-1;
close(infile);
end;

```

```

Procedure OpenShedfile(Var shedfile:text);
begin
  Assign(shedfile,'shed.dat ');
  rewrite(shedfile);
end;

```

```

Procedure InitShed(Var NoShed:Arr11; numL:integer);
var K:integer;
begin
  for K:=1 to numL do
    NoShed[K]:=0;
  Writeln;
end;

```

```

Procedure InitCancelShed(CancelShed:setup; numL:integer);
var K:integer;
begin
  for K:=1 to numL do
    CancelShed[K]:=False;;
  Writeln;
end;

```

```

Procedure InitTaken(var Taken:setup; numL:integer);
var K:integer;
begin
  for K:=1 to numL do
    Taken[K]:=False;
  Writeln;
end;

```

```

Procedure InitdisplayArrays(numL:integer);
Var I,J:integer;
begin
  for I:=1 to numL do
    begin

```

```

    Sarray[I]:=0;
    Rarray[I]:=0;
end;

for J:=1 to 12 do
begin
    SSarray[J]:=0;
    NoASarray[J]:=0;
end;

end;

```

#### **Procedure MenuTotShedReq;**

```

begin
    Writeln('Do you wish to enter Shed Requirement Y/N ');
    Readln(choiceS);
    choiceS:=Ucase(choiceS);
end;

```

#### **Procedure EnterTotShedReq;**

```

Var I:integer;
begin
    For I:=1 to 12 do
    begin
        Clrscr;
        Writeln('Enter Shed Requirements in whole kW');
        Gotoxy(6,10);Write('Req[' ,I*15,'min] = '); Read(Req[I]);
    end;
end;

```

#### **Procedure LoadDemand(Var LDem:Arr2);**

```

Var x1, y1, x2, y2 : integer;
begin
    x1:=2; y1:=2; x2:=78; y2:=23;      { Init_Tx window coordinates }

    Wipe_Up(x1,y1,x2,y2, Magenta);
    Win_Box(x1,y1,x2,y2, LightBlue{Magenta},
        ' [p]           Maximum Demand Profile ');
    For I:=1 to 12 do
    begin
        Repeat
            Window(3,3,65,6);
            TextBackground(Blue); ClrScr;
            TextColor(White);
            Gotoxy(1,1);
            Writeln('Enter Maximum Load Demand in MWs ');
            Gotoxy(1,3);

            Write('Maximum Load Demand [' ,I*15,'min] = '); Read(LDem[I]);

            if Trunc(LDem[I]) in ([0..250]) then
            else
                Beep(0);

```

```

Until (LDem[I]>=0) and (LDem[I]<=250)
end;
  TextColor(Green);
  Flash_Msg(18,22,62,22, Green, White,
  ' < Press any key to return to Main Menu >');

end;

Procedure TotShedReq(Var LDem,Gen,Fuel,Heat,Gloc,Pim,Pex,Req:Arr2);
var L:integer;
  x1, y1, x2, y2:integer;
  ch:char;
  Pg:real;

begin
  x1:=2; y1:=2; x2:=78; y2:=23;      { Init_Tx window coordinates }
  Wipe_Up(x1,y1,x2,y2, Magenta);
  Win_Box(x1,y1,x2,y2, White{Magenta},
  ' [b]      Fuel Input Rates');
  Repeat
    Window(3,3,65,6);
    TextBackground(White); ClrScr;
    TextColor(Black);
    Gotoxy(1,1);
    Writeln('Enter Maximum Capacity of CoGenerator (MWs) '); Readln(Gcap);
    if trunc(Gcap) in ([0..250]) then
      else
        Beep(0);
    Until (Gcap>=0) and (Gcap<=250);

    Repeat
      Window(3,3,65,6);
      TextBackground(White); ClrScr;
      TextColor(Black);
      Gotoxy(1,1);
      Writeln('For the Cogeneration relationship between');
      Writeln('HEAT RATE and RATED POWER GENERATION: ');
      Writeln('Hi = (a/Pg) + b + c*Pg - Enter value of coefficient a');
      Writeln('for the given Cogenerator. ');
      Readln(a);
      if trunc(a) in ([0..250]) then
        else
          Beep(0);
        Until (a>=0) and (a<=500);

