

University of Southern Queensland
Faculty of Engineering and Surveying

IMPACT OF DEMAND-SIDE MANAGEMENT ON SUBSTATIONS

A dissertation submitted by

David Thomas Chalmer GRAY

in fulfilment of the requirements of

Course ENG4111/ENG4112 Project

towards the degree of

Bachelor of Engineering (Electrical and Electronic)

Submitted: October 2004.

Table of Content

Abstract	1
Certification	3
Acknowledgments	4
Nomenclature	5
Glossary	6
1. Background	9
1.1 Introduction.....	9
1.2 What is Demand-Side Management.....	10
1.3 Project Justification.....	11
1.4 Project Aims.....	11
1.5 Understanding of Demand-Side Management Impact	11
1.6 Possible Impacts of Change	12
2. Demand-Side Management Systems	14
2.1 Control Theory.....	14
2.1.1 <i>Introduction to Load Control Theory</i>	14
2.1.2 <i>Type of Load Control Used</i>	15
2.1.3 <i>ABB Master Station LCM-500 (Load Control Master 500)</i>	15
2.2 Theory of Tariff Arrangements	16
2.2.1 <i>Introduction of Tariff Arrangements</i>	16
2.2.2 <i>The Application of Tariff Switching</i>	16
2.3 Other Forms of Load Control/ Demand-Side Management	17
2.3.1 <i>Other forms of Load Control</i>	17
2.3.2 <i>Power Factor Correction</i>	17
2.3.3 <i>Voltage Reduction</i>	18
2.3.4 <i>Frequency Reduction</i>	19
2.3.5 <i>Private Generation</i>	19
2.4 Relevant Standards.....	20
2.5 Relevant Codes	20
2.6 Technical References	21
3. Project Methodology	23
3.1 Methodology Introduction	23
3.2 Preliminary Tasks	23
3.2.1 <i>Technical Research</i>	23
3.2.2 <i>Choice of Substations</i>	23
3.2.3 <i>Gathering and Analysis of Substation Data</i>	24

3.2.4	<i>Determination of Tariff Switching Times</i>	24
3.3	Report.....	24
3.3.1	<i>Data</i>	24
3.3.2	<i>Analysis Dates</i>	25
3.3.3	<i>Analysis</i>	25
3.3.4	<i>Conclusions</i>	25
4.	Data Analysis and Results	27
4.1	Introduction.....	27
4.2	Nemmco Load Profiles	28
4.2.1	<i>Discussion on Figure 6 and Figure 7</i>	28
4.3	Substation Number 1	29
4.3.1	<i>Substation Number 1 Configuration</i>	29
4.3.2	<i>Load growth for Substation Number 1</i>	29
4.3.3	<i>Substation Number 1 Transformer Load Summary</i>	30
4.3.4	<i>Substation 1 Transformer Summary</i>	30
4.3.5	<i>Substation Number 1 Example of Domestic Feeder</i>	31
4.3.6	<i>Substation 1 Domestic Feeder Summary</i>	31
4.3.7	<i>Substation Number 1 Example of Industrial Feeder</i>	32
4.3.8	<i>Substation 1 Industrial Feeder Summary</i>	32
4.4	Substation Number 2 Data	33
4.4.1	<i>Substation Number 2 Configuration</i>	33
4.4.2	<i>Load growth for Substation Number 2</i>	33
4.4.3	<i>Substation Number 2 Transformer Load Summary</i>	34
4.4.4	<i>Substation 2 Transformer Summary</i>	34
4.4.5	<i>Substation Number 2 Example of Domestic Feeder</i>	35
4.4.6	<i>Substation 2 Domestic Feeder Summary</i>	35
4.4.7	<i>Substation Number 2 Example of Industrial Feeder</i>	36
4.4.8	<i>Substation 2 Industrial Feeder Summary</i>	36
4.5	Substation Number 3 Data	37
4.5.1	<i>Substation Number 3 Configuration</i>	37
4.5.2	<i>Load growth for Substation Number 3</i>	37
4.5.3	<i>Substation Number 3 Transformer Load Summary</i>	38
4.5.4	<i>Substation 3 Transformer Summary</i>	38
4.5.5	<i>Substation Number 3 Example of Domestic Feeder</i>	39
4.5.6	<i>Substation 3 Domestic Feeder Summary</i>	39
4.5.7	<i>Substation Number 3 Example of Industrial Feeder</i>	40
4.5.8	<i>Substation 3 Industrial Feeder Summary</i>	40
4.6	Substation Number 4 Data	41
4.6.1	<i>Substation Number 4 Configuration</i>	41
4.6.2	<i>Load growth for Substation Number 4</i>	41
4.6.3	<i>Substation Number 4 Transformer Load Summary</i>	42

4.6.4	<i>Substation 4 Transformer Summary</i>	42
4.6.5	<i>Substation Number 4 Example of Domestic Feeder</i>	43
4.6.6	<i>Substation 4 Domestic Feeder Summary</i>	43
4.6.7	<i>Substation Number 4 Example of Industrial Feeder</i>	44
4.6.8	<i>Substation 4 Industrial Feeder Summary</i>	44
4.7	<i>Substation Number 5 Data</i>	45
4.7.1	<i>Substation Number 5 Configuration</i>	45
4.7.2	<i>Load growth for Substation Number 5</i>	45
4.7.3	<i>Substation Number 5 Transformer Load Summary</i>	46
4.7.4	<i>Substation 5 Transformer Summary</i>	46
4.7.5	<i>Substation Number 5 Example of Domestic Feeder</i>	47
4.7.6	<i>Substation 5 Domestic Feeder Summary</i>	47
4.7.7	<i>Substation Number 5 Example of Industrial Feeder</i>	48
4.7.8	<i>Substation 5 Industrial Feeder Summary</i>	48
4.8	<i>Substation Number 6 Data</i>	49
4.8.1	<i>Substation Number 6 Configuration</i>	49
4.8.2	<i>Load growth for Substation Number 6</i>	49
4.8.3	<i>Substation Number 6 Transformer Load Summary</i>	50
4.8.4	<i>Substation 6 Transformer Summary</i>	50
4.8.5	<i>Substation Number 6 Example of Domestic Feeder</i>	51
4.8.6	<i>Substation 6 Domestic Feeder Summary</i>	51
4.8.7	<i>Substation Number 6 Example of Industrial Feeder</i>	52
4.8.8	<i>Substation 6 Industrial Feeder Summary</i>	52
4.9	<i>Substation Number 7 Data</i>	53
4.9.1	<i>Substation Number 7 Configuration</i>	53
4.9.2	<i>Load growth for Substation Number 7</i>	53
4.9.3	<i>Substation Number 7 Transformer Load Summary</i>	54
4.9.4	<i>Substation 7 Transformer Summary</i>	54
4.9.5	<i>Substation Number 7 Example of Domestic Feeder</i>	55
4.9.6	<i>Substation 7 Domestic Feeder Summary</i>	55
4.9.7	<i>Substation Number 7 Example of Industrial Feeder</i>	56
4.9.8	<i>Substation 7 Industrial Feeder Summary</i>	56
4.9.9	<i>Substation Number 7 Example of Capacitor Bank Operation</i>	57
4.9.10	<i>Substation 7 Capacitor Bank Summary</i>	57
4.10	<i>Substation Number 8 Data</i>	58
4.10.1	<i>Substation Number 8 Configuration</i>	58
4.10.2	<i>Substation Number 8 Transformer Load Summary</i>	59
4.10.3	<i>Substation 8 Transformer Summary</i>	59
4.10.4	<i>Substation Number 8 Example of Feeder</i>	60
4.10.5	<i>Substation 8 Feeder Summary</i>	60
4.11	<i>Substation Number 9 Data</i>	61

4.11.1	<i>Substation Number 9 Configuration</i>	61
4.11.2	<i>Load growth for Substation Number 9</i>	61
4.11.3	<i>Substation Number 9 Transformer Load Summary</i>	62
4.11.4	<i>Substation 9 Transformer Summary</i>	62
4.11.5	<i>Substation Number 9 Example of Domestic Feeder</i>	63
4.11.6	<i>Substation 9 Domestic Feeder Summary</i>	63
4.11.7	<i>Substation Number 9 Example of Domestic / Industrial Feeder</i>	64
4.11.8	<i>Substation 9 Industrial Feeder Summary</i>	64
4.12	Discussion of Results.....	65
4.12.1	<i>6pm Load peaks</i>	65
4.12.2	<i>Low feeder power factor</i>	66
4.12.3	<i>Air-conditioning</i>	67
4.12.4	<i>Improved demand-side management options</i>	67
4.12.5	<i>Capacitor Bank effectiveness</i>	67
5.	Discussion	69
5.1	Introduction.....	69
5.2	Air-Conditioning Load.....	69
5.2.1	<i>Introduction</i>	69
5.2.2	<i>Tariff Control</i>	70
5.2.3	<i>Thermostat Adjustment</i>	70
5.2.4	<i>Load Cycling</i>	71
5.2.5	<i>Congestion Pricing</i>	71
5.2.6	<i>Conclusion</i>	72
5.3	Under Frequency Load Shedding.....	73
5.4	Rotational Load Shedding.....	74
5.5	Voluntary Load Shedding	75
5.6	Retail Pricing.....	75
5.7	Energy Conservation.....	76
5.8	Energy Storage.....	76
5.9	Temperature Effects on Plant.....	77
5.10	Issues and Assumptions.....	77
6.	Conclusions and Recommendations	79
6.1	Project Objectives	79
6.1.1	<i>Review of Demand-Side Management Options</i>	79
6.1.2	<i>Assessment of current documentation</i>	80
6.1.3	<i>Gathering and Analysis of data</i>	80
6.2	Recommendations/ Further Work	80
6.2.1	<i>Tariff switching time changes</i>	80
6.2.2	<i>Congestion Pricing</i>	80
6.2.3	<i>Voluntary Load Shedding</i>	81

6.2.4 Customer Liaison	81
6.3 Conclusion	81
Reference List.....	82

List of Tables

Table 1- List of Substations for Analysis	23
Table 2 - Summary of Substation Number 1 Data	29
Table 3 - Summary of Substation Number 2 Data	33
Table 4 - Summary of Substation Number 3 Data	37
Table 5 - Summary of Substation Number 4 Data	41
Table 6 - Summary of Substation Number 5 Data	45
Table 7- Summary of Substation Number 6 Data	49
Table 8 - Summary of Substation Number 7 Data	53
Table 9 - Summary of Substation Number 8 Data	58
Table 10 - Summary of Substation Number 9 Data	61
Table 11 - Table of signal sent for Tariff 33 switching between 6pm and 10pm.....	65
Table 12 - Table of frequency and timings for Under Frequency Load Shedding.....	73
Table 13 - Table of Ergon Energy Corporation Tariff Arrangements.....	88

List of Figures

Figure 1: Overview of General Load Control Configuration	15
Figure 2- Example of the switching patterns for receivers for various tariffs	16
Figure 3 – Reactive Power triangle	17
Figure 4 - Capacitive Power triangle.....	17
Figure 5 - Power triangle after the affects of a Capacitor Bank are included.....	18
Figure 6 – Graph of total DNSP load for 15 th July 2003	28
Figure 7 - Graph of total DNSP load for 9 th December 2003	28
Figure 8 - Graph of Load Growth for 5 years for Substation 1	29
Figure 9 - Graph of the Total Winter Load on Substation 1	30
Figure 10 - Graph of the Total Summer Load on Substation 1	30
Figure 11 - Graph of the Winter Load on Substation 1 Feeder 2	31
Figure 12 - Graph of the Summer Load on Substation 1 Feeder 2.....	31
Figure 13 - Graph of the Winter Load on Substation 1 Feeder 5	32
Figure 14 - Graph of the Summer Load on Substation 1 Feeder 5.....	32
Figure 15 - Graph of Substation 2 Load Growth for the past 9 years.....	33
Figure 16 - Graph of the Total Winter Load on Substation 2.....	34
Figure 17 - Graph of the Total Summer Load on Substation 2	34

Figure 18 - Graph of the Winter Load on Substation 2 Feeder 3	35
Figure 19 - Graph of the Summer Load on Substation 2 Feeder 3	35
Figure 20 - Graph of the Winter Load on Substation 2 Feeder 4	36
Figure 21 - Graph of the Summer Load on Substation 2 Feeder 4	36
Figure 22 - Graph of Substation 3 Load Growth for the past 9 years.....	37
Figure 23 - Graph of the Total Winter Load on Substation 3.....	38
Figure 24 - Graph of the Total Summer Load on Substation 3	38
Figure 25 - Graph of the Winter Load on Substation 3 Feeder 5	39
Figure 26 - Graph of the Summer Load on Substation 3 Feeder 5.....	39
Figure 27 - Graph of the Winter Load on Substation 3 Feeder 3	40
Figure 28 - Graph of the Summer Load on Substation 3 Feeder 3.....	40
Figure 29 - Graph of Substation 4 Load Growth for the past 14 years.....	41
Figure 30 - Graph of the Total Winter Load on Substation 4.....	42
Figure 31 - Graph of the Total Summer Load on Substation 4	42
Figure 32 - Graph of the Winter Load on Substation 4 Feeder 1	43
Figure 33 - Graph of the Summer Load on Substation 4 Feeder 1	43
Figure 34 - Graph of the Winter Load on Substation 4 Feeder 7	44
Figure 35 - Graph of the Summer Load on Substation 4 Feeder 7.....	44
Figure 36 - Graph of Substation 5 Load Growth for the past 13 years.....	45
Figure 37 - Graph of the Total Winter Load on Substation 5.....	46
Figure 38 - Graph of the Total Summer Load on Substation 5	46
Figure 39 - Graph of the Winter Load on Substation 5 Feeder 1	47
Figure 40 - Graph of the Summer Load on Substation 5 Feeder 1	47
Figure 41 - Graph of the Winter Load on Substation 5 Feeder 3	48
Figure 42 - Graph of the Summer Load on Substation 5 Feeder 3.....	48
Figure 43- Graph of Load Growth for 13 years for Substation 6	49
Figure 44 - Graph of the Total Winter Load on Substation 6.....	50
Figure 45 - Graph of the Total Summer Load on Substation 6	50
Figure 46 - Graph of the Winter Load on Substation 6 Feeder 1	51
Figure 47 - Graph of the Summer Load on Substation 6 Feeder 1	51
Figure 48 - Graph of the Winter Load on Substation 6 Feeder 4	52
Figure 49 - Graph of the Summer Load on Substation 6 Feeder 3.....	52
Figure 50 - Graph of Load Growth for 14 years for Substation 7	53
Figure 51 - Graph of the Total Winter Load on Substation 7.....	54
Figure 52 - Graph of the Total Summer Load on Substation 7	54
Figure 53 - Graph of the Winter Load on Substation 7 Feeder 6	55
Figure 54 - Graph of the Summer Load on Substation 7 Feeder 6.....	55

Figure 55 - Graph of the Winter Load on Substation 7 Feeder 7	56
Figure 56 - Graph of the Summer Load on Substation 7 Feeder 7	56
Figure 57 - Graph of the Winter Load on Substation 7 Capacitor Bank	57
Figure 58 - Graph of the Summer Load on Substation 7 Capacitor Bank	57
Figure 59 - Graph of the Total Summer Load on Substation 8	59
Figure 60 - Graph of the Summer Load on Substation 8 Feeder 1	60
Figure 61 - Graph of Load Growth for 14 years for Substation 9	61
Figure 62 - Graph of the Total Winter Load on Substation 9	62
Figure 63 - Graph of the Total Summer Load on Substation 9	62
Figure 64 - Graph of the Winter Load on Substation 9 Feeder 4	63
Figure 65 - Graph of the Summer Load on Substation 9 Feeder 4	63
Figure 66 - Graph of the Winter Load on Substation 9 Feeder 3	64
Figure 67 - Graph of the Summer Load on Substation 9 Feeder 3	64
Figure 68 - Graph of Residential air-conditioning load curve	69
Figure 69 - Graph of Average Temperature Maximum and Minimum	90
Figure 70 – Graph of Typical Retail Electricity Prices for 24 hour	92
Figure 71 – Close up graph of Typical Electricity Prices	92

Appendix List

Appendix 1 - Project Specification	84
Appendix 2 - Summary of the Queensland Tariff Arrangement	86
Appendix 3 – Graph of Average Maximum and Minimum Temperature	89
Appendix 4 - Example of a Daily Electricity Price Schedule	91
Appendix 5 - Workplace Health and Safety	93

Abstract

With the significant increase in the consumption of electricity over the past few years, it has been hard for electricity entities to keep up with the sudden increases in demand. The replacement and upgrade of substation transformers and associated equipment is very expensive and time consuming to obtain and install. Also the wanton use of electricity without understanding the consequences and its impact on the environment is negligent on the part of the individual.

For the purpose of this project Demand-Side Management is any action taken to reduce the consumption of electricity supply to a customers premises, to assist an Electricity Entity in the stability of the electricity network. This leads to the principle that Demand-Side Management can be used to defer capital expenditure by attempting to average a feeder or substation load over a longer period and reduce the amount of peaks and troughs.

As will be seen later in the report, air-conditioning load is one of the fastest growing domestic loads, with significant increases over the past 2 to 3 years. As a result the electricity networks are being overloaded due to the unexpected increase in electricity demand.

There are many different methods of demand-side management mentioned in this report, most of these can be used to manage air-conditioner load, however the methods would not be acceptable to customers.

After looking at various forms of demand-side management I believe that congestion pricing is the method that is most suitable and fair for managing customers air-conditioning load. Congestion pricing operates similar to tariff control, however the difference is that electricity prices are increased during high demand periods.

Voluntary Load Shedding should be encouraged amongst those industrial organisations that can defer their load times. As such congestion pricing and voluntary load shedding are two methods of demand-side management that need to be seriously considered by electricity entities.

Irrespective of what type of demand-side management method employed, for demand-side management to be effective the customer must actively support it.

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111 & ENG4112 *Research Project*

Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Engineering and Surveying, and the staff of the University of Southern Queensland, do not accept any responsibility for the truth, accuracy or completeness of material contained within or associated with this dissertation.

Persons using all or any part of this material do so at their own risk, and not at the risk of the Council of the University of Southern Queensland, its Faculty of Engineering and Surveying or the staff of the University of Southern Queensland.

This dissertation reports an educational exercise and has no purpose or validity beyond this exercise. The sole purpose of the course pair entitled "Research Project" is to contribute to the overall education within the student's chosen degree program. This document, the associated hardware, software, drawings, and other material set out in the associated appendices should not be used for any other purpose: if they are so used, it is entirely at the risk of the user.