      Repeat
        Window(3,3,65,6);
        TextBackground(White); ClrScr;
        TextColor(Black);
        Gotoxy(1,1);
        Writeln('For the Cogeneration relationship between');
        Writeln('HEAT RATE and RATED POWER GENERATION: ');
        Writeln('Hi = (a/Pg) + b + c*Pg - Enter value of coefficient b');
        Writeln('for the given Cogenerator. ');
        Readln(b);
        if trunc(b) in ([0..250]) then

```

```

else
  Beep(0);
Until (b>=0) and (b<=250);

Repeat
  Window(3,3,65,6);
  TextBackground(White); ClrScr;
  TextColor(Black);
  Gotoxy(1,1);
  Writeln('For the Cogeneration relationship between');
  Writeln('HEAT RATE and RATED POWER GENERATION: ');
  Writeln('Hi = (a/Pg) + b + c*Pg - Enter value of coefficient c');
  Writeln('for the given Cogenerator. ');
  Readln(c);
if trunc(c) in ([0..250]) then
  else
    Beep(0);
Until (c>=0) and (c<=250);

```

```

For I:=1 to 12 do
begin
  Repeat
    Window(3,3,65,6);
    TextBackground(Blue); ClrScr;
    TextColor(White);
    Gotoxy(1,1);
    Writeln('Enter Fuel Input Rate in Mkal/h ');
    Gotoxy(1,3);
    Write('Fuel Input Rate [',I*15,'min] = '); Read(Fuel[I]);
    if ( Round(Fuel[I])>=0) and (Round(Fuel[I])<=2000 ) ) then
      else
        Beep(0);
Until (Fuel[I]>=0) and (Fuel[I]<=2000);

```

```

Repeat
  Window(3,3,65,6);
  TextBackground(Blue); ClrScr;
  TextColor(White);
  Gotoxy(1,1);
  Writeln('Enter Imported Power in MW ');
  Gotoxy(1,3);
  Write('Power Imports [',I*15,'min] = '); Read(Pim[I]);
  if Trunc(Pim[I]) in ([0..250]) then
    else
      Beep(0);
Until (Pim[I]>=0) and (Pim[I]<=250);

```

```

Repeat
  Window(3,3,65,6);
  TextBackground(Blue); ClrScr;
  TextColor(White);
  Gotoxy(1,1);
  Writeln('Enter Exported Power in MW ');
  Gotoxy(1,3);
  Write('Power Exports [',I*15,'min] = '); Read(Pex[I]);
  if Trunc(Pex[I]) in ([0..250]) then
    else
      Beep(0);

```

```

Until (Pex[I]>=0) and (Pex[I]<=250);

Pg:= -b/(2*c)  + sqrt ( sqr(b) - 4*c* (a - Fuel[I] ) ) / (2*c);

Gloc[I] := Pg * Gcap / 100;

Heat[I] := Fuel[I] / Pg;

Gen[I]:= (Pg* Gcap/100) + Pim[I] - Pex[I];

Req[I]:= LDem[I] - Gen[I];

end;{for}
  TextColor(Green);
  Flash_Msg(18,22,62,22, Green, White,
    ' < Press any key to return to Main Menu >');
end;

```

### **Procedure displayCt;**

```

var J:integer;
begin
  For J:=1 to numL do
    Write('Ct['J,']=',Ct[J],'kw ');
  Writeln;
  Writeln;
end;

```

### **Procedure displayReq;**

```

var L:integer;
begin
  For L:=1 to 12 do
    Write('Req['L*15,'min]=' ,Req[L],'Kw          ');
  Writeln;
  Writeln;
end;

```

### **Procedure displayShed(slot:integer);**

```

var J:integer;
begin

  Writeln(' Time = ',slot * 15:3,' minutes ');
  For J:=1 to numL do
    Write('NoShed['J,']=',NoShed[J],'  ');
  Writeln;
  Writeln;
end;

```

### **Procedure displayAllShed(slot:integer);**

```

var J:integer;
begin

  Writeln(' All cicuits Shed ');
  Writeln(' Time = ',slot * 15:3,' minutes ');
  For J:=1 to numL do

```

```

    Write('NoShed['J,']=',NoShed[J], ' ');
Writeln;
Writeln;
end;

```

**Procedure PerformShedding( Var NoShed:Arr11; Var Taken:setup;**

```

    Var Cancelshed:setup; Var ct:Arr1;
    Var Req:Arr2; Var slot:integer; Var Unshedsz:real;
    Var Allshed:boolean; Var TotShed:real;
    Var SS:real; Var shedfile:text;
    Var Sarray:Arr11; Var Rarray:Arr11;
    Var SSarray:Arr2; Var NoASarray:Arr12;
    Var NoAllShed:integer; Var NumL:integer);

```

```

var Size,Sheddiff:real;
    I,J,K,P:integer;
    done,Nomore:boolean;
    count,T,S,oldslot:integer;

```

begin

```

    if oldslot <> slot then
    begin
        writeln(shedfile);
        for I:=1 to numL do
            Cancelshed[I]:=False;
    end;

```

```

Size:= Req[slot];
oldslot:= slot;
Writeln(' For a shed requirement of = ',size:4,' MW ');
I:=0;
shedDiff:=0;
Nomore:=False;
Complete:=False;

```

Repeat

```

I:=I+1;
if (Unshedsz > size) and (Unshedsz > 0) and (size > 0) then
begin

```

```

    if Taken[I]=False then
        shedDiff:=size-ct[I]
    else if Taken[I+1]=False then
        shedDiff:=size-ct[I+1]
    else if Taken[I+2]=False then
        shedDiff:=size-ct[I+2]
    else if ( ( abs(size-ct[I])<= abs(size-ct[I+1])) and
        ( abs(size-ct[I])<= abs(size-ct[I+2])) ) then
        shedDiff:=size-ct[I]
    else if ( ( abs(size-ct[I+1])<= abs(size-ct[I] )) and
        ( abs(size-ct[I+1])<= abs(size-ct[I+2])) ) then
        shedDiff:=size-ct[I+1]
    else if ( ( abs(size-ct[I+2])<= abs(size-ct[I] )) and
        ( abs(size-ct[I+2])<= abs(size-ct[I+1])) ) then
        shedDiff:=size-ct[I+2];

```

```

    count:=I; done:=False;
    for J:=1 to numL do
    begin

```

```

    if ( (size-ct[J] <= shedDiff) and (size>=ct[J]) and
        (Taken[J]=false) ) then
        begin
            done:=True;
            shedDiff:= size-ct[J];
            count:=J
            end;

    if ( ( abs(size-ct[J]) <= abs(shedDiff) ) and
        (done=False) and (Taken[J]=false) ) then
        begin
            shedDiff:= size-ct[J];
            count:=J
            end

    end;

if ( Cancelshed[count]=False ) then begin
    Unshedsz:= Unshedsz - ct[count];
    SS:=SS + ct[count];
    NoShed[count]:= NoShed[count] + 1;
    Cancelshed[count]:=True;
    Taken[count]:=True;
    Allshed:=False;
    toss:=toss + 1;
    write(shedfile,count,' ');
end;

    if ( ShedDiff > 1 ) then begin
        Complete:=False;
        size:= shedDiff
        end
    else if ( Sheddifff = 1 ) then begin
        Complete:=True;
        size:= shedDiff
        end
    else if (Sheddifff < 1 ) then begin
        Complete:=True;
        size:=0;
        end;
end{ if (Unshedsz>size) and (Unshedsz>0) and (size>0) then }

else if ( Unshedsz=size ) and ( Unshedsz > 0 ) and (size>0) then
    begin
For P:= 1 to numL do
    begin

        if (Taken[P]=False) and (CancelShed[P]=False) then
            begin
                Noshed[p]:= Noshed[p] + 1;
                Taken[P]:=True;
                Cancelshed[P]:=True;
                SS:=SS + ct[p];
                write(shedfile,p,' ');
                size:= size - ct[p];
            end

    end;
end;

```

```

    complete:=True;
    Allshed:=True;
end
else if ( Unshedsz < size) and ( Unshedsz > 0 ) and (size>0) then
begin
    For P:= 1 to numL do
        begin
            if (Taken[P]=False) and (CancelShed[P]=False) then
                begin
                    Noshed[p]:= Noshed[p] + 1;
                    Taken[P]:=True;
                    Cancelshed[p]:=True;
                    SS:=SS + ct[p];
                    write(shedfile,p,' ');
                end
            end;
            size:= size - Unshedsz;
            Complete:= False;
            UnshedSz:=TotShed;
            Allshed:=True;
        end
    else if (size=0) then
        begin
            Complete:=True;
        end;

    if (AllShed=True) then
        begin
            NoAllShed:= NoAllShed + 1;
            displayAllShed(slot);
            for T:=1 to numL do
                Taken[T]:=False;
            end;