Prof G Baker
Dean
Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

David Thomas Chalmer GRAY

Student Number: 0018165616

(Signature)

(Date)

Acknowledgments

I would like to acknowledge and thank:

Mr. Ron Sharma – Faculty of Engineering and Surveying, University of Southern Queensland

Mr. Ken Lewis – Network Operations Analysis Manager, Ergon Energy Corporation

Mr. Malcolm Adkins – Network Forecast Officer, Ergon Energy Corporation

Mr. Wayne Ivers – Metering Support Technical Officer, Ergon Energy Corporation

My wife, Tina and children Jordyn, Alexandra and Hamish

DAVID GRAY

University of Southern Queensland

October 2004

Nomenclature

Term	Description	Units
A	Amperes	A
f	Frequency	Hz
GVA	Giga Volt Amperes	GVA
I²R	Reactive Power Losses	
kV	kilo Volts	kV
kVA	kilo Volt Amperes	kVA
MVA	Mega Volt Amperes	MVA
MWh	Mega Watt hours	MWh
P	Real Power	W
pf	Power Factor	-
π	Phi	-
Q	Reactive Power	VAr
S	Active Power	VA
θ	Theta	° or radians
V	Volts	V
VA	Volt Amperes	VA
VAr	Volt Amperes Reactive	VAr
W	Watts	W
X_L	Reactive Impedance	Ω
Z	Impedance	Ω

Glossary

- ◆ ABB – Asea Brown Boveri Company
- ◆ Bund Wall – Is a raised wall around the outside of a transformer to prevent oil spills
- ◆ Contestable Customers - Contestable customers are generally customers whose electricity consumption exceeds 200MWh/ year
- ◆ Domestic – Refers to a customer who consumption of electricity is primarily for personal use
- ◆ DNSP – Is a distribution network service provider like Ergon Energy Corporation or Energex Corporation who manage the supply of electricity to customers
- ◆ Electricity Act 1994 – An act of parliament that contains the laws that govern the supply and use of electricity around Queensland
- ◆ Electricity Retailer – Is the retail side of an electricity business and is the primary interface for customers
- ◆ Ergon Energy Corporation – Is the distribution company of Ergon Energy controls and maintains the poles, wires and assets for regional Queensland
- ◆ Ergon Energy Pty Ltd – Is the retail company of Ergon Energy who manages the customer interface and sale of electricity around Australia
- ◆ Franchise Customers – Also referred to as a Market Customer, is a customer who is entitled to purchase power from any registered electricity retailer
- ◆ Industrial – Refers to a customer who consumes electricity to carry out a business, it must be noted that not all businesses will exhibit an industrial load consumption
- ◆ Load Control Unit – Is a system used to turn electricity on and off or to change an electricity meter between high and low tariff
- ◆ N-1 – This means that the loss of a single piece of plant will not cause an outage to occur
- ◆ National Electricity Code – A Federal act of parliament that contains the laws that govern the supply and use of electricity across Australia

- ◆ NEMMCO – Is the National Electricity Market Management Company and oversee the stability of the electricity network around Australia by managing the interface between the Electricity Generators, TNSP and DNSP's
- ◆ Tariff – Is a method of offering customers lower priced electricity to consume power off peak, or at a time that will offer less impact on the electricity network
- ◆ TNSP – Is a transmission network service provider like Powerlink Queensland Corporation who manage the supply of electricity at high voltage to DNSP's

CHAPTER 1

BACKGROUND

1. Background

1.1 Introduction

With the ever-increasing use of electricity across the country and around the world, it is hard for electricity entities like Ergon Energy Corporation to keep up with sudden increases in demand. The replacement and upgrade of substation transformers and associated equipment is very expensive and time consuming to obtain and install. Also the wanton use of electricity without understanding the consequences and its impact on the environment is negligent on the part of the individual. It is therefore incumbent on electricity entities to manage the load and attempt to mitigate the impact of the load on the entity assets.

All electricity corporations in the state of Queensland are required to offer franchise customers a reduction in cost of electricity supply by varying the times that supply is available. Contestable customers are not required to be offered tariff controlled electricity at reduced prices as they are offered electricity at a rate different to non-contestable customers. The most common type of electricity load that customers choose to vary is for the heating of hotwater for domestic installations and fixed plant, such as permanently connected dishwashers, dryers and to a larger extent air-conditioners. Hotwater load is usually supplied by electricity at non-peak demand times, this is done by utilising various tariffs. By doing this, the overall impact on the electrical system can be reduced, by attempting to reduce the peak demand in the supply of electricity.

However there has not been a significant review carried out on the overall impact of the current demand-side management processes and systems to determine how effective they have been.

1.2 What is Demand-Side Management

‘What is Demand Side Management?’ this question can raise more issues than one might originally think. Demand Side Management can be and is viewed differently by each organisation and even people within the organisation.

“Demand Side Management refers to the actions taken on the customer’s side of the meter to change the amount or timing of energy consumption.” (US Department of Energy, 2004)

However, discussions with operational staff in Ergon Energy Corporation suggest that Demand Side Management is where a customer is guided to make appropriate choices to suit the Electricity Entities capabilities. This type of philosophy will assist the DNSP in managing the electricity network and is not just a sales tool for an Electricity Retailer.

So as can be seen the question of ‘What is Demand Side Management?’ alone can create a large debate, however subtle the differences are. For the purpose of this document Demand Side Management will be referred to as:

Actions taken to reduce the consumption of electricity supply to the customer premises, to assist a Distribution Network Service Provider in the stability of the electrical network.

Demand Side Management is achieved by two main methods:

1. Load Reduction – Load reduction refers to the reduction of electricity by means of the installation of energy saving technologies and other forms of energy reduction methodologies, for example, load reduction agreements with customers.
2. Load Levelling – Load levelling refers to smoothing out the peaks and dips in energy supply. Some form of Load Control generally performs load levelling and this is the area that is of particular interest in this report.
3. There are also methods used on the DNSP’s side of the electricity network that can be referred to as Demand-Side Management. Included in this area is the use of capacitive storage devices to “absorb” sudden small load variations, short term generation commonly referred to as load lopping or peak demand lopping.

1.3 Project Justification

A new substation with a typical 2 by 10MVA transformer capacity costs approximately \$6Million to construct. This would include the cost of purchase and installation of the transformer and other ancillary items like protection, circuit breakers, busbar, civil works, buildings and feeder installation. This cost is often compounded when upgrading an older substation.

For example a 2 x 16MVA substation with 16MVA of load needs to be upgraded to a 2 x 25MVA substation, with this change there is a requirement to upgrade other pieces of plant within the substation. Some of these included new Bund walls for oil containment, new transformer circuit breakers, protection upgrades including new protection relays, current and voltage transformers and quite often re-configuring the substation layout. This change would typically cost around \$2.3Million and relies on the major portion of the current substation equipment being able to be reused.

As can be seen the cost of upgrading a substation is substantial, so if an upgrade project can be delayed then the cost savings can be significant. For example a \$2 million project delayed by four years could have an annual saving of approximately \$200,000 per annum. This allows for the saving to be spent on assets that can have a greater impact on improving the electricity network reliability.

1.4 Project Aims

The aim of the project is to determine what is the actual impact of Demand-Side Management in substations. This will be achieved by analysing the load profiles of various substations and determining what has been the impact of the tariff switching on the substation. Currently Queensland's predominate form of Demand-Side Management for load control is through tariff control (tariff control will be explained further in the next chapter - Chapter 2).

Once the impact of tariff load control has been determined, further analysis will look at whether or not other forms of Demand-Side Management will be beneficial.

1.5 Understanding of Demand-Side Management Impact

One possible consequence of this report is that Ergon Energy Corporation makes representation to the Queensland Government to review its current practices with a view to moving in new directions. At present Ergon Energy Corporation and the Queensland Electricity Supply Industry are only mandated to have tariff demand-side management on offer to their customers.

Part of the purpose of this report is an attempt to raise the understanding of different methods of dealing with Demand-Side Management.

1.6 Possible Impacts of Change

There are a number of topics that may be impacted by this project:

- A change may be needed to the current tariff arrangements, an example maybe that Tariff 31 may mean a change such that the customer still gets 8 hours but instead of being between 10pm and 7 am, it may need to be between 8pm and 8am (This is an illustrative example only).
- A change of view may be required to what Demand Side Management actually is, instead of just tariff control, it might extend to hedging offers where a customer of a certain size is given 24 hours notice to reduce load by 50%.
- It may also mean that further analysis is required to determine the nature of our current loads. In that they will most likely differ from what they were 10 to 15 years ago with the increase in air-conditioning

CHAPTER 2

DEMAND-SIDE

MANAGEMENT SYSTEMS

2. Demand-Side Management Systems

2.1 Control Theory

2.1.1 Introduction to Load Control Theory

Load Control can be carried out at two (2) separate locations:

1. Manually from a central location to de-centralised Load Control Units.

In the case of a Manual Control a control signal is sent to the required de-centralised Load Control Unit which then instigates for an open or close signal to be sent to the remote receivers, as can be seen in the diagram 1 below. This is generally only done when there is a problem on the electrical supply system or there has been a request from the Electricity Supply Retailer to shed loads for Electricity market manipulation; or

2. Automatically from the pre-programmed de-centralised Load Control Unit.

This is the most common form of control where a customer receives cheaper electricity supply to be on a tariff arrangement. Tariffs are explained in more detail in section 2.2. In this case at various times throughout the day and night customers loads are turned on and off in an attempt to maximise the efficiency of the use of electricity supply usage and in so doing attempt to level the load.

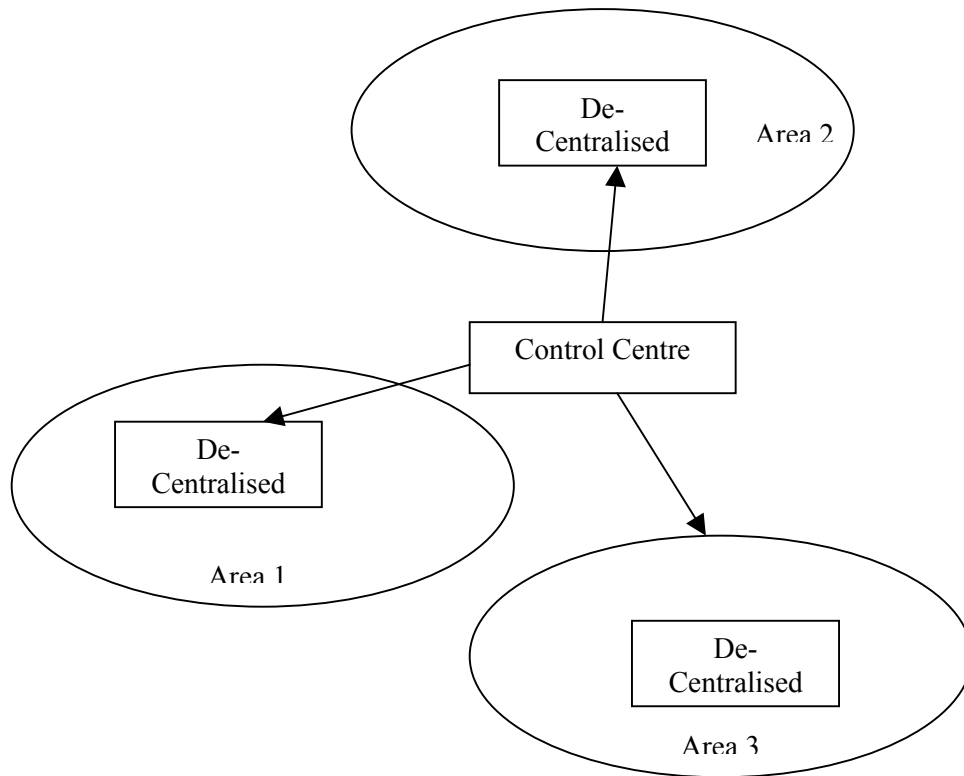


Figure 1: Overview of General Load Control Configuration

2.1.2 Type of Load Control Used

The Central Region of Ergon Energy Corporation has two main types of Load Control being used these are ABB and Enermet. The ABB master station system is briefly described below in 2.1.3.

2.1.3 ABB Master Station LCM-500 (Load Control Master 500)

The LCM-500 master station is a fully automatic control and monitoring system for the management of load. It operates using audio frequency ripple control technology where information is passed over the electricity entity wires. The system has the following functions:

- ◆ Man-machine interface
- ◆ Message processing and station monitoring
- ◆ Analysis of network load and other analogue values
- ◆ Load management functions
- ◆ Load forecasting functions
- ◆ Command generation

2.2 Theory of Tariff Arrangements

2.2.1 Introduction of Tariff Arrangements

All electricity supply is bound by various legal and business requirements, part of those requirements are for customers to be offered supply at a certain cost for being on a specified tariff. These tariffs also have limitations placed on them under the Electricity Act 1994 and by the Electricity Retailer. A summary of the tariffs for the state of Queensland is listed in Appendix 2.

Some of the limitation and constraints placed on the Electricity Supplier are the maintenance of supply to a customer for a specified period for any 24-hour period, several examples are included below:

Tariff 31 customer must have 8-hour availability of supply between 10pm and 7am or an 8-hour block of supply as determine by the Electricity Supplier.

Tariff 65 customers are Irrigation – Time of Use Customers that are charged at 12 hours “High” rate and 12 hours at “Low” rate. That is to say that when the tariff is on the “High rate” the customer pays more for their electricity than when they are the “Low rate”.

2.2.2 The Application of Tariff Switching

Central Region Ripple Telegrams consist of a 50 bit coded message injected onto the network by a ripple control injection plant. The 50 on/off pulses (bits) are interpreted by the receiver, then any commands associated with the received message are activated.

The 50 bits are divided into groups, whereby each group of bits defines a characteristic of the message being transmitted. An example of the from switching patterns is shown below:

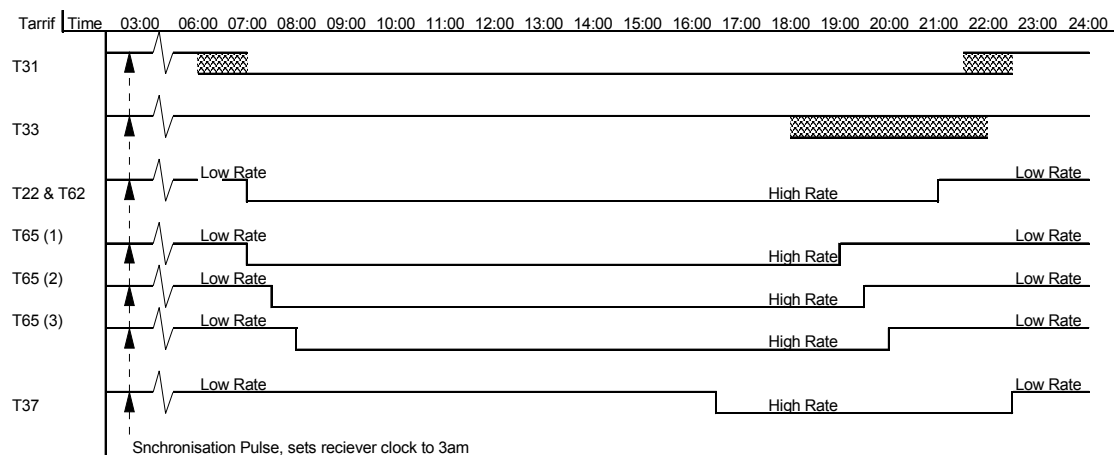


Figure 2- Example of the switching patterns for receivers for various tariffs.

2.3 Other Forms of Load Control/ Demand-Side Management

2.3.1 Other forms of Load Control

Until now only tariff based load control has been covered, this is because it is the predominate form of load management currently being used. However, there are other forms of load management, some of which are not so widely used. Below are several of the more common methods that are utilised.

2.3.2 Power Factor Correction

Power Factor correction is generally carried out substation level, but what is power factor correction. Power factor correction effectively reduces the total flow through the power network by local injection or absorption of imaginary power to match the corresponding customer production levels. This reduces overall power system energy I^2R losses, and allows improved asset utilisation by freeing up network plant capacity for real power transmission. Power factor correction is based on the principle of reducing the reactive power by counteracting the reactive power with a capacitive power correction (Grainger & Stevenson 1994).

$$S_1 = P_1 + jQ_1$$

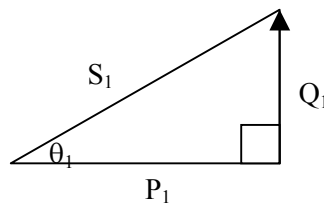


Figure 3 – Reactive Power triangle

$$S_2 = P_2 + jQ_2$$

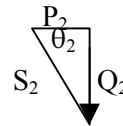


Figure 4 - Capacitive Power triangle

S_1 is a representation of load based on a substation as Q_1 the reactive power increases. $\theta_1 = \text{atan}(Q_1/P_1)$ increases the power factor $\text{pf}_1 = \cos \theta_1$ decreases. So if $\text{pf} = 1$ then $\theta = 0^\circ$ and if $\text{pf} = 0.9$ then $\theta = 25.8^\circ$. As can be seen as the power factor decreases the angle θ increases and as θ increases the reactive power increases and therefore the overall power increases. Capacitive power works in the opposite direction to reactive power and counteracts the effects of the reactive power. So when the effects of the Capacitor Bank are included in the system the impact of the reactive power on the electrical system in general and in particular at a substation is reduced.

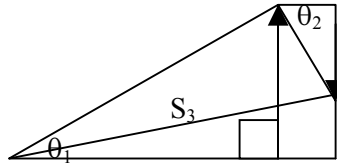


Figure 5 - Power triangle after the affects of a Capacitor Bank are included

The overall power can be broken up such that the reactive power Q_3 is now $Q_1 + Q_2$, however because Q_2 is in the capacitive it is in the negative direction. $P_3 = P_1 + P_2$ and $S_3 = \sqrt{P_3^2 + Q_3^2}$.

Therefore by adding capacitor banks to the electrical system the overall power consumed can be reduced as well as improving the power factor.

2.3.3 Voltage Reduction

This form of load management can be used at the lower high voltages, i.e. 11 and 22kV. Voltage reduction works on the basic principle of $V = I \cdot Z$ and relies on the fact that the majority of load at the distribution level is a constant impedance. Therefore by reducing the voltage, the current will be reduced proportionately.

For example: Let $I = 100\text{A}$, $V = 22,000\text{ V}$ and Z be a constant impedance.

$$\therefore 22,000 = 100 \times Z$$

$$\therefore Z = 220 \Omega$$

By maintaining the constant impedance and reducing the voltage to 20kV, the current can be reduced to 90.91 A. As can be seen the current flow is reduced by approximately 10% or the same proportion as the voltage is reduced. This form of control is particularly useful for relieving overload situations on 11 and 22 kV feeders without turning customers supply off. The down side is that when there is a constant power load on the system, by reducing the voltage the current can increase.

2.3.4 Frequency Reduction

Frequency reduction is used primarily for motor starting and will have no impact on anything but the reactive aspect of a load. This can be proven by the following formula (Grainger & Stevenson 1994):

Example 1:

Let assume that the inductance (L) is 100mH and a frequency (f) of 50Hz.

$$X_L = 2\pi fL = 2 * \pi * 50 * 100 \times 10^{-3} = 31.4\Omega$$

Example 2:

Let assume that the inductance (L) is 100mH does not change however the frequency (f) changes to 45Hz.

$$X_L = 2\pi fL = 2 * \pi * 45 * 100 \times 10^{-3} = 28.3\Omega$$

As can be seen by reducing the frequency the reactive impedance X_L is reduced.

2.3.5 Private Generation

One of the most fashionable forms of system grid load reduction at the moment is private generation. Private generation can take several forms from Photovoltaic Cells on a customer's roof to a large gas fired generator. Ergon Energy Corporation has stepped into the market place with the world's first "green electricity" powerplant. Ergon Energy Corporation and SunCoast Gold Macadamias have built and are operating a 1.5MW generator near Gympie Queensland that is fuelled by macadamia nut shells.

It should be noted that the average customer Photovoltaic Cell configuration costs approximately \$15/W_p, this equates to an approximate cost of \$30,000 for a 2kW system. (Australian Greenhouse Office 2004)

2.4 Relevant Standards

There are essentially three separate standards, that relate to tariffs, these are:

- AS 1284.6 – 1992 Electricity metering, Part 6: Ripple control receivers for tariff and load control.
- AS 1284.10.1 – 1996 Electricity metering, Part 10.1: Data exchange for meter reading and load control – Direct local data exchange via hand-held unit (HHU) – IEC Standard interface.
- AS 1852(691) – 1975 International Electrotechnical Vocabulary, Chapter 691: Tariffs for electricity.

2.5 Relevant Codes

There are two different sources that make reference to code one at a state level, the other at a National level. At a Queensland state level we have:

- Section 62 and 90 of the Electricity Act 1994 allow for the Minister to decide on the prices, or the methodology to fix the prices, that a retail entity may charge. This allows for the tariff arrangements to be put in place and varied by Government intervention. In 2003 the retail electricity price where changed, via Queensland Government Gazette, June 2003, No. 47.
- The National Electricity Code also makes reference to the issue of and actively promotes the ethos of Demand-Side Management.

2.6 Technical References

The majority of the technical reference papers and reports in circulation have been commissioned by a Distribution Network Service Provider, Electricity Retailers or other Government agencies to deal with methods of impacting on the retail price of electricity.

However, Integral Energy commissioned a report titled “DM Programs for Integral Energy” prepared by Charles River Associates (Asia Pacific) Pty Ltd in August 2003. There is a significant amount of information in this report that was prepared for Integral Energy that relates to the various Demand Management Strategies and how these strategies can impact on the Electrical Supply Network.

A report from Enermet titled “Mitigating Domestic Air-Conditioning Effects on Electricity Networks” by Andrew Gillespie (2004), covered the load management of air-conditioning. In summary the report proposed utilising the existing ripple control system to inform customers of periods of high demand. If the customer chose to continue using the air-conditioning they would be charged at a higher rate. This methodology will be discussed further in Chapter 5.

CHAPTER 3

PROJECT METHODOLOGY

3. Project Methodology

3.1 Methodology Introduction

This section covers the overall methodology used for developing this report. It will cover the preliminary tasks, gathering of metering data, the layout of the report and the reasoning behind the choices made.

3.2 Preliminary Tasks

3.2.1 *Technical Research*

The initial information gathering exercise to determine how demand-side management is being handled in Ergon Energy Corporation. This information came primarily from the Metering department, Planning department and various technical manuals associated with the specific technology being used for tariff management.

3.2.2 *Choice of Substations*

The number of substations that have been chosen for this project has been limited to nine (9) all located in Rockhampton and surrounding area (List included in below Table 1). This was done to assist in the data gathering exercise and to allow ready access to the substations for further detailed assessment. The data presented in the Results Chapter does not have the respective substation name attached. This has been done for confidentiality purposes.

Substation
Yeppoon
Lakes Creek
Rockhampton Glenmore
Parkhurst
Pandoin
Frenchville
Rockhampton South
Malchi
Canning Street

Table 1- List of Substations for Analysis

3.2.3 Gathering and Analysis of Substation Data

The gathering and analysis of the metering data for each of the substations that have been chosen was time consuming and meant utilising Microsoft Access to manipulate the data to produce information that was useful for further analysis purposes.

The tariff 31 and tariff 33 switching times and power factor for each of the feeders was also obtained and superimposed onto the feeders and substation data to give a visual representation of how effective current methods of demand-side management methods are.

3.2.4 Determination of Tariff Switching Times

The next step after gathering the substation metering data was to try to match the tariff switching times against the load profiles obtained. This will be done utilising the master controller signalling times to determine when a particular tariff is turned on and off. This will then give a visual representation of the impact of the load control methodology on substations and should show how effective the current load control practices are in demand-side management.

3.3 Report

The final report should cover off the following issues:

3.3.1 Data

The data has been presented in an easy to read format, representing a summer and a winter load profile for each substation for:

- ◆ The substation overall;
- ◆ An Industrial feeder; and
- ◆ A domestic feeder.

The tariff switching times were then superimposed over the top of the profiles. By representing the data at both feeder and substation level.

3.3.2 Analysis Dates

The dates to be analysed are the 15th July 2003 and 9th December 2003, these dates were chosen to account for the extremes of temperature for winter and summer in Appendix 3 shows the Bureau of Meteorology report for the respective days. A Wednesday was chosen in an attempt to clearly show the comparison between industrial and domestic feeder loads.

3.3.3 Analysis

All assumptions made during the analysis of the data are detailed and explained in Chapter 5 Discussion.

3.3.4 Conclusions

The final conclusions for the report tie the overall report together, and possibly make some recommendations for future improvements. The conclusion and recommendations touch on things such as; the future of Demand Side Management, New Technologies and any recommendations to Ergon Energy Corporation for improvement in Demand-Side Management practices.

CHAPTER 4

DATA ANALYSIS

AND

RESULTS

4. Data Analysis and Results

4.1 Introduction

The data presented in this section is a summary of the data that was extracted from each of the substations metering data. The data has been presented in graph format with an analytical description afterward. If all graphs of each feeder for the nine substations were included then the data would be excessively repetitive and not add any value to the analysis. So therefore graphs of only two feeders and the total substation load have been included, and at the end of the analysis a feeder that has an “ideal” load profile will be included for comparison.

For commercial reasons each of the substations and feeders included in this analysis are only referred to by a number.

4.2 Nemmco Load Profiles

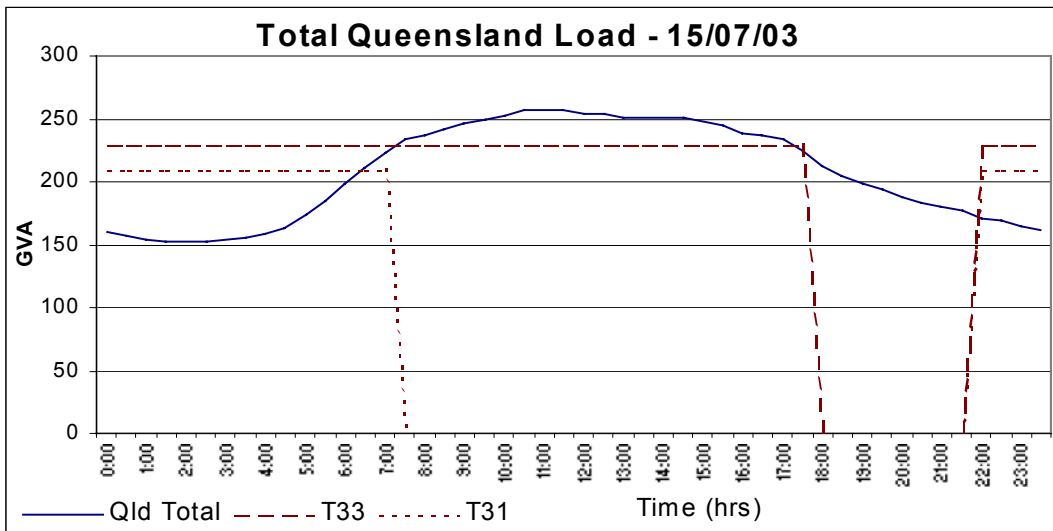


Figure 6 – Graph of total DNSP load for 15th July 2003

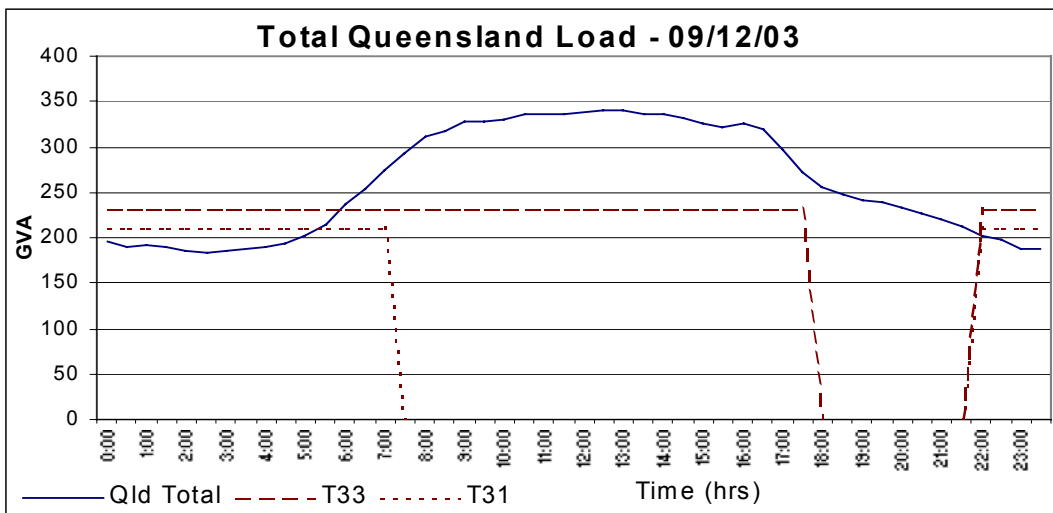


Figure 7 - Graph of total DNSP load for 9th December 2003

4.2.1 Discussion on Figure 6 and Figure 7

The data shown in Figure 6 and Figure 7 is data gathered from NEMMCO public records. The graphs are summation of Ergon Energy Corporation and Energex Corporation loads for the 15th July and 9th December 2003.

As can be seen the summer load is approximately 130% of the winter load. Whilst some of this is due to load growth data presented after each substation configuration shows how much the load in each substation has risen in the past few years. Most of this summer load increase is due to air-conditioning.

4.3 Substation Number 1

4.3.1 Substation Number 1 Configuration

Substation 1 has the following configuration:

Transformers	2 by 25 MVA 66/11kV	2 by 10MVA 66/22kV
Capacitor Bank	2 by 4 MVar @ 11kV	
Number of Feeders	6 @ 11kV	2 @ 22kV
Ripple Control	Nil	
Peak Load	20.41 MVA	
Number of Customers	10,316	

Table 2 - Summary of Substation Number 1 Data

4.3.2 Load growth for Substation Number 1

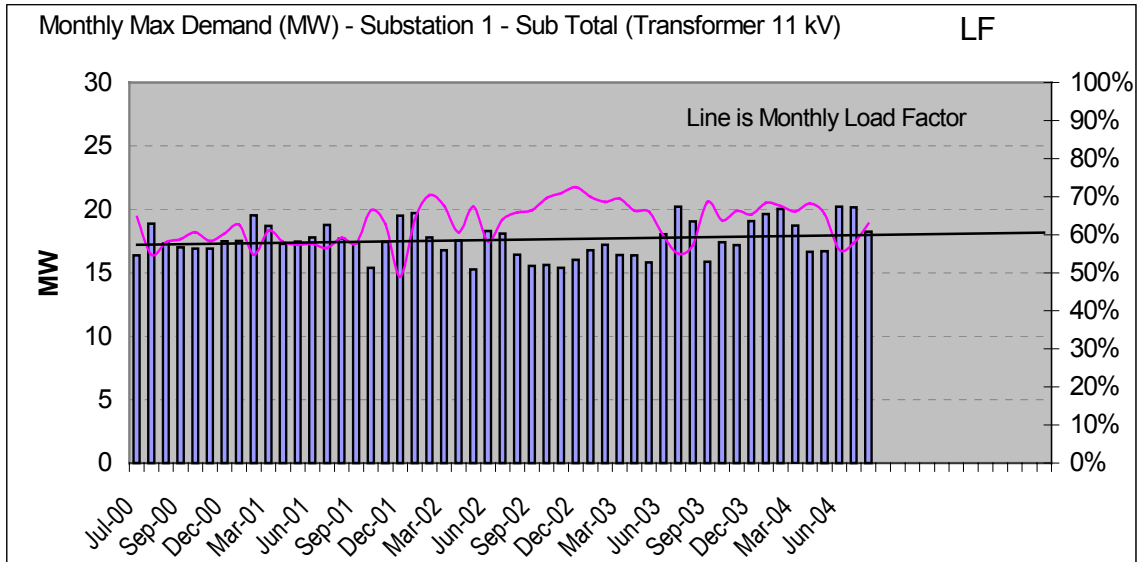


Figure 8 - Graph of Load Growth for 5 years for Substation 1

4.3.3 Substation Number 1 Transformer Load Summary

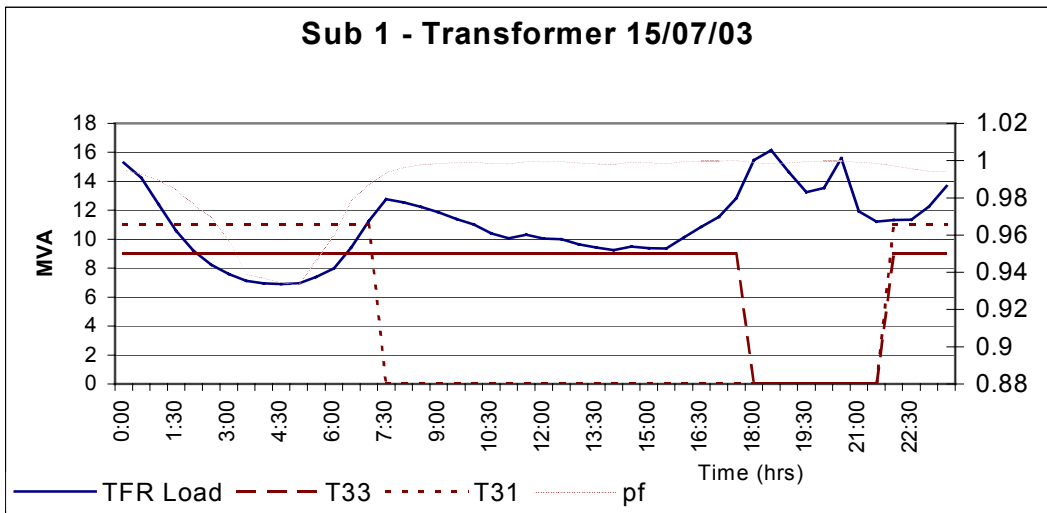


Figure 9 - Graph of the Total Winter Load on Substation 1

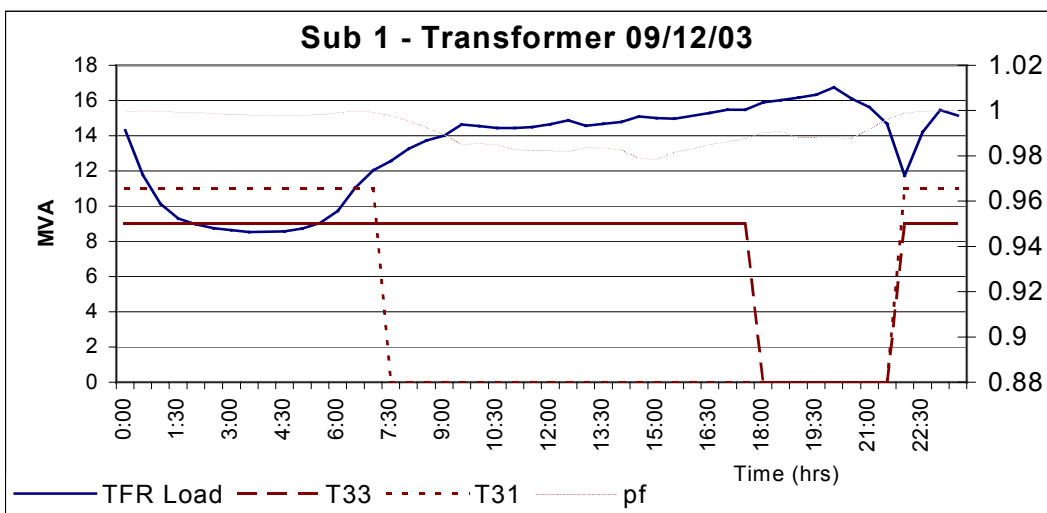


Figure 10 - Graph of the Total Summer Load on Substation 1

4.3.4 Substation 1 Transformer Summary

Load: The first of the two peaks in the winter load (Figure 9) is around dinnertime, also a review of the tariff 33 switching times indicates that Channels 1, 4 and 6 being turned on corresponds to this peak as well. The interesting thing about the summer load (Figure 10) is the manner in which the load ramps up from early morning. This tends to indicate air-conditioning load progressively ramping up as the ambient temperature gets hotter throughout the day.

Power Factor: In this case the power factor for both Figure 9 and Figure 10 is stable.

4.3.5 Substation Number 1 Example of Domestic Feeder

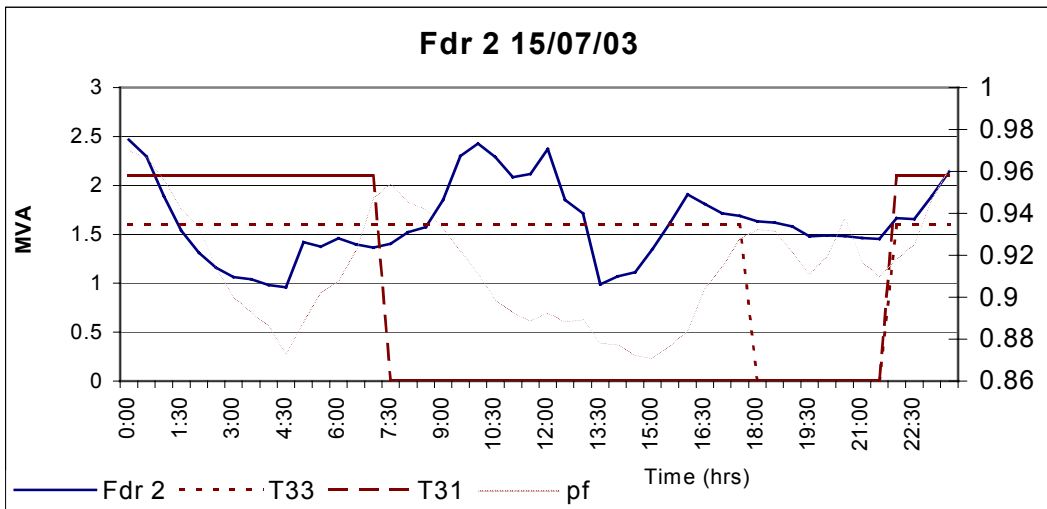


Figure 11 - Graph of the Winter Load on Substation 1 Feeder 2

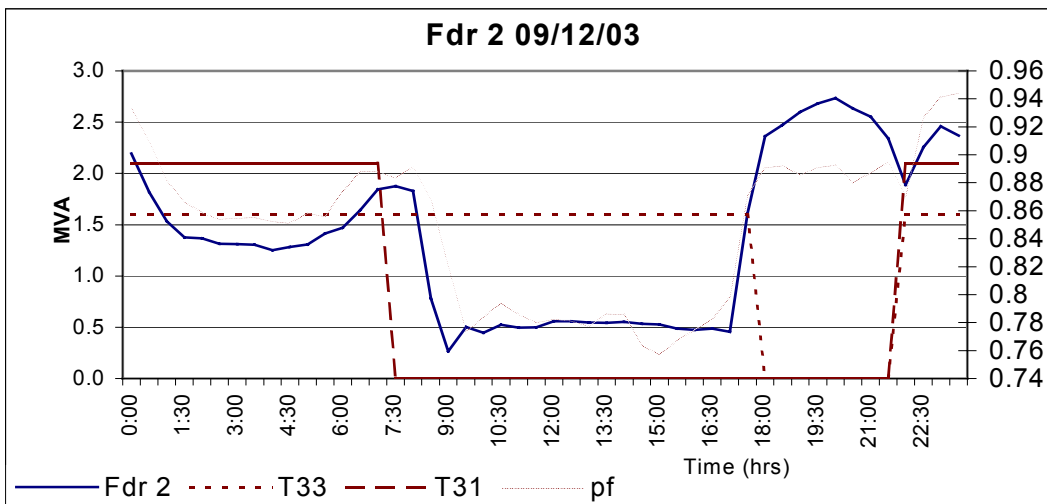


Figure 12 - Graph of the Summer Load on Substation 1 Feeder 2

4.3.6 Substation 1 Domestic Feeder Summary

Load: The load varies greatly during the winter period (Figure 11) however, the summer load (Figure 12) is very good representation of a domestic feeder with relatively no load between business hours and high loads after hours. Of concern in the summer load is the nature of the afternoon peaks, these indicate that there maybe high air-conditioner usage at dinnertime, then a second peak at approximately 2300 hrs where the hotwater tariff switches on.

Power Factor: The interesting thing about the power factor in summer (Figure 12) in particular is that the changes follow very closely with the load changes. Also as the hotwater is switched on the power factor approaches unity.