            I:=0;
            Until Complete=True;

end;

```

```

Procedure determine( slot:integer; SS:real; NoAllShed:integer;
    Var SSarray:Arr2; Var NoASarray:ArrI2);
begin
    SSarray[slot]:=SS;
    NoASarray[slot]:=NoAllShed;
end;

```

```

Procedure Action( Var NoShed:ArrI1; Var Taken:setup;
    Var Cancelshed:setup; Var ct:Arr1;
    Var Req:Arr2; Var slot:integer; Var Unshedsz:real;
    Var Allshed:boolean; Var TotShed: real;
    Var SS: real; Var Shedfile:text;
    Var Sarray:ArrI1; Var Rarray:ArrI1;
    Var SSarray:Arr2; Var NoASarray:ArrI2;
    Var NoAllShed:integer; Var NumL:integer);

```

```

begin
OpenShedFile(Shedfile);
Repeat
PerformShedding(NoShed,Taken,Cancelshed,ct,Req,slot,Unshedsz,AllShed,
TotShed,SS,Shedfile,Sarray,Rarray,
SSarray,NoASarray,
NoAllShed,NumL);
if Complete=True then
begin
write(shedfile,999);
determine(Slot,SS,NoAllShed,SSarray,NoASarray);
SS:=0;
slot:=slot + 1;
end;
Until slot=13;
end;

```

**Procedure displayResults(slot:integer; Req:Arr2; SSarray:Arr2; NoASarray:Arr12;  
Var Sarray:Arr11; Var Rarray:Arr11; Var NumL:integer);**

```

var
int:integer;
chSlot,I,J,Y,K,count:integer;

```

```

Var x1, y1, x2, y2:integer;
ch:char;

```

```

begin
Assign(ShedRes,'shed.dat');
reset(ShedRes);

```

```

x1:=1; y1:=1; x2:=80; y2:=25;      { Init_Tx window coordinates }
Wipe_Up(x1,y1,x2,y2, LightCyan);
TextBackground(Cyan); ClrScr;
TextColor(Black);

```

```

Gotoxy(1,1); Write('T(min)');
Gotoxy(8,1); Write('REQ(MW)');
Gotoxy(16,1); Write('SHEDccts');
Gotoxy(41,1); Write('RESTccts');
Gotoxy(68,1); Write('SHED(MW)');
Gotoxy(77,1); Write('A/S');

```

```

(*****Begin of determining Shed Loads and Restored Loads *****)
for K:=1 to 12 do begin { 12 time slots}

```

```

for J:=1 to NumL do
Rarray[J]:=0;
if (K>=2) then begin
for I:=1 to numL do
Rarray[I]:= Sarray[I];
end;

```

```

for J:= 1 to NumL do
Sarray[J]:=0;

```

```

I:=0;
Repeat
read(ShedRes,int);
  if (int<>999) then
    begin
      I:=I + 1;
      Sarray[I]:=int;
    end
  else if int=999 then
    readln(ShedRes)
Until int=999;

```

```

if (K>=2) then begin
  For J:=1 to NumL do
    begin
      For I:=1 to NumL do
        begin
          if (Rarray[I] = Sarray[J]) then
            Rarray[I]:=0;
        end;
      end;
    end;
end;{if (K>=2) then begin }

```

(\*\*\*\*\*End of determining Shed Loads and Restored Loads \*\*\*\*\*)

(\*\* begin of display Tabular Results \*\*\*\*\*)

```

Y:= 2*K;
Gotoxy(1,Y); Write(K*15);
Gotoxy(8,Y); Write(Req[K]:3:1);
Gotoxy(16,Y); count:=0;
  For I:=1 to numL do begin
    if (Sarray[I]<>0) then begin
      count:=count + 1;
      Write(Sarray[I],' ');
    end;
    if (Sarray[I]<>0) and (count = 8) then
      Gotoxy(16,Y+1);
    end;

  Gotoxy(41,Y); count:=0;
  For I:=1 to numL do begin
    if (Rarray[I]<>0) then begin
      count:=count + 1;
      Write(Rarray[I],' ');
    end;
    if (Rarray[I]<>0) and (count = 8) then
      Gotoxy(41,Y+1);

  end;
  Gotoxy(68,Y); Write(SSarray[K]:3:1);
  Gotoxy(79,Y); Write(NoASarray[K]);

```