4.3.7 Substation Number 1 Example of Industrial Feeder

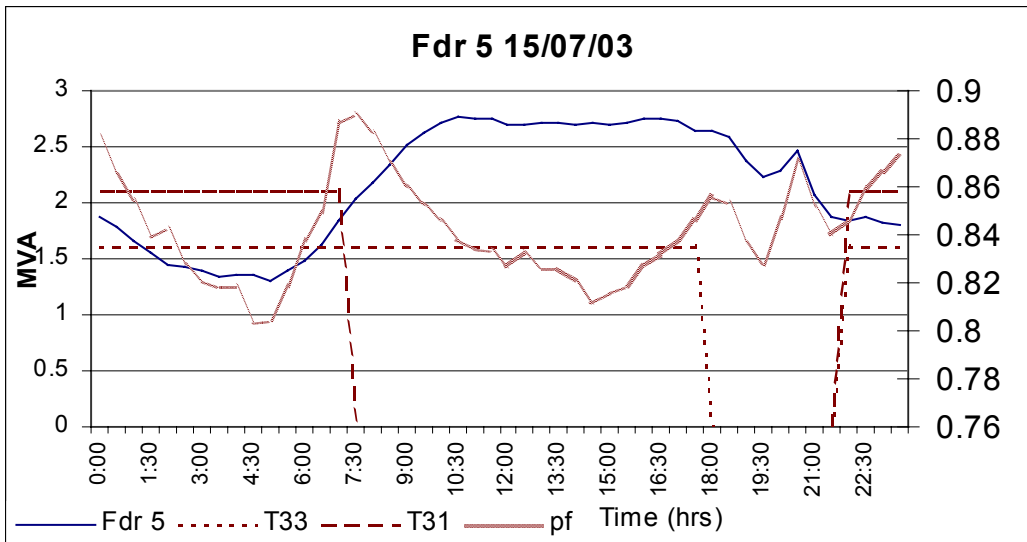


Figure 13 - Graph of the Winter Load on Substation 1 Feeder 5

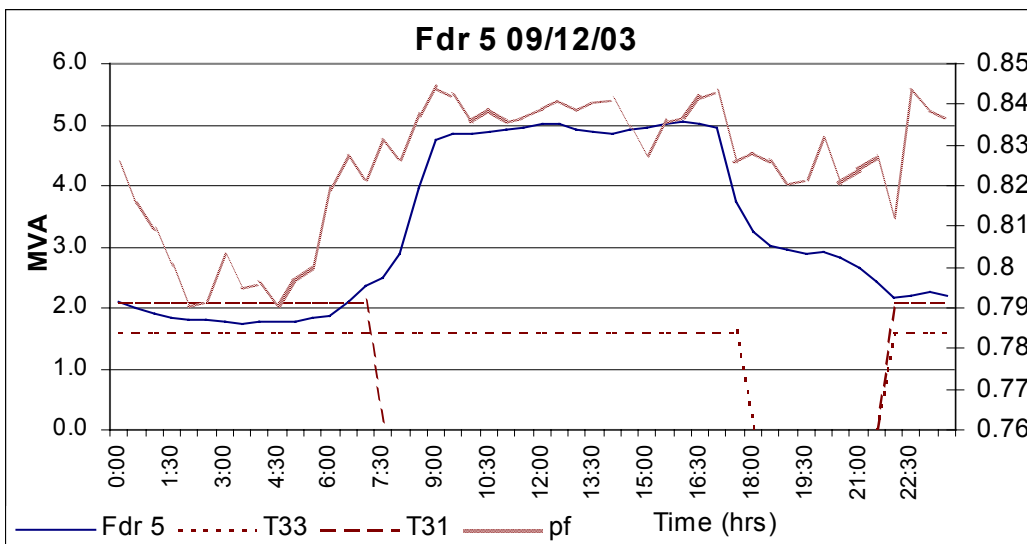


Figure 14 - Graph of the Summer Load on Substation 1 Feeder 5

4.3.8 Substation 1 Industrial Feeder Summary

Load: In Figure 13 and Figure 14 the base load for both the winter and summer periods is similar in appearance, however the day peak in summer is approximately 200% of the winter load. This would possibly be attributed primarily to air-conditioning load, also the tariff control does not make any difference to the load profile.

Power Factor: The power factor in both summer (Figure 14) and winter (Figure 13) is relatively consistent, however in both cases the power factor gets to a low level, ie. near 0.8.

4.4 Substation Number 2 Data

4.4.1 Substation Number 2 Configuration

Substation 2 has the following configuration:

Transformers	2 by 20 MVA 66/11kV	
Capacitor Bank	1 by 5.4 MVAr @ 12kV	
Number of Feeders	6 @ 11kV	
Ripple Control	Nil	
Peak Load	14.75 MVA	
Number of Customers	2830	

Table 3 - Summary of Substation Number 2 Data

4.4.2 Load growth for Substation Number 2

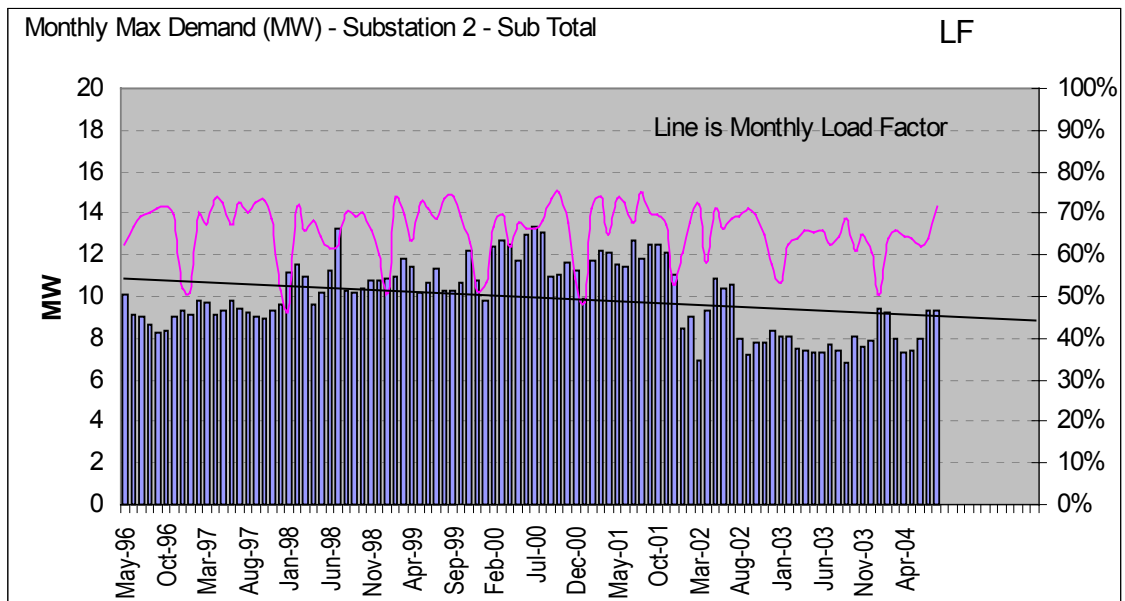


Figure 15 - Graph of Substation 2 Load Growth for the past 9 years

4.4.3 Substation Number 2 Transformer Load Summary

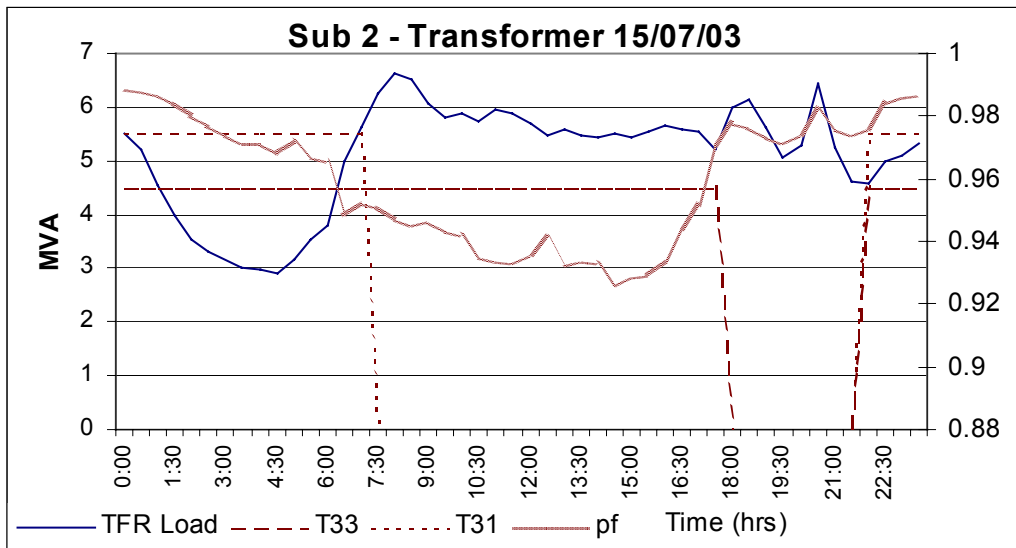


Figure 16 - Graph of the Total Winter Load on Substation 2

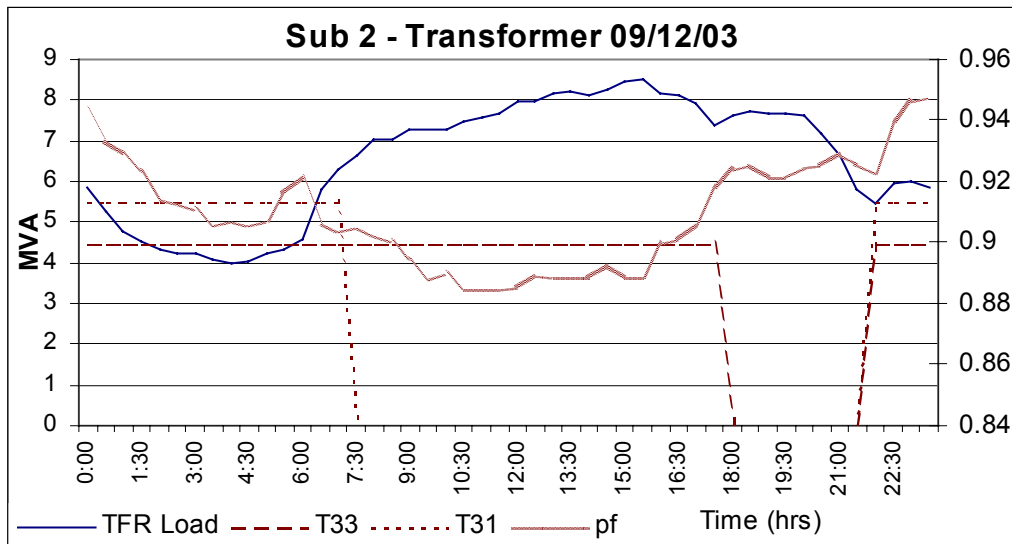


Figure 17 - Graph of the Total Summer Load on Substation 2

4.4.4 Substation 2 Transformer Summary

Load: This substation has had a significant decrease in load over the past few years, this has been solely to the closing of a large industrial enterprise that was being supplied from the substation. This substation has a similar issue with the substation 1 with the two peaks in the winter load (Figure 16). In Figure 17 the load on this substation indicates a heavy air-conditioning load progressively ramping up as the ambient temperature gets hotter throughout the day. The power factor for this substation is relatively stable most of the time, however in winter as the load increases so does the power factor indicating that the load is becoming more resistive.

4.4.5 Substation Number 2 Example of Domestic Feeder

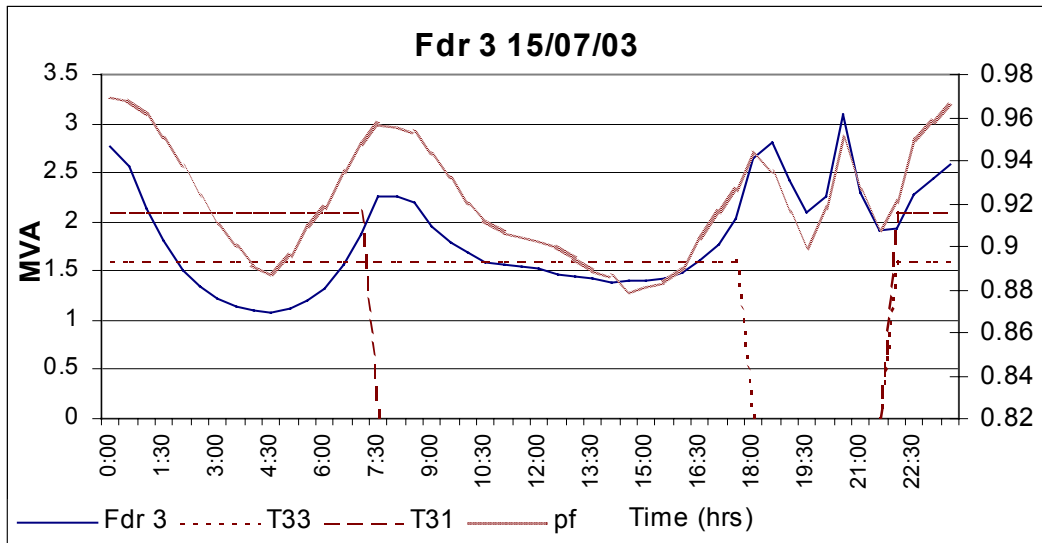


Figure 18 - Graph of the Winter Load on Substation 2 Feeder 3

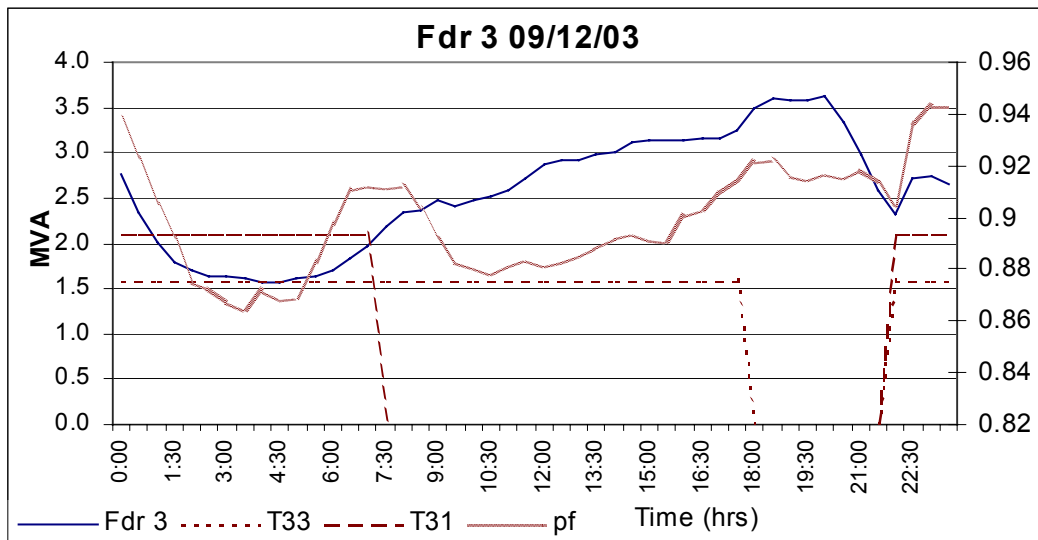


Figure 19 - Graph of the Summer Load on Substation 2 Feeder 3

4.4.6 Substation 2 Domestic Feeder Summary

Load: In Figure 18 the load peaks around the 6pm mark which appear to be hotwater peaks. Also in Figure 19 the summer load ramps from 6am to 8pm with a 500kVA rise between 6pm and 8pm.

Power Factor: Changes in the power factor during winter (Figure 18) followed the load this is probably due to the changing proportions of resistive and reactive load. As more resistive load came on line the power factor rose. In Figure 19 the summer load power factor is all over the place this would be due to the type of load, most likely air-conditioning load with motors switching in an out.

4.4.7 Substation Number 2 Example of Industrial Feeder

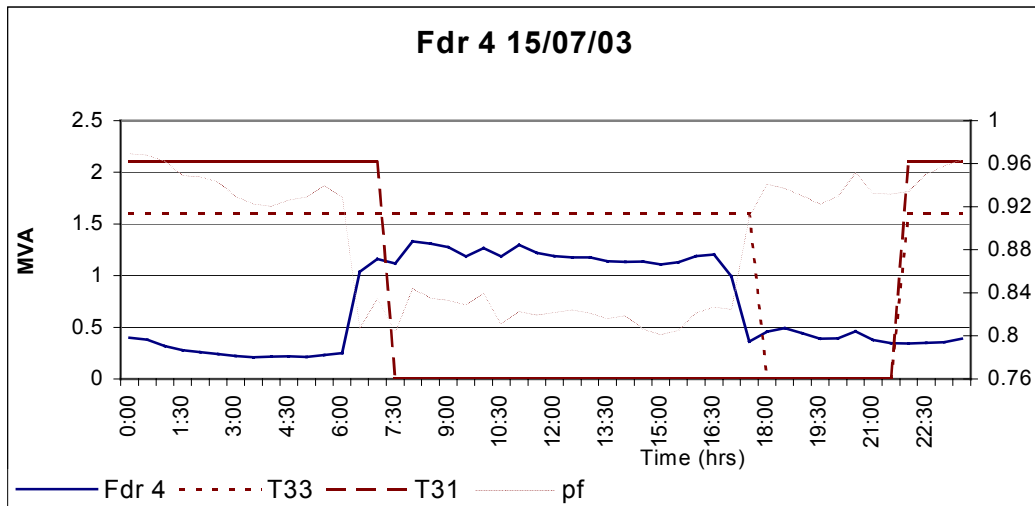


Figure 20 - Graph of the Winter Load on Substation 2 Feeder 4

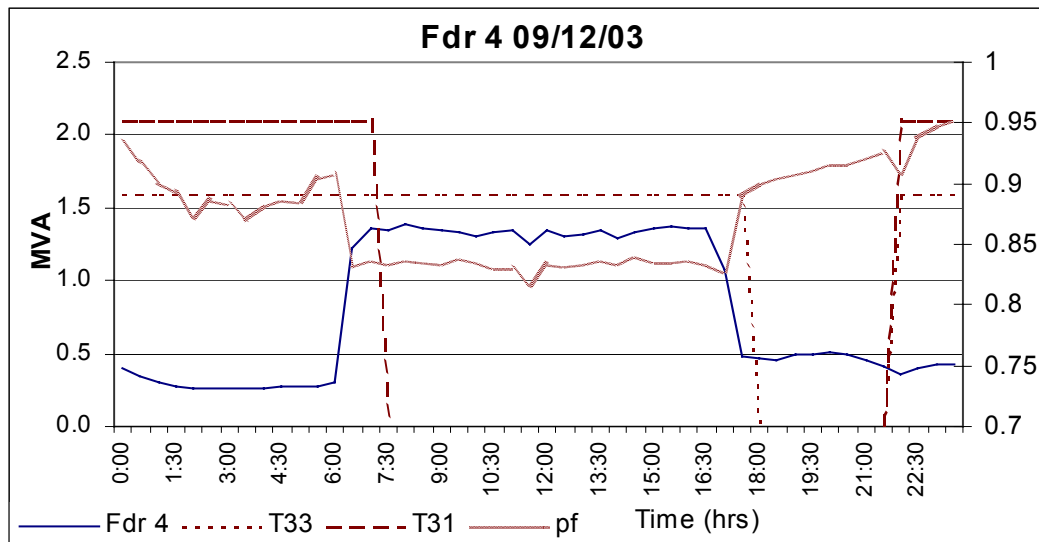


Figure 21 - Graph of the Summer Load on Substation 2 Feeder 4

4.4.8 Substation 2 Industrial Feeder Summary

Load: In Figure 20 and Figure 21 the summer and winter peaks for this feeder are almost identical.

Power Factor: In Figure 20 and Figure 21 there is no problem with the power factor on this feeder.