```

end; {for K:=1 to 12 do }
(** end of display Tabular Results *****)
close(ShedRes);
  TextColor(Green);
  Flash_Msg(18,22,62,22, Green, White,
  ' < Press any key to return to Main Menu >');
end;

```

**Procedure displayGen(slot:integer; Fuel, Heat, Gloc, Pex, Pim, Gen: Arr2);**

```

var
  int:integer;
  chSlot,I,J,Y,K,count:integer;

Var x1, y1, x2, y2:integer;
  ch:char;
begin
Assign(ShedRes,'shed.dat');
reset(ShedRes);

  x1:=1; y1:=1; x2:=80; y2:=25;      { Init_Tx window coordinates }
  Wipe_Up(x1,y1,x2,y2, LightCyan);
  (*Win_Box(x1,y1,x2,y2, LightRed{Magenta},
    '[p]          Load Shedding Procedure');
  Window(3,3,65,6);*)
  TextBackground(Cyan); ClrScr;
  TextColor(Black);

  Gotoxy(1,1); Write('T(min)');
  Gotoxy(8,1); Write('Fuel(MKCal/h)');
  Gotoxy(22,1); Write('Heat(MKCal/MWh)');
  Gotoxy(38,1); Write('Local Gen(MW)');
  Gotoxy(52,1); Write('NetImports(MW)');
  Gotoxy(67,1); Write('Total Gen(MW)');

(** begin of display Tabular Results *****)
For K:=1 to 12 do begin
  Y:= 2*K;
  Gotoxy(1,Y); Write(K*15);
  Gotoxy(12,Y); Write(Fuel[K]:3:1);
  Gotoxy(26,Y); Write(Heat[k]:3:1);
  Gotoxy(40,Y); Write(Gloc[k]:3:1);
  Gotoxy(55,Y); Write(Pim[K] - Pex[k]:3:1);
  Gotoxy(69,Y); Write(Gen[k]:3:1);

end; {for K:=1 to 12 do }
(** end of display Tabular Results *****)

```

```

close(ShedRes);
  TextColor(Green);
  Flash_Msg(18,22,62,22, Green, White,
  ' < Press any key to return to Main Menu >');
end;

```

```

procedure Usr_Int_Face( Var NoShed:Arr11; Var Taken:setup;
  Var Cancelshed:setup; Var ct:Arr1;
  Var LDem,Gen,Fuel,Heat,Gloc,Pim,Pex,Req:Arr2;

```

```

    Var slot:integer; Var Unshedsz: real;
    Var Allshed:boolean; Var TotShed: real;
    Var SS:real; Var Shedfile:text;
    Var Sarray:Arr11; Var Rarray:Arr11;
    Var SSarray:Arr2; Var NoASarray:Arr12;
    Var NoAllShed:integer; Var NumL: integer;
    Var writefile:text; Var infile:text);
{ This procedure reads the user's choice from the main menu and takes the
  necessary actions }
var
  Choice: Char;
begin { Usr_Int_Face }
  Desktop;
  Main_Menu;
  repeat                                { loop until valid choice }
    Choice:= UpCase(ReadKey);
    if Choice in ([ '1','C','2','M','3','F','4','V','5','H','6','Q']) then
    else
      Beep(0);
  until (Choice IN [ '1','C','2','M','3','F','4','V','5','H','6','Q']);
  case (Choice) of
    '1','C': begin                      { send a file }
      Highlight(16,5,40,5,[ ] apacity of Loads','1','C');
      Delay(DTIME*2);
      SelectCapacity(ct,TotShed,NumL,writefile);
      Unshedsz:=TotShed;
    end;
    '2','M': begin                      { receive a file }
      Highlight(16,7,40,7,[ ] ax Demand','2','M');
      Delay(DTIME*2);
      LoadDemand(Ldem);
    end;
    '3','F': begin                      { view a file }
      Highlight(16,9,40,9,[ ] uel Input Rates','3','F');
      Delay(DTIME*2);
      ReadFile(TotShed,ct,NumL,infile,writefile);
      Unshedsz:=TotShed;
      TotShedReq(LDem,Gen,Fuel,Heat,Gloc,Pim,Pex,Req);
      displayGen(slot,Fuel,Heat,Gloc,Pex,Pim,Gen);
    end;
    '4','V': begin
      Highlight(41,5,64,5,[ ] iew Load Shedding','4','V');
      Delay(DTIME*2);
      Action(NoShed,Taken,Cancelshed,ct,Req,
        slot,Unshedsz,Allshed,TotShed,SS,Shedfile,
        Sarray,Rarray,
        SSarray,NoASarray,
        NoAllShed,NumL);
      close(shedfile);
      displayResults(slot,Req,SSarray,NoASarray,Sarray,Rarray,NumL);