4.5 Substation Number 3 Data

4.5.1 Substation Number 3 Configuration

Substation 3 has the following configuration:

Transformers	2 x 100MVA 132/66kV	2 x 20MVA 66/11kV
Capacitor Bank	1 x 24MVar	
Number of Feeders	8 x 11kV	
Ripple Control	Yes	
Peak Load	30.78 MVA	
Number of Customers	7543	

Table 4 - Summary of Substation Number 3 Data

4.5.2 Load growth for Substation Number 3

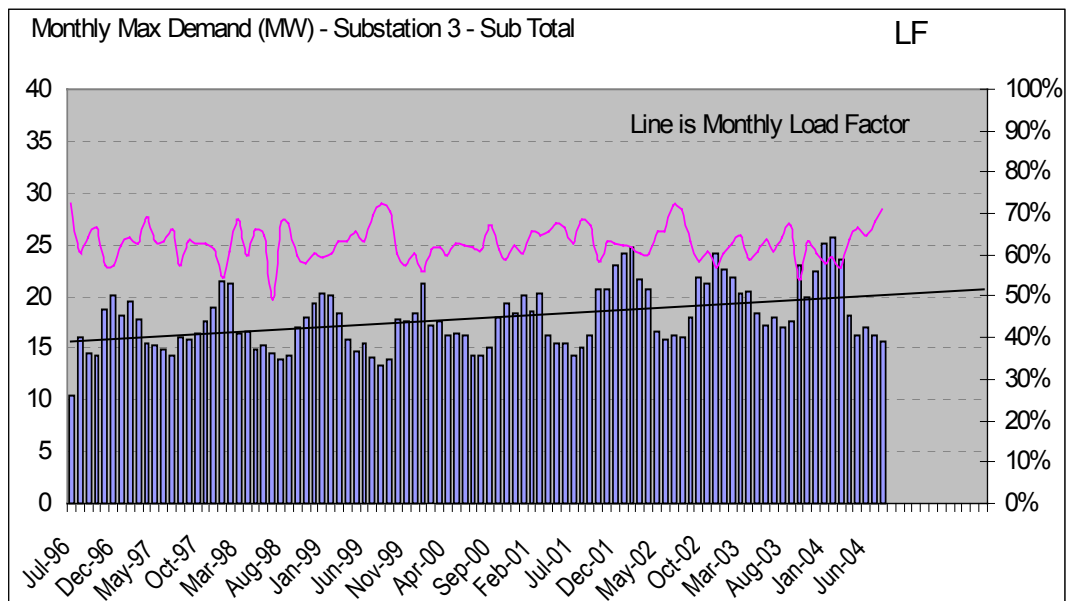


Figure 22 - Graph of Substation 3 Load Growth for the past 9 years

4.5.3 Substation Number 3 Transformer Load Summary

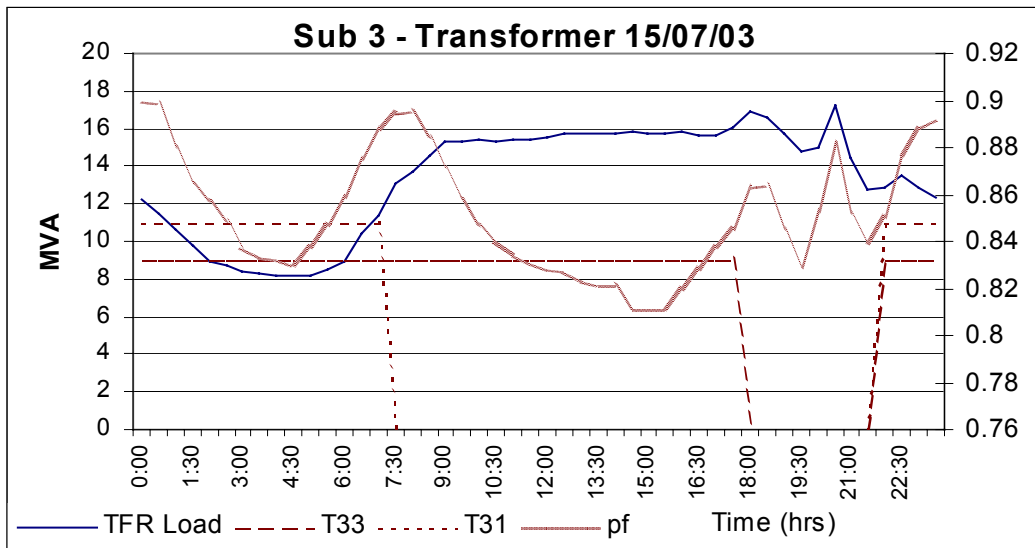


Figure 23 - Graph of the Total Winter Load on Substation 3

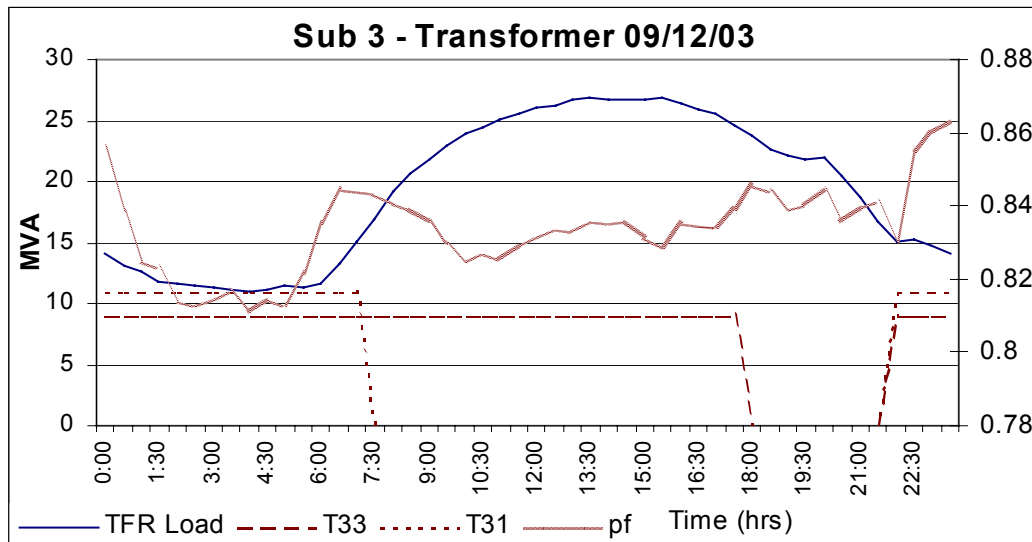


Figure 24 - Graph of the Total Summer Load on Substation 3

4.5.4 Substation 3 Transformer Summary

Load: Figure 23 again shows the load peaks around the 6pm – 8pm timeframe, this also indicates that a review is required on the hotwater switching times. In Figure 24 there is not much that can be done unless better demand-side management practices are employed.

Power Factor: Whilst the power factor in both Figure 23 and Figure 24 appears erratic it only has a narrow bandwidth, however power factor correction may make some difference to the overall load.

4.5.5 Substation Number 3 Example of Domestic Feeder

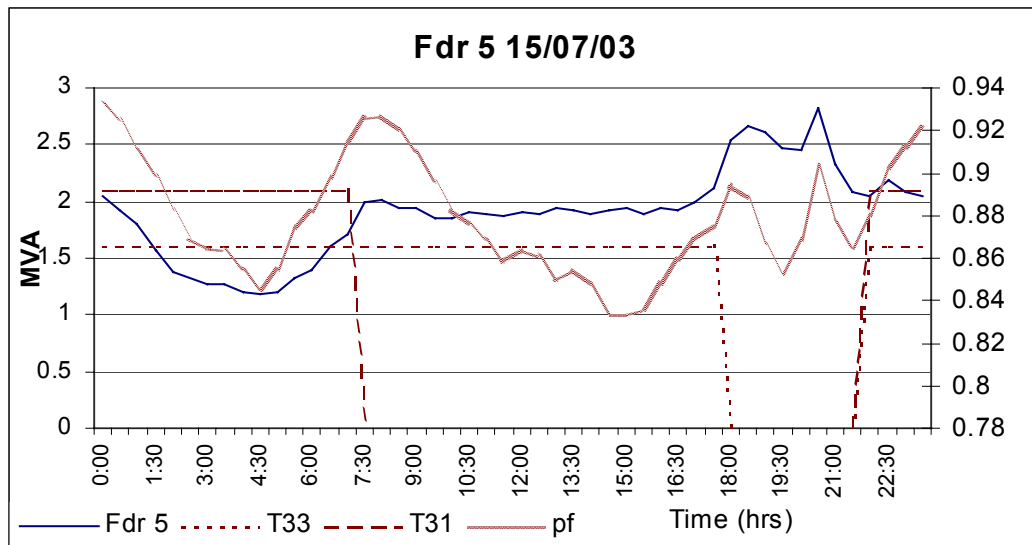


Figure 25 - Graph of the Winter Load on Substation 3 Feeder 5

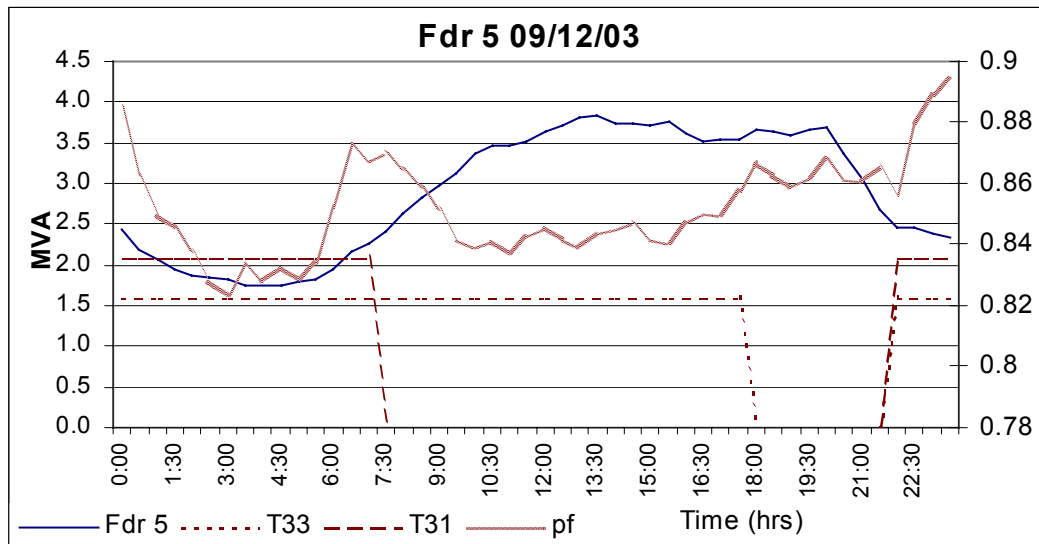


Figure 26 - Graph of the Summer Load on Substation 3 Feeder 5

4.5.6 Substation 3 Domestic Feeder Summary

Load: The winter load in Figure 25 indicates that some work may be required on the hotwater switching times. Also Figure 26 is exceeding the feeder design limit for summer and will need load moved or upgrading.

Power Factor: As can be seen in Figure 25 and Figure 26 the power factor is relatively stable for this feeder.

4.5.7 Substation Number 3 Example of Industrial Feeder

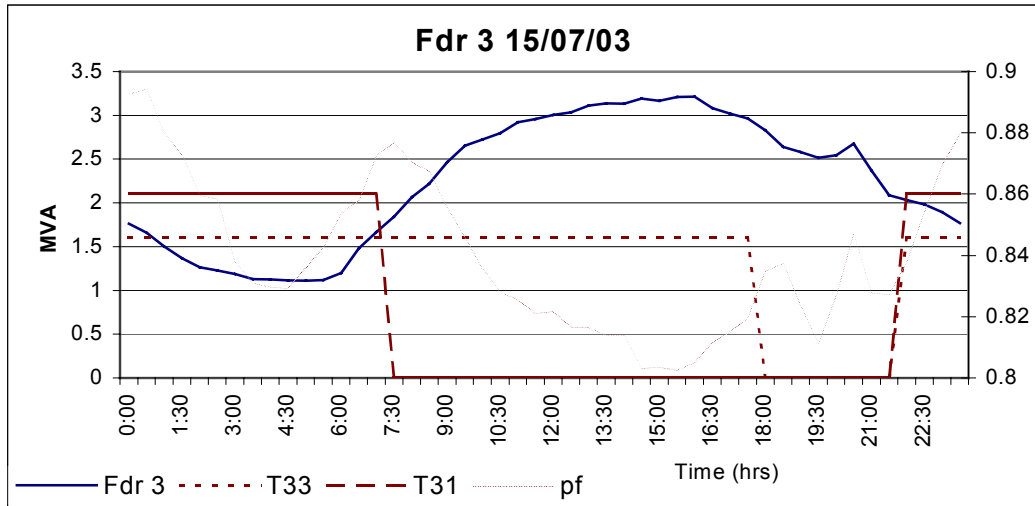


Figure 27 - Graph of the Winter Load on Substation 3 Feeder 3

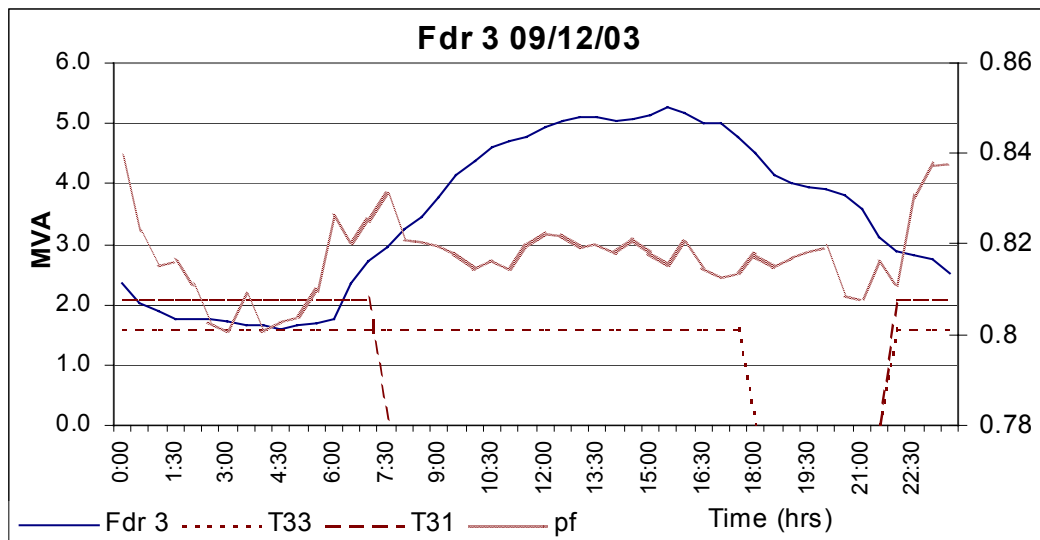


Figure 28 - Graph of the Summer Load on Substation 3 Feeder 3

4.5.8 Substation 3 Industrial Feeder Summary

Load: There is a 2MVA difference between winter (Figure 27) and summer (Figure 28), otherwise this feeder exhibits the typical industrial characteristics.

Power Factor: For both winter (Figure 27) and summer (Figure 28) the power factor is around 0.82-0.84 and it is stable. There would be savings and advantages by improving the power factor to around 0.9.

4.6 Substation Number 4 Data

4.6.1 Substation Number 4 Configuration

Substation 4 has the following configuration:

Transformers	2 x 20MVA 66/11kV
Capacitor Bank	1 x 5.4MVar at 12kV
Number of Feeders	7 x 11kV
Ripple Control	Nil
Peak Load	19.86 MVA
Number of Customers	5131

Table 5 - Summary of Substation Number 4 Data

4.6.2 Load growth for Substation Number 4

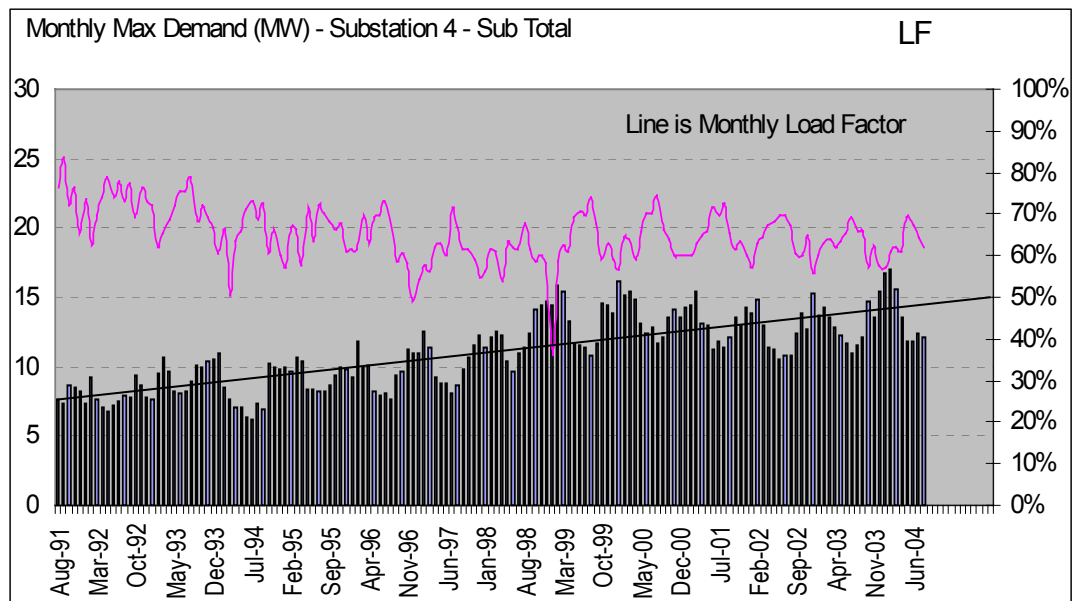


Figure 29 - Graph of Substation 4 Load Growth for the past 14 years

4.6.3 Substation Number 4 Transformer Load Summary

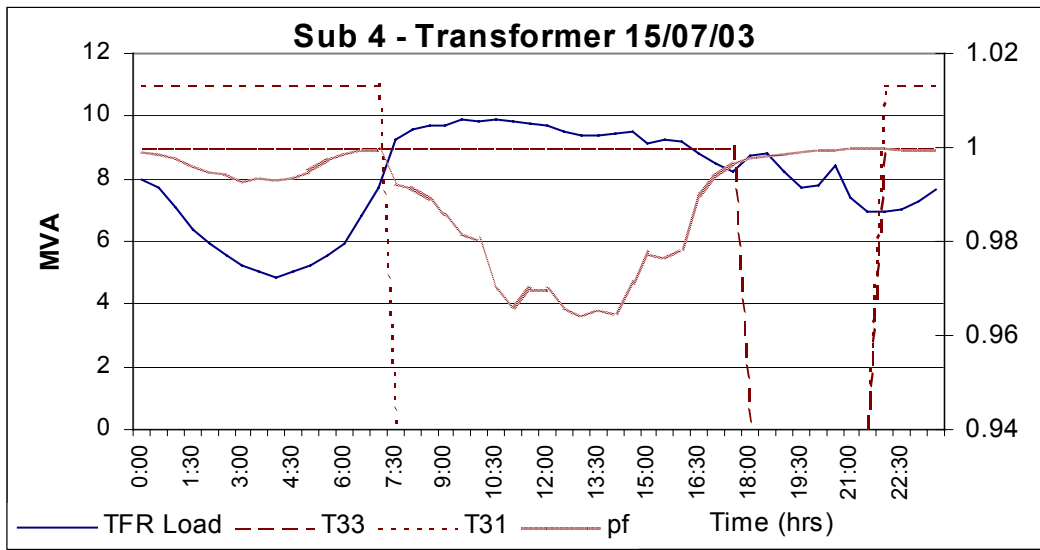


Figure 30 - Graph of the Total Winter Load on Substation 4

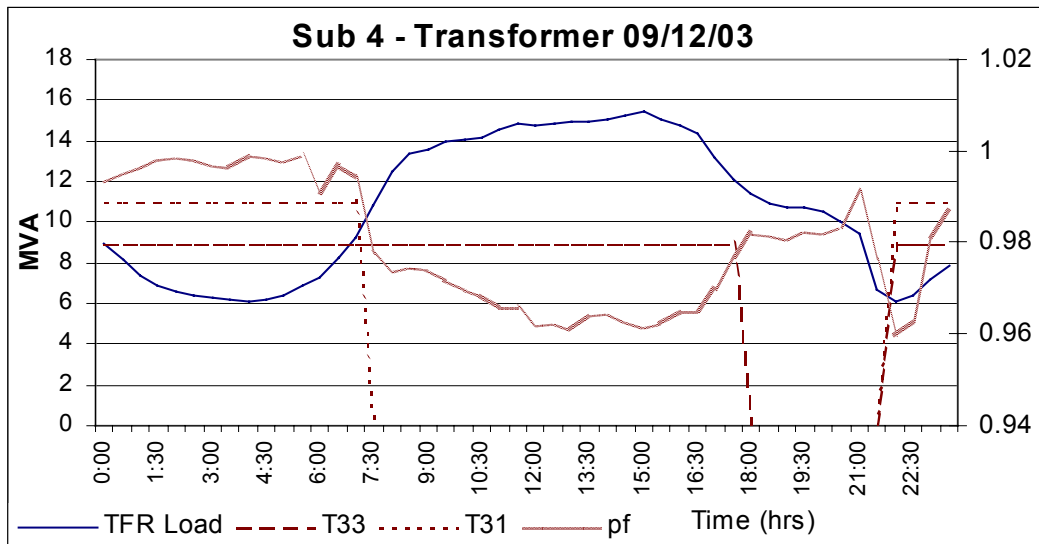


Figure 31 - Graph of the Total Summer Load on Substation 4

4.6.4 Substation 4 Transformer Summary

Load: The winter load in Figure 30 has a morning peak around 9am. The summer load in Figure 31 indicates that better demand-side management practices could make a difference to the overall load profile.