      NumL:=75;
      for P:=1 to 75 do
        begin
          ct[P]:=0;
          Sarray[P]:=0;
          Rarray[P]:=0;
        end;

```

```

for Q:=1 to 12 do
begin
  Req[Q]:=0;
  SSarray[Q]:=0;
  NoAsArray[Q]:=0;
end;

  OpenShedfile(Shedfile);
  InitShed(NoShed,NumL);
  InitTaken(Taken,NumL);
  InitCancelShed(Cancelshed,NumL);
  InitdisplayArrays(NumL);
  SS:=0;
  NoAllShed:=0;
  slot:=1;
  AllShed:=False;
  TotShed:=0;
  Unshedsz:= TotShed;
end;
'S','H': begin           { show about & help info }
  Highlight(41,7,64,7,[' ] elp/About','S','H');
  Delay(DTIME*2);
  About;
  LS_Help;
end;
'G','Q': begin           { quit or shell to dos? }
  Highlight(41,9,64,9,[' ] uit/DOS shell','G','Q');
  Delay(DTIME*2);
  Quit;
end;
end; {case}
Ushr_Int_Face( NoShed,Taken,Cancelshed,ct,LDem,Gen,Fuel,Heat,Gloc,Pim,Pex,Req,
  slot,Unshedsz,Allshed,TotShed,SS,Shedfile,
  Sarray,Rarray,
  SSarray,NoASarray,
  NoAllShed, NumL, writefile, infile);
end; { Ushr_Int_Face }

{*****
*           MAIN PROGRAM           *
*****}

begin { Main }

  NumL:=75;

  for P:=1 to 75 do
  begin
    ct[P]:=0;
    Sarray[P]:=0;
    Rarray[P]:=0;
  end;

  for Q:=1 to 12 do
  begin
    Req[Q]:=0;

```

```

SSarray[Q]:=0;
NoAsArray[Q]:=0;
end;

OpenShedfile(Shedfile);
InitShed(NoShed,NumL);
InitTaken(Taken,NumL);
InitCancelShed(Cancelshed,NumL);
InitdisplayArrays(NumL);
SS:=0;
NoAllShed:=0;
slot:=1;
AllShed:=False;
TotShed:=0;
Unshedsz:= TotShed;

ClrScr;
Desktop;                                { display background }
Delay(DTIME*3);
About;                                  { display about info }
Desktop;
Wipe_Up(14,3,66,13,Blue);
Main_Menu;                              { display main menu }
Usr_Int_Face( NoShed,Taken,Cancelshed,ct,LDem,Gen,Fuel,Heat,Gloc,
              Pim,Pex,Req,slot,Unshedsz,Allshed,TotShed,SS,Shedfile,
              Sarray,Rarray,
              SSarray,NoASarray,
              NoAllShed,NumL,writefile,infile);
end. { Main }