Power Factor: The power factor for both Figure 30 and Figure 31 is good and stable.

4.6.5 Substation Number 4 Example of Domestic Feeder

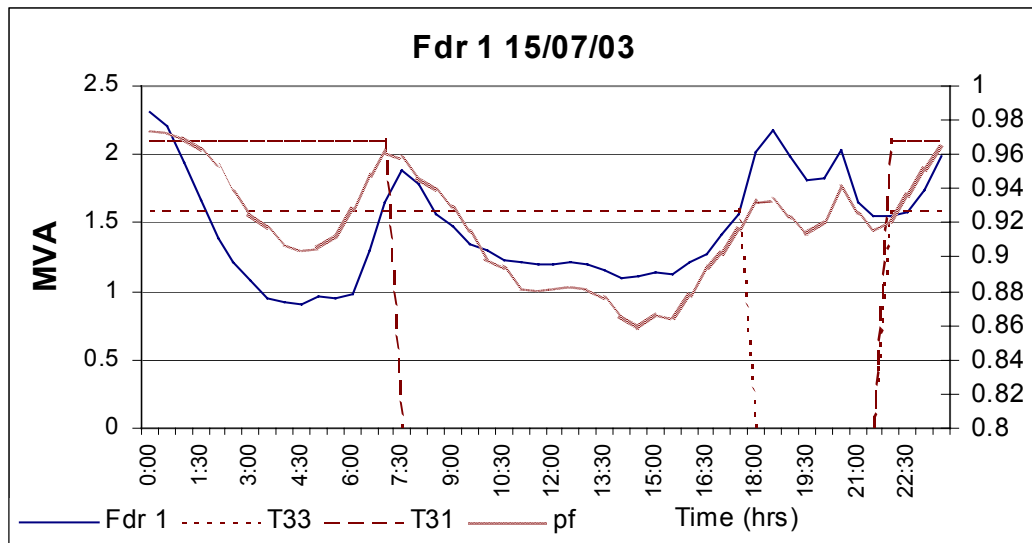


Figure 32 - Graph of the Winter Load on Substation 4 Feeder 1

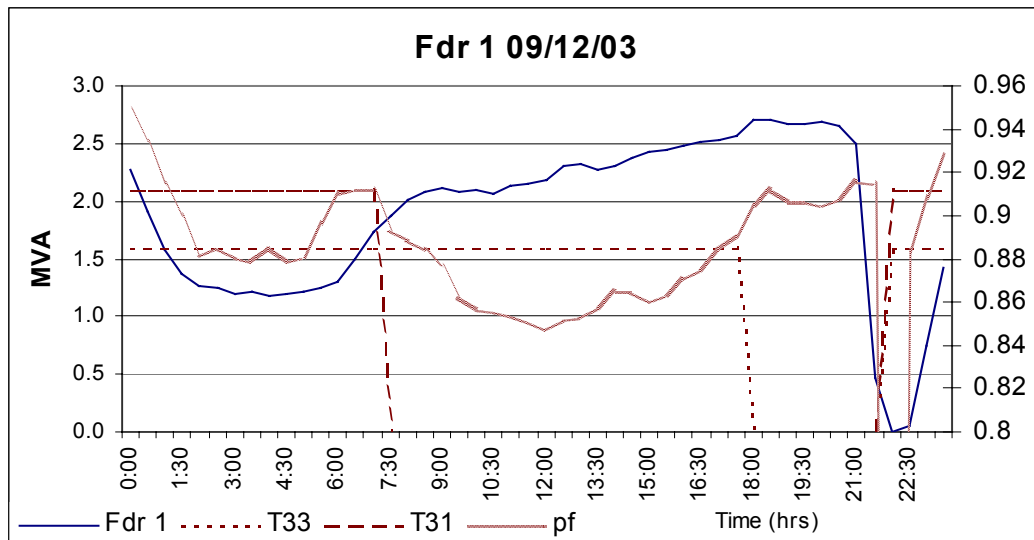


Figure 33 - Graph of the Summer Load on Substation 4 Feeder 1

4.6.6 Substation 4 Domestic Feeder Summary

Load: The winter load in Figure 32 again shows a peak between 6pm and 8pm. The summer load in Figure 33 has a steady ramp up possibly due to air-conditioning load, until an outage at about 10pm.

Power Factor: Except for the outage at 10pm the power factor for both Figure 32 and Figure 33 is stable.

4.6.7 Substation Number 4 Example of Industrial Feeder

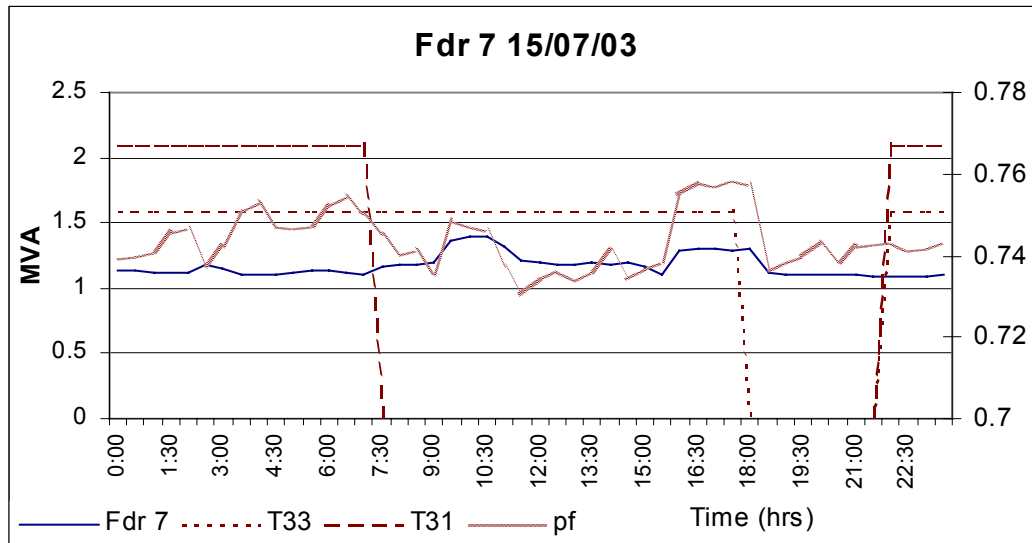


Figure 34 - Graph of the Winter Load on Substation 4 Feeder 7

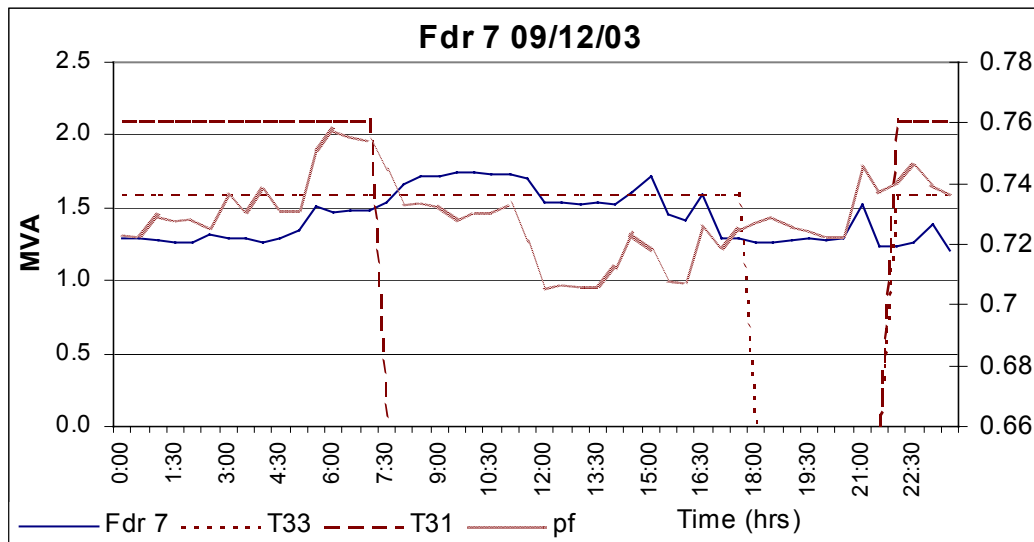


Figure 35 - Graph of the Summer Load on Substation 4 Feeder 7

4.6.8 Substation 4 Industrial Feeder Summary

Load: There is very little load variation for both the winter (Figure 34) and summer (Figure 35) loads.

Power Factor: The power factor for both winter (Figure 34) and summer (Figure 35) is stable, however further investigation is required to determine why this feeder has a low power factor near 0.7.

4.7 Substation Number 5 Data

4.7.1 Substation Number 5 Configuration

Substation 5 has the following configuration:

Transformers	2 x 10MVA 66/22kV
Capacitor Bank	Nil
Number of Feeders	4 x 22kV
Ripple Control	Nil
Peak Load	8.63MVA
Number of Customers	2071

Table 6 - Summary of Substation Number 5 Data

4.7.2 Load growth for Substation Number 5

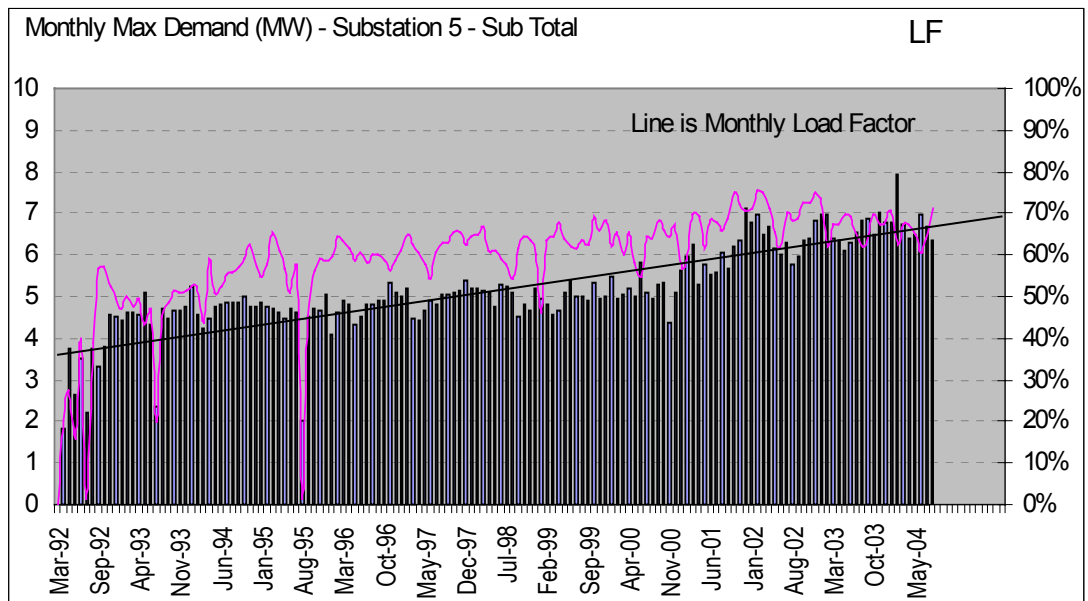


Figure 36 - Graph of Substation 5 Load Growth for the past 13 years

4.7.3 Substation Number 5 Transformer Load Summary

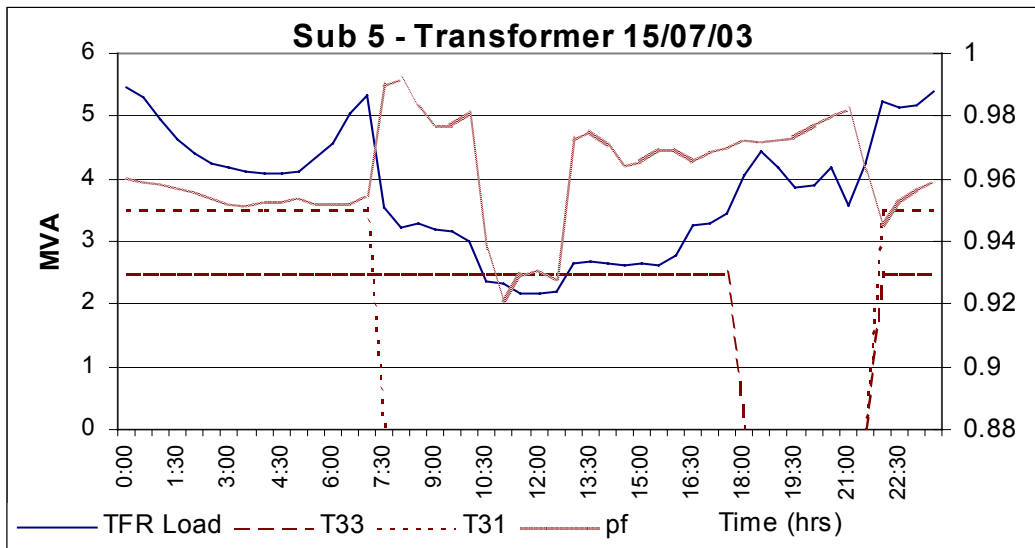


Figure 37 - Graph of the Total Winter Load on Substation 5

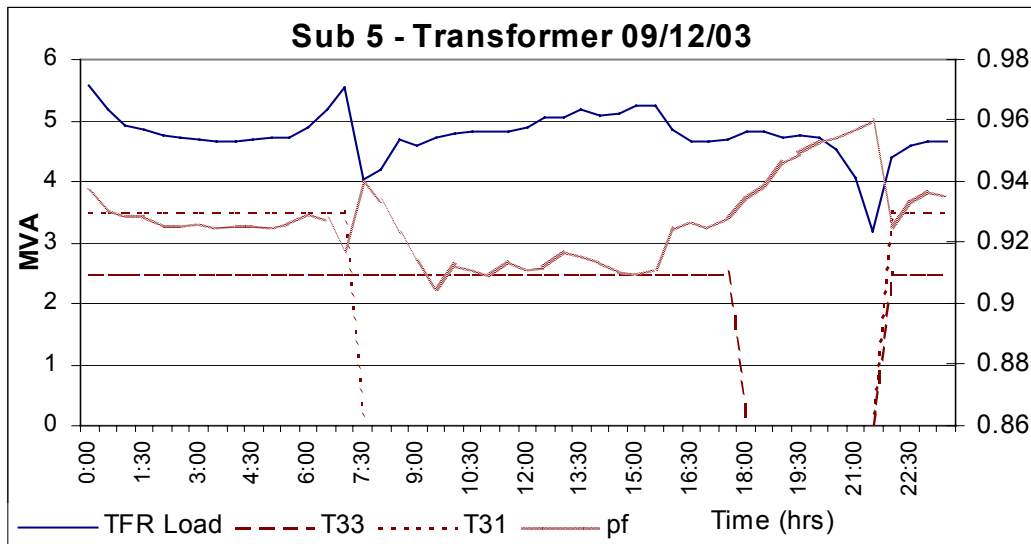


Figure 38 - Graph of the Total Summer Load on Substation 5

4.7.4 Substation 5 Transformer Summary

Load: In Figure 37 and Figure 38 there is a 6am peak that will require further investigation, although it is prevalent in both summer and winter it indicates that there maybe an industrial load that needs to be to start and finish approximately a half an hour earlier.

Power Factor: The power factor for both winter (Figure 37) and summer (Figure 38) is good and stays above 0.9, almost reaching unity.

4.7.5 Substation Number 5 Example of Domestic Feeder

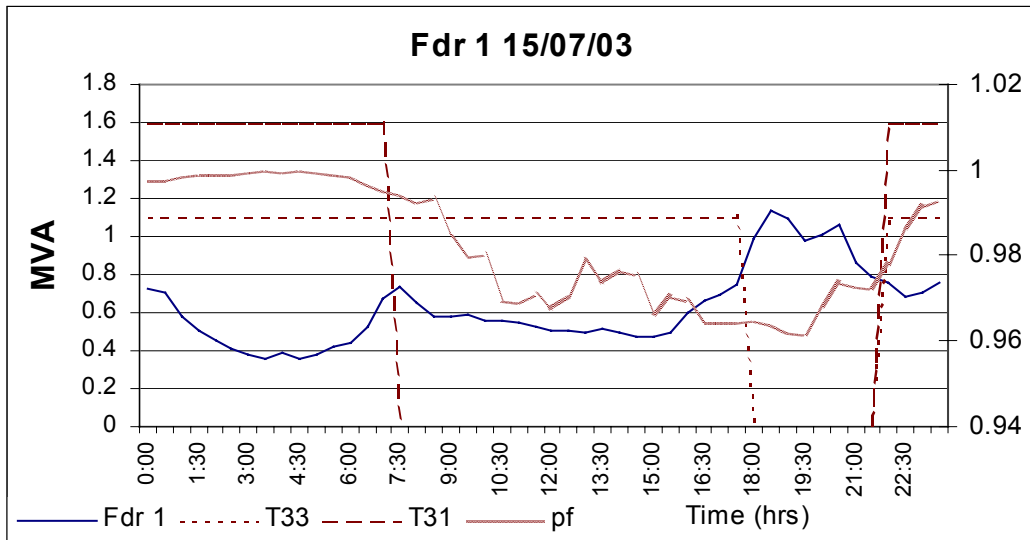


Figure 39 - Graph of the Winter Load on Substation 5 Feeder 1

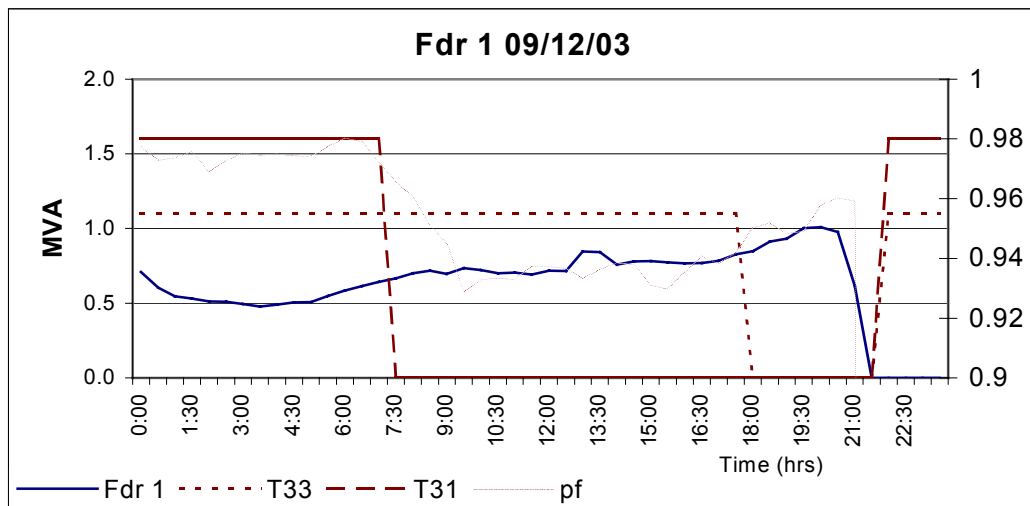


Figure 40 - Graph of the Summer Load on Substation 5 Feeder 1

4.7.6 Substation 5 Domestic Feeder Summary

Load: The winter load (Figure 39) peaks between 6pm and 8pm need further investigation. However the winter peak is larger than the summer (Figure 40) peak, even though there is an outage at approximately 10pm.

Power Factor: The power factor in both Figure 39 and Figure 40 is good and stable.

4.7.7 Substation Number 5 Example of Industrial Feeder

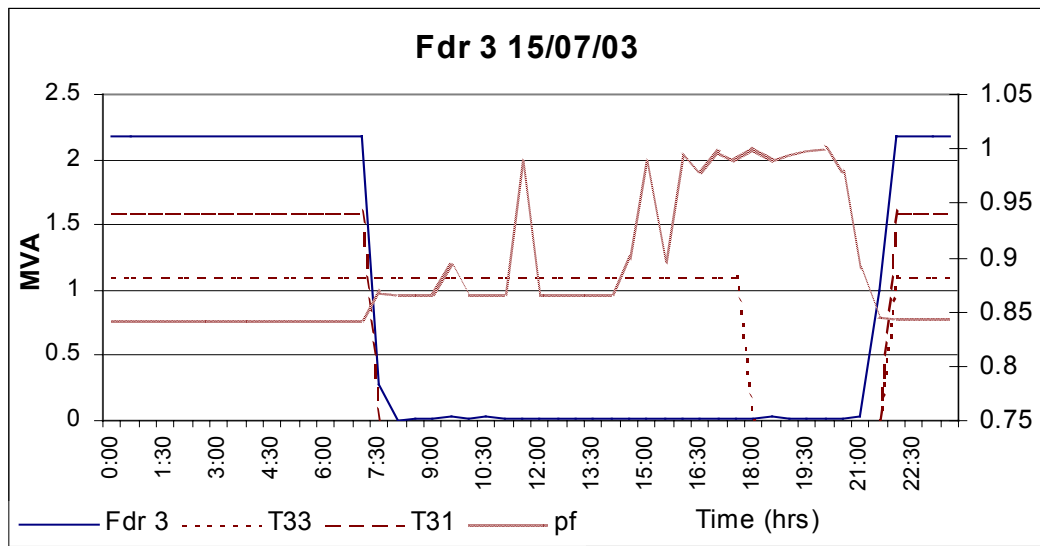


Figure 41 - Graph of the Winter Load on Substation 5 Feeder 3

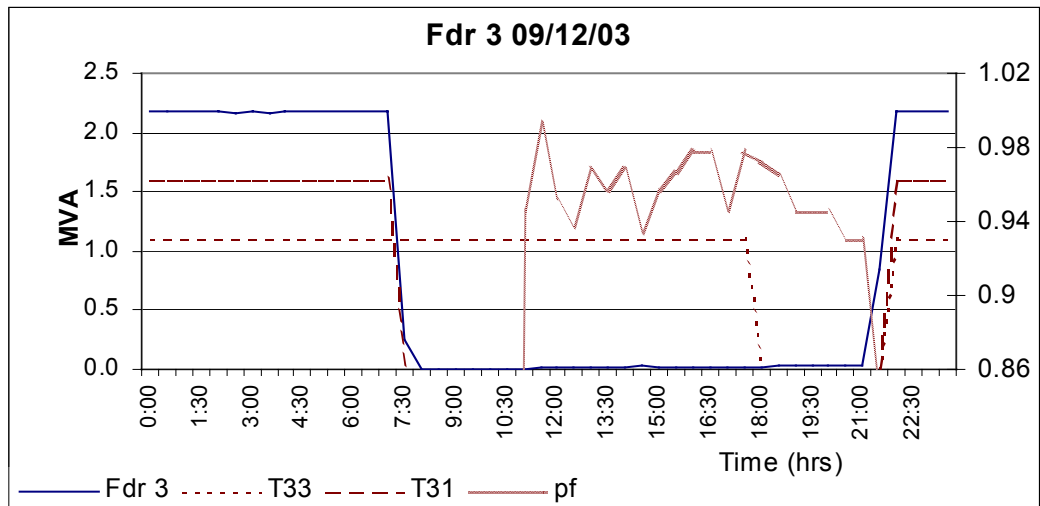


Figure 42 - Graph of the Summer Load on Substation 5 Feeder 3

4.7.8 Substation 5 Industrial Feeder Summary

Load: Figure 40 and Figure 41 depicts a feeder that has a dedicated pumping load that utilises off peak times to pump water. This feeder combined with a typical industrially loaded substation would possibly make an ideal feeder.

Power Factor: The power factor in both Figure 40 and Figure 41 is typical of a dedicated pumping load with motor starting not being detected due to the fact that the data is read in 15 minute intervals.

4.8 Substation Number 6 Data

4.8.1 Substation Number 6 Configuration

Substation 6 has the following configuration:

Transformers	2 x 20MVA 66/11kV
Capacitor Bank	1 x 5.4MVar at 12kV
Number of Feeders	6 x 11kV
Ripple Control	Nil
Peak Load	20.78 MVA
Number of Customers	6372

Table 7- Summary of Substation Number 6 Data

4.8.2 Load growth for Substation Number 6

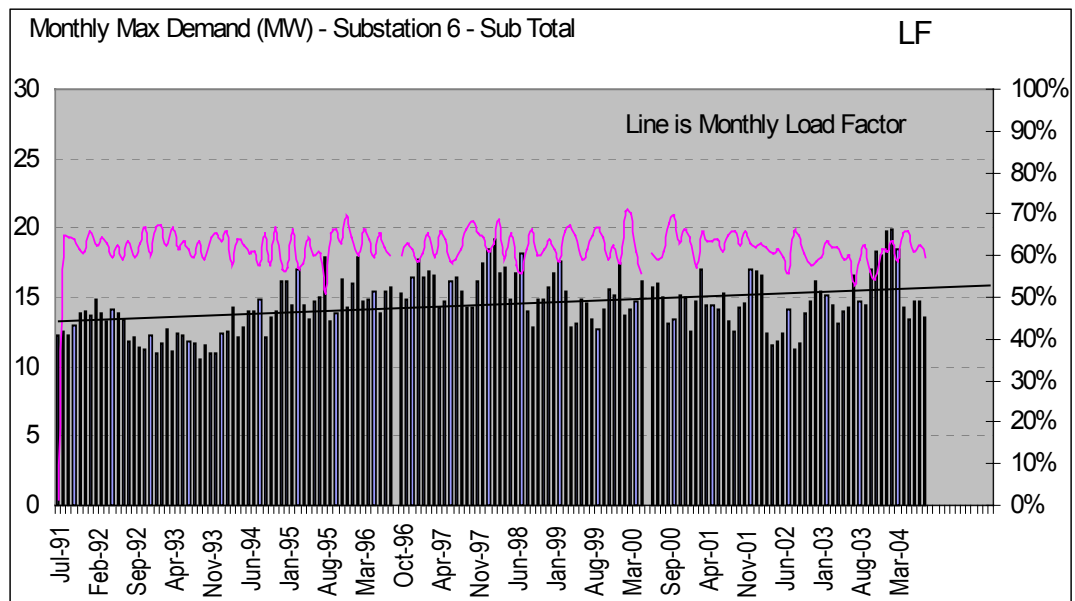


Figure 43- Graph of Load Growth for 13 years for Substation 6

4.8.3 Substation Number 6 Transformer Load Summary

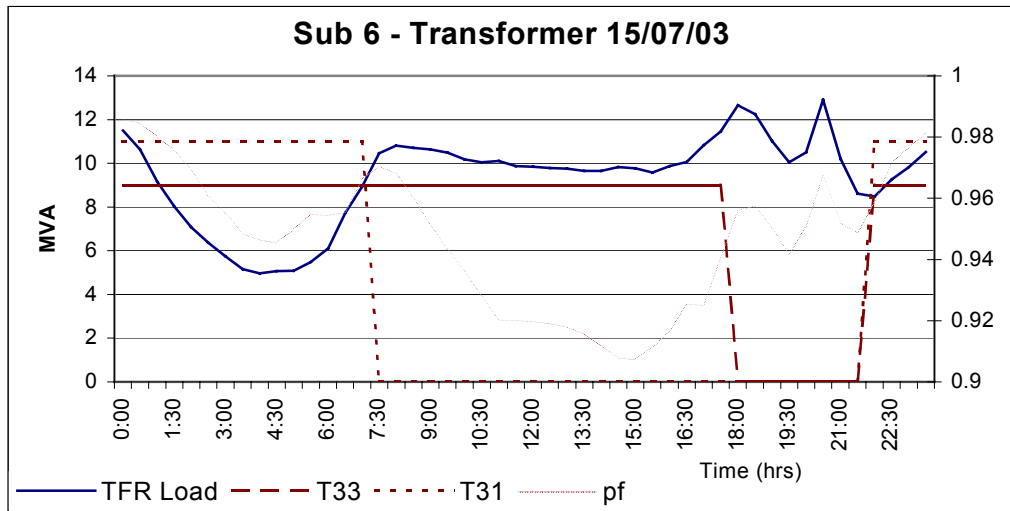


Figure 44 - Graph of the Total Winter Load on Substation 6

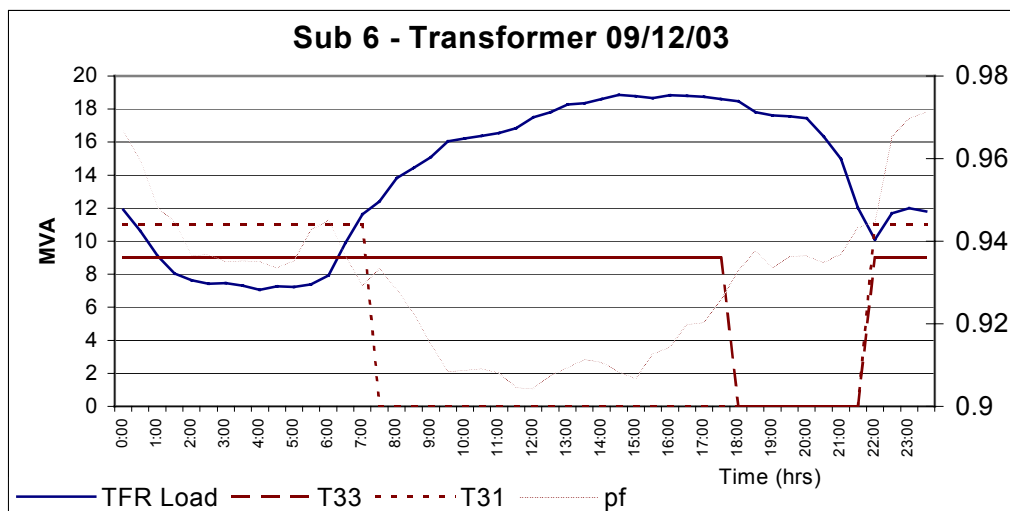


Figure 45 - Graph of the Total Summer Load on Substation 6

4.8.4 Substation 6 Transformer Summary

Load: Figure 44 shows that the winter load peaks between 6pm and 8pm, this needs further investigation. The summer load in Figure 45 is approximately 6MVA higher than the winter peak, this is possibly due to air-conditioner load.

Power Factor: The power factor in Figure 44 and Figure 45 remains above 0.9 and is stable.

4.8.5 Substation Number 6 Example of Domestic Feeder

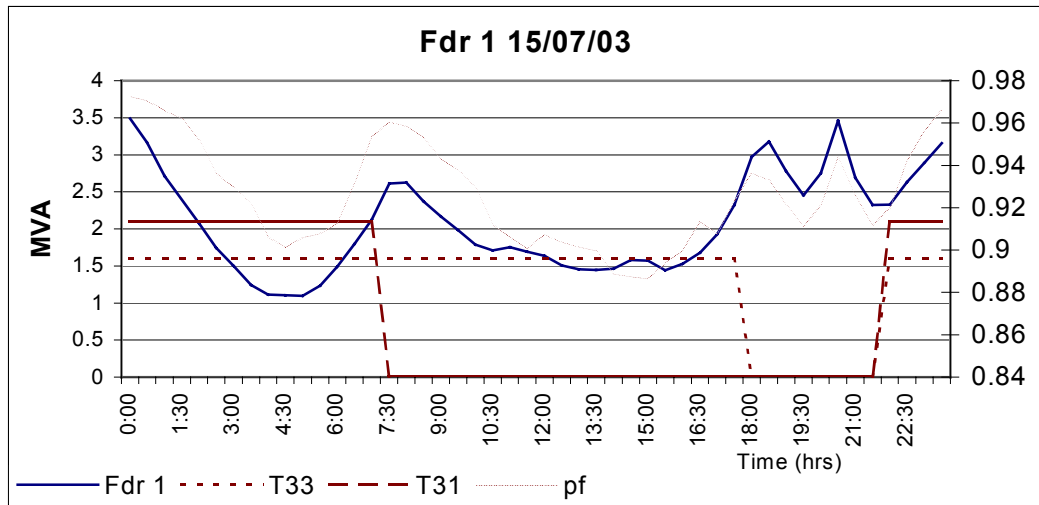


Figure 46 - Graph of the Winter Load on Substation 6 Feeder 1

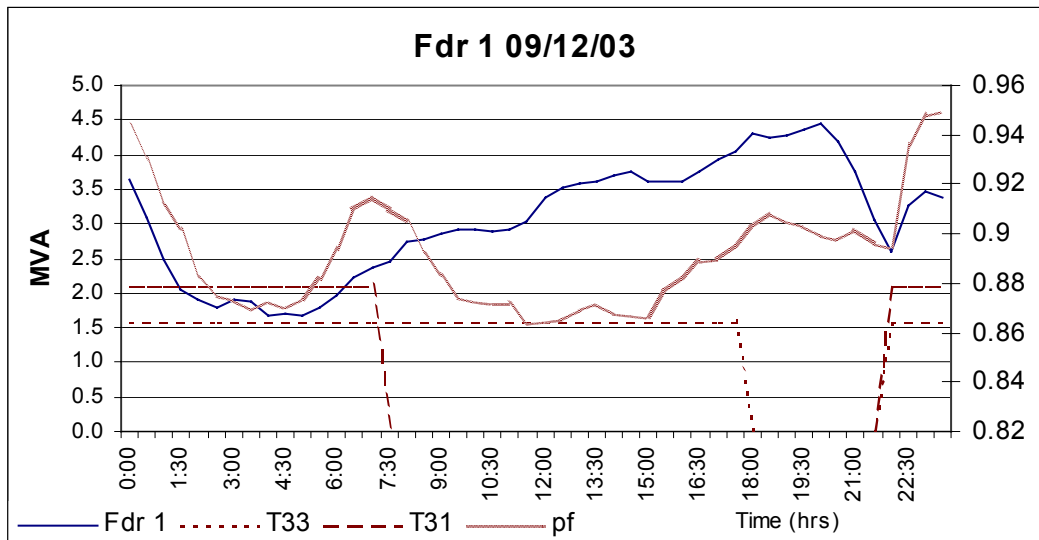


Figure 47 - Graph of the Summer Load on Substation 6 Feeder 1

4.8.6 Substation 6 Domestic Feeder Summary

Load: In Figure 46 the winter peaks between 6pm and 8pm and then again at midnight, all of these indicate that there is an issue with the hotwater control. The summer load in Figure 47 again shows a typical ramp up due to air-conditioning usage.

Power Factor: The power factor in Figure 46 and Figure 47 is relatively stable although it does get down to 0.86 in summer.

4.8.7 Substation Number 6 Example of Industrial Feeder

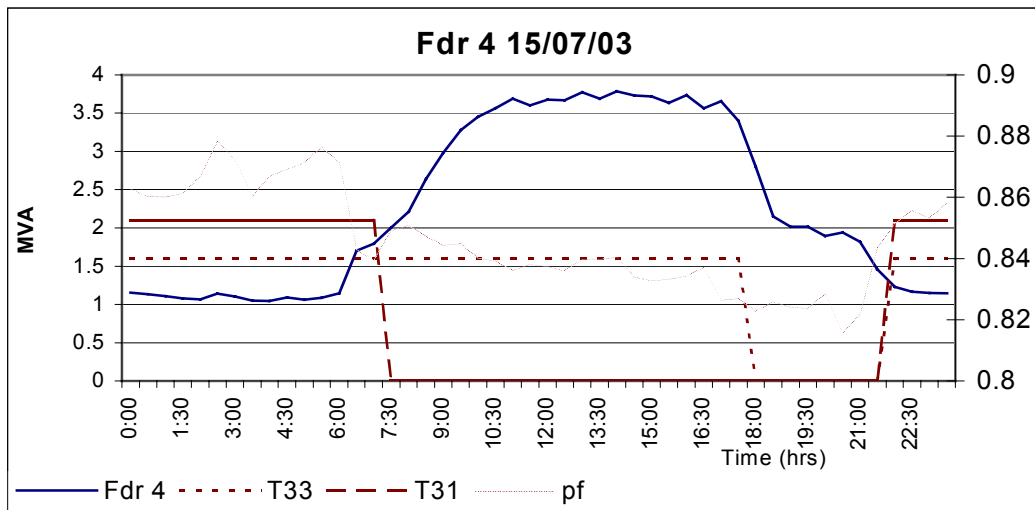


Figure 48 - Graph of the Winter Load on Substation 6 Feeder 4

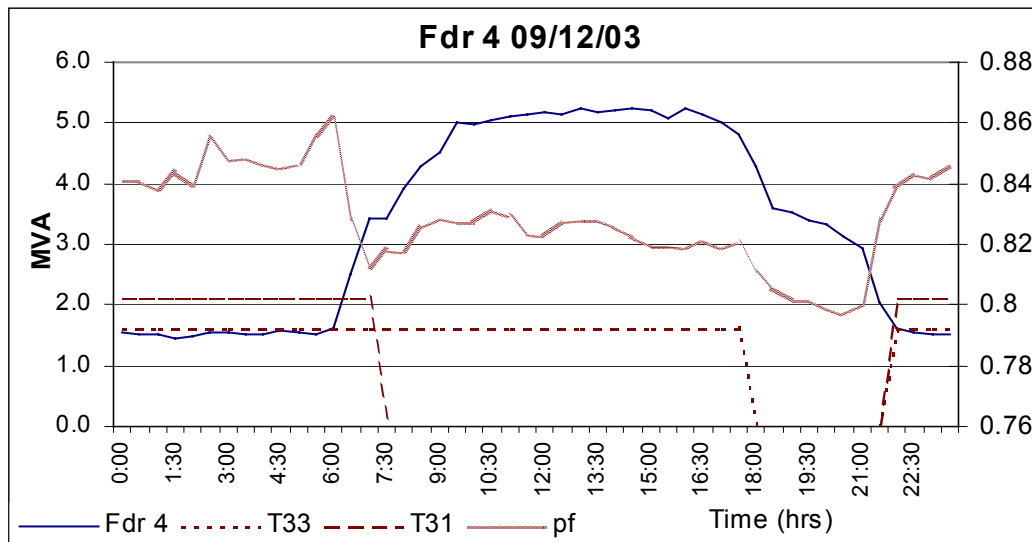


Figure 49 - Graph of the Summer Load on Substation 6 Feeder 3

4.8.8 Substation 6 Industrial Feeder Summary

Load: The feeder depicted in Figure 48 and Figure 49 is a typical industrial, however demand-side management options will be limited due to the types of load that are experienced on this feeder.