{*****
*               END OF PROGRAM               *
*****}

```

Appendix B Victorian Cogeneration Plant Register

ST = Steam Turbine  
GT = Gas Turbine  
CCGT = Combined  
Cycle Gas Turb  
RCP = Reciprocating  
Gas Engine

Information as at 12/01/97

HOST	LOCATION	OWNER (IF DIFFERENT FROM HOST)	INDUSTRY	TYPE	CONFIGURATION	SIZE (MW)	YEAR COMMISSIONED	PRIMARY FUEL	HEAT USE
VICTORIA									
Alfred Hospital	Melbourne	National Mutual	Health	GT	1 x 6.0	6.00	1994	Natural Gas	Air Conditioning/Hospital Needs
Ancor Paper	Fairfield		Paper	ST	1 x 10.0	10.00	1987	Natural Gas	Paper Processing
Ancor Paper	Maryvale		Paper	ST	2 x 12.5	25.00	1978-1989	Natural Gas	Paper Processing
Ann Caudle Centre	Bendigo	National Mutual	Health	GT	1 x 8.0	8.00	1994	Natural Gas	Air Conditioning/Hospital Needs
Austin Repat Medical Centre	Fredriksberg		Health	GT	1 x 3.8	3.80	1991	Natural Gas	Air Conditioning/Hospital Needs
Ulterior Base Hospital	Dallalati		Health	RCP	2 x 1.0	2.00	1992	Natural Gas	Air Conditioning/Hospital Needs
Capital Australasia	Altona		Chemical	ST	1 x 13.0	13.00	1990	Waste Gas	Process Heating
Cadbury Schweppes	Altona	National Mutual	Food	ST	1 x 2.0	2.00	1988	Natural Gas	Food Processing
Charles JFE Pty Ltd	Dallalati		Food	RCP	4 x 0.015, 1 x 0.13	0.19	1990	Waste Gas	Process Heating
Crown Casino	Melbourne		Building	RCP	6 x 0.925	5.55	1997	Natural Gas	Heating
Dandenong Hospital	Dandenong	National Mutual	Health	GT	1 x 6.0	6.00	1994	Natural Gas	Air Conditioning/Hospital Needs
Donvale Hospital	Donvale		Health	RCP	1 x 0.03	0.03	1996	Natural Gas	Heating
Echuca Hospital	Echuca		Health	RCP	1 x 0.681	0.68	1996	Natural Gas	Hot Water/Preheat Boiler
Energy Brix	Morewell		Briquette	ST	3 x 30.0, 1 x 20.0	110.00	1955	Coal	Coal Drying
Esso-BHP	Longford		Oil and Gas	GT	2 x 8.0	16.00	1992	Natural Gas	Process Heating
Flicka Fabrics Pty Ltd	Sunshine		Misc Manufact	RCP	1 x 0.03	0.03	1992	Natural Gas	Drying Process
Geelong Hospital	Geelong	National Mutual	Health	GT	1 x 6.0	6.00	1994	Natural Gas	Air Conditioning/Hospital Needs
Grace McKellar Centre	North Geelong		Health	RCP	2 x 1.0	2.00	1994	Natural Gas	Hot Water/Hospital Needs
Honiculture	Berwick	Energy Developments Ltd	Horticultural	RCP	5 x 1.0	5.00	1992	Landfill Gas	Heating for Greenhouse
Kodak Australia	Coburg		Chemical	ST	1 x 1.2, 1 x 0.5	1.70	1980	Natural Gas	Process Heating
Kyabram Hospital	Kyabram		Health	RCP	1 x 0.485	0.49	1992	Natural Gas	Hot Water/Heating
Larode University	Dundooa		Education	GT	1 x 6.0	6.00	1987	Natural Gas	Hot Water
Melbourne Water	Currim Downs		Water	RCP	5 x 1.5	7.50	1971	Waste Gas	Plant Heating
Alti Park Aquatic Centre	Epping		Recreation	RCP	1 x 0.104	0.10	1996	Landfill Gas	Pool/Space/Hot Water
Preston & Northcote Community Hosp	Preston		Health	RCP	1 x 0.2	0.20	1989	Coal	Hot Water/Space Heating/Sterilisation
Ringwood Aquatic Centre	Ringwood	National Mutual	Recreation	RCP	1 x 0.12	0.12	1992	Natural Gas	Pool/Space/Hot Water
Royal Melbourne Hospital	Melbourne		Health	GT	2 x 6.0	12.00	1994	Natural Gas	Air Conditioning/Steam etc for Hospital
Sandringham District & Memorial Hosp	Sandringham		Health	RCP	1 x 0.125	0.13	1991	Natural Gas	Hot Water/Heating
Shell Refining	Corio	National Mutual	Oil Refining	ST	1 x 4.5, 1 x 5.0, 1 x 51.0, 1 x 25.0	85.50	1968-1992	Waste Gas	Refinery Process
St Vincent's Hospital	Melbourne	Cogenco	Health	GT	1 x 6.0	6.00	1994	Natural Gas	Air Conditioning/Steam etc for Hospital
Unichema	South Melbourne		Misc. Manuf.	GT	2 x 5.5	11.00	1994	Natural Gas	Food Processing
Total						350.00			

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