Power Factor: If the power factor of the feeder in Figure 48 and Figure 49 was improved to around 0.9 there may be some slight improvement in load and voltages.

4.9 Substation Number 7 Data

4.9.1 Substation Number 7 Configuration

Substation 7 has the following configuration:

Transformers	2 x 20MVA 66/11kV
Capacitor Bank	4 x 3MVar at 13.5kV
Number of Feeders	7 x 11kV
Ripple Control	Nil
Peak Load	21.69 MVA
Number of Customers	2558

Table 8 - Summary of Substation Number 7 Data

4.9.2 Load growth for Substation Number 7

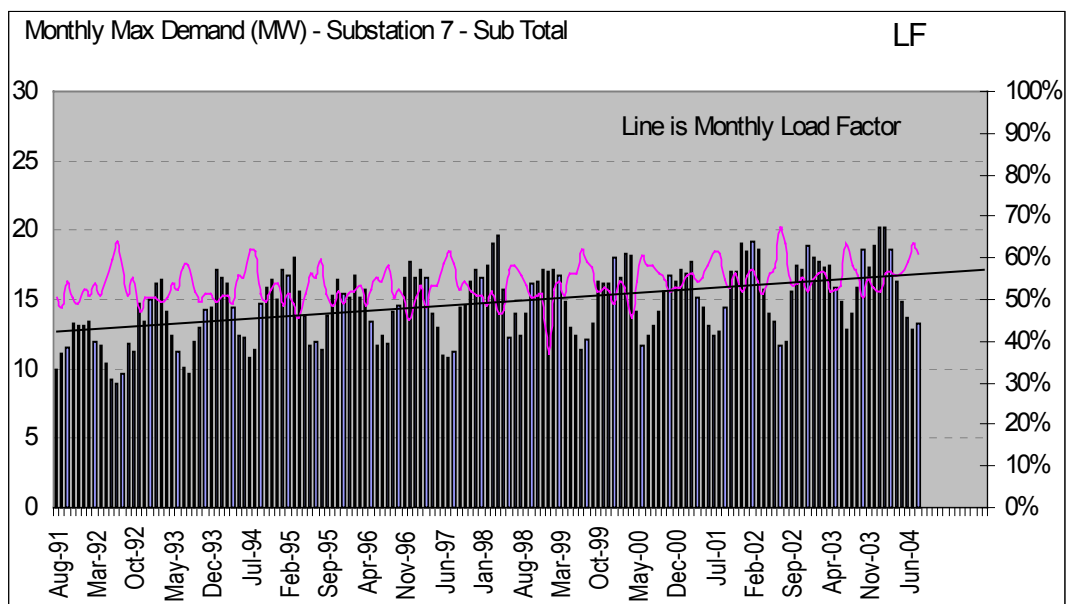


Figure 50 - Graph of Load Growth for 14 years for Substation 7

4.9.3 Substation Number 7 Transformer Load Summary

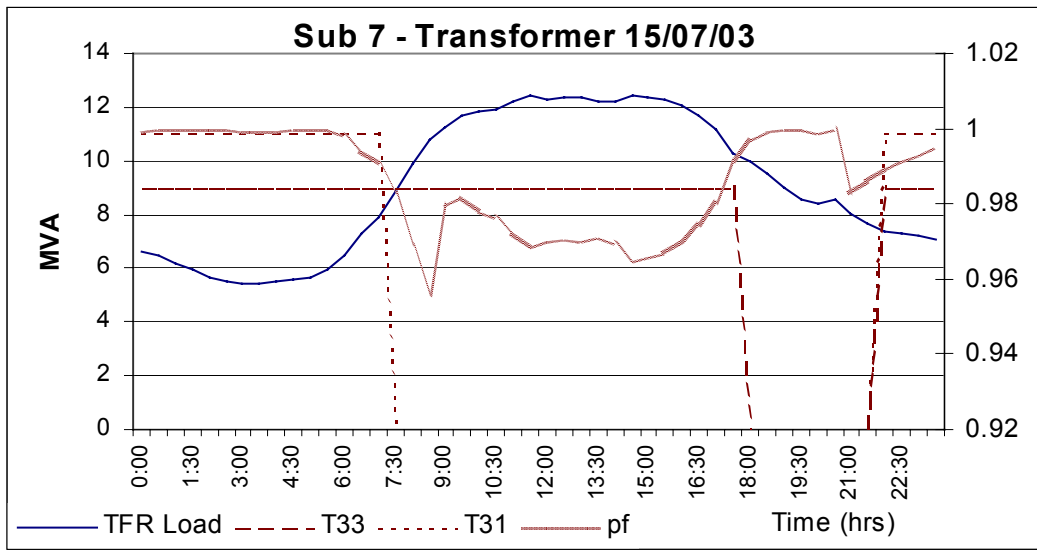


Figure 51 - Graph of the Total Winter Load on Substation 7

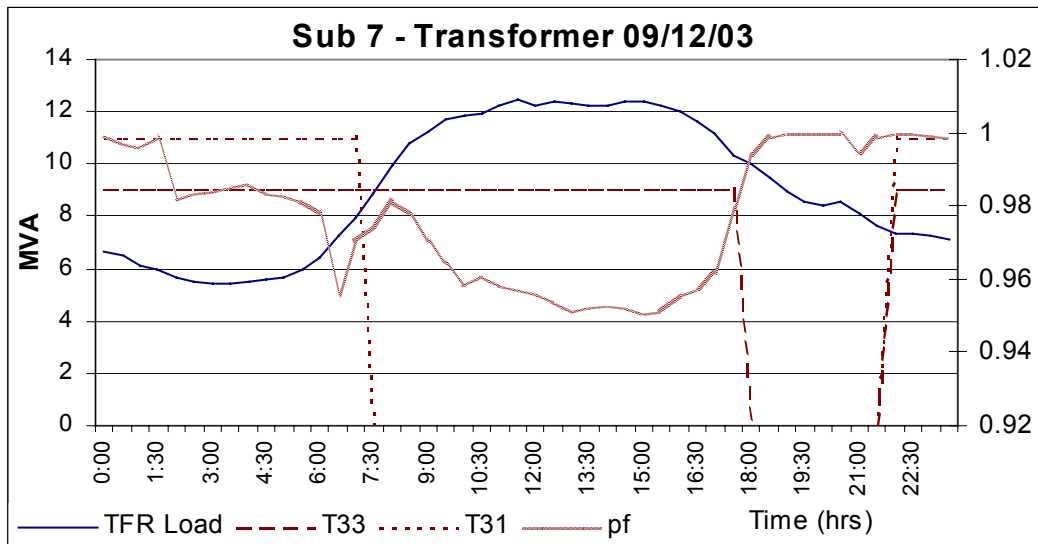


Figure 52 - Graph of the Total Summer Load on Substation 7

4.9.4 Substation 7 Transformer Summary

Load: The impact of industrial load is very evident in Figure 51 and Figure 52, with the summer and winter load profiles almost identical.

Power Factor: The power factor in this substation is relatively stable and as shown in Figure 51 and Figure 52, this is due to the capacitor banks the load profile of which is included in Figure 57 and Figure 58.

4.9.5 Substation Number 7 Example of Domestic Feeder

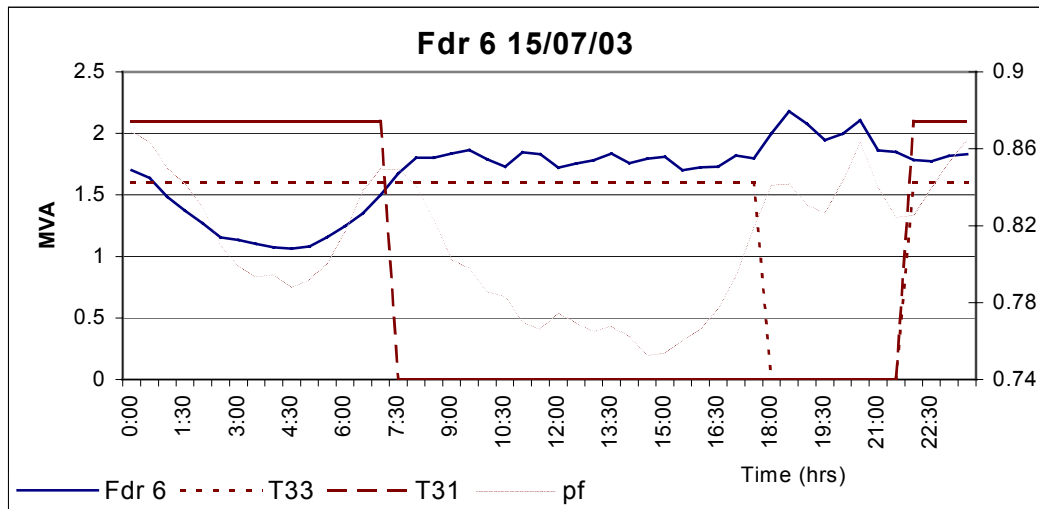


Figure 53 - Graph of the Winter Load on Substation 7 Feeder 6

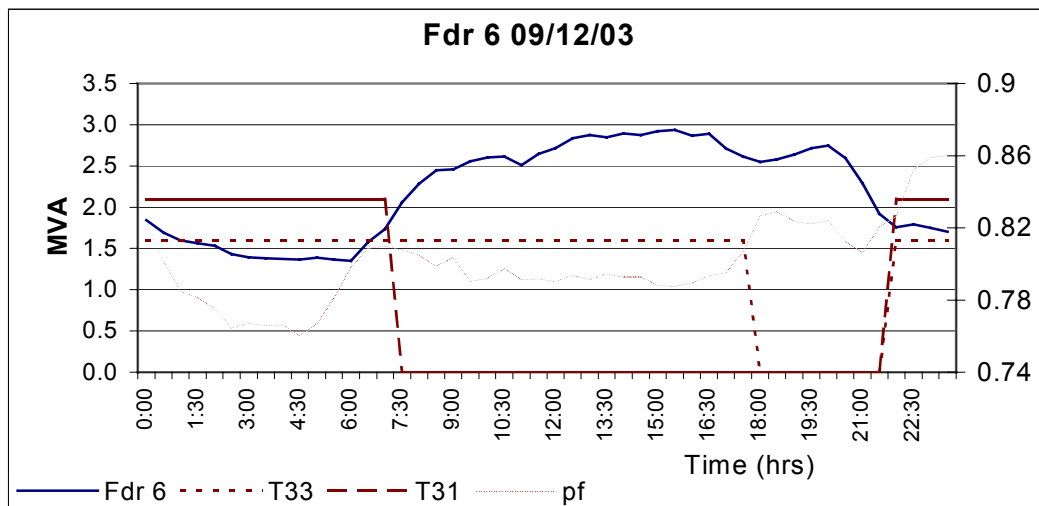


Figure 54 - Graph of the Summer Load on Substation 7 Feeder 6

4.9.6 Substation 7 Domestic Feeder Summary

Load: Minor peaks occur in Figure 53 between 6pm and 8pm. The summer load in Figure 54 indicates a heavy air-conditioner load during the day with approximately a 30% load increase.

Power Factor: Whilst the power factor in Figure 53 and Figure 54 is relatively stable, the power factor does get down to 0.76 during winter which would be good to improve.

4.9.7 Substation Number 7 Example of Industrial Feeder

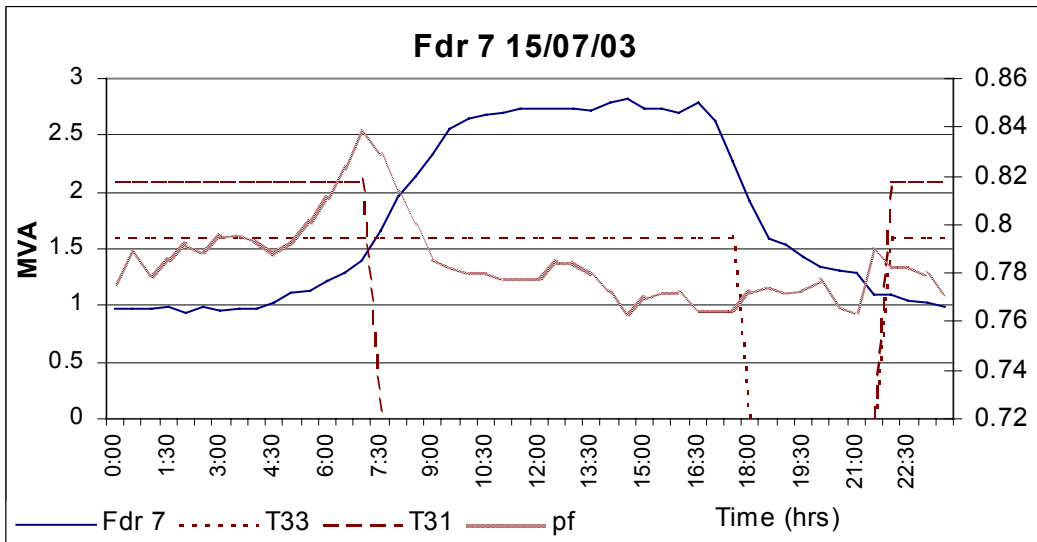


Figure 55 - Graph of the Winter Load on Substation 7 Feeder 7

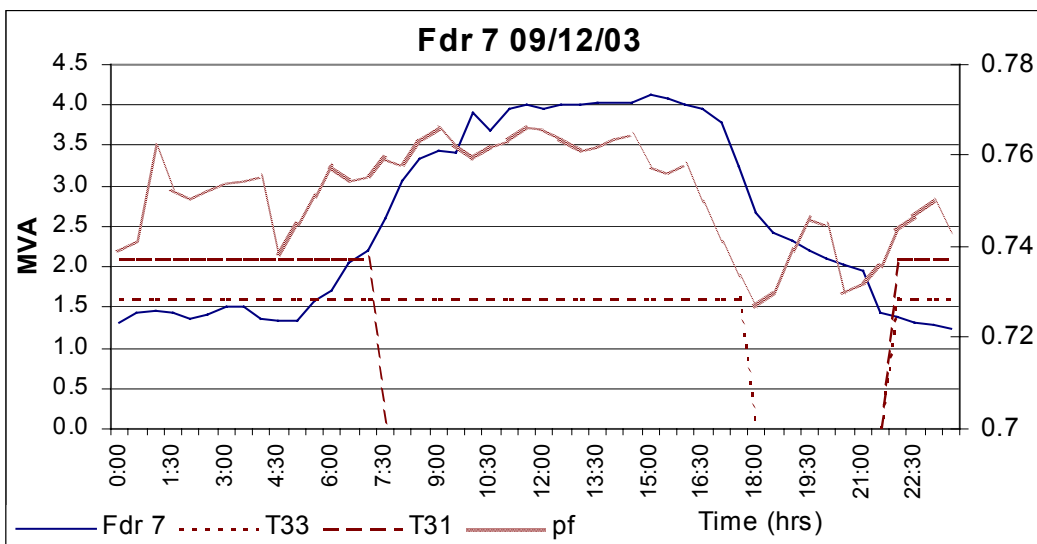


Figure 56 - Graph of the Summer Load on Substation 7 Feeder 7

4.9.8 Substation 7 Industrial Feeder Summary

Load: Figure 55 represents the winter load profile, whilst Figure 56 represents the summer load profile, both are similar. Demand side management options that smooth the profile would make a significant improvement in this feeder.

Power Factor: The power factor for Figure 55 and Figure 56 is relatively stable, however by increase same to average around the 0.9 mark could make significant improvements in the overall performance of the substation.

4.9.9 Substation Number 7 Example of Capacitor Bank Operation

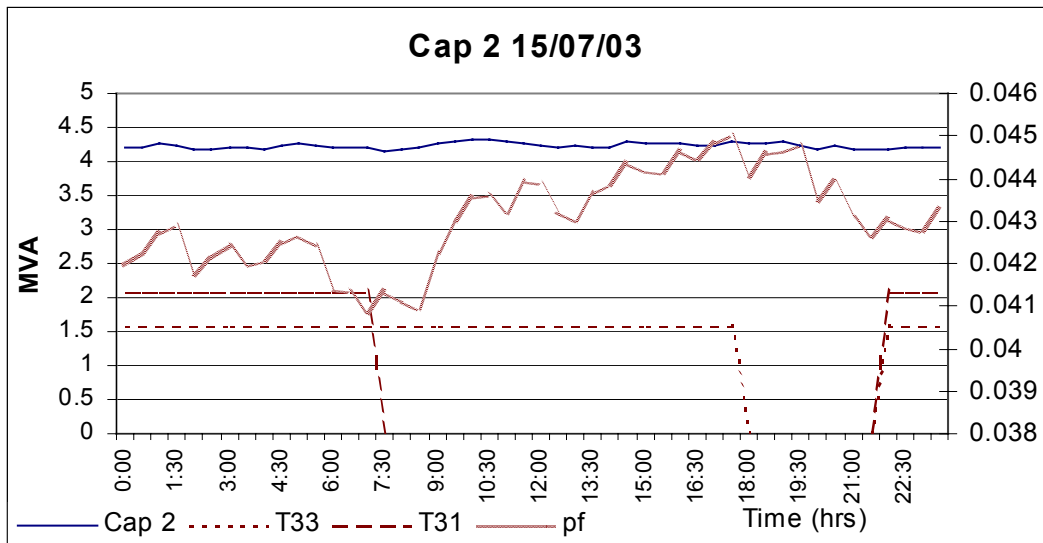


Figure 57 - Graph of the Winter Load on Substation 7 Capacitor Bank

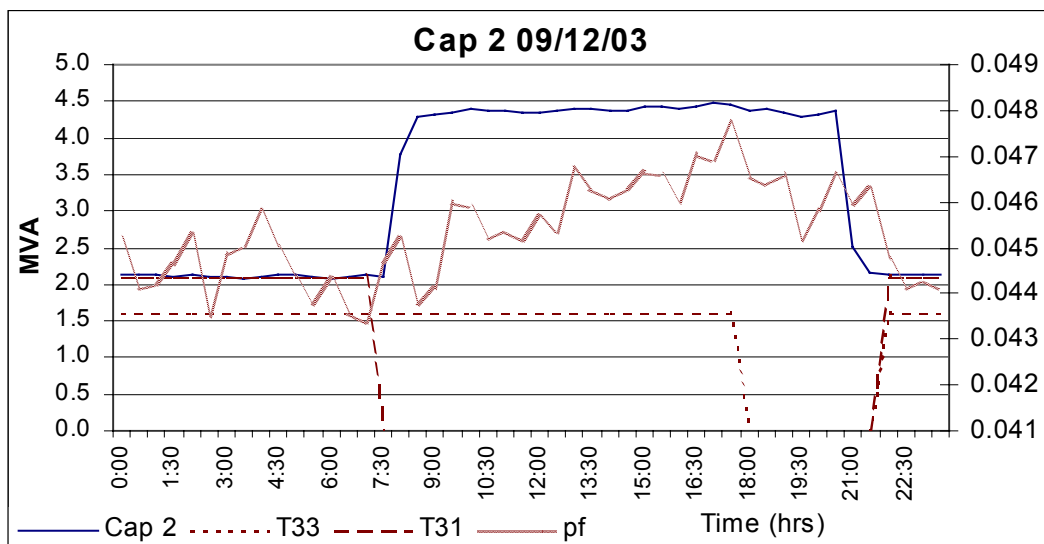


Figure 58 - Graph of the Summer Load on Substation 7 Capacitor Bank

4.9.10 Substation 7 Capacitor Bank Summary

The load profile for both Figure 57 and Figure 58 should be flat and stable as they are actually only either on or off and a “dedicated” source that provides voltage and power factor support. The power factor for these figures indicates that the angle is very steep and there is relatively no resistive load on the system as explained in section 2.3.2.

4.10 Substation Number 8 Data

4.10.1 Substation Number 8 Configuration

Substation 8 has the following configuration:

Transformers	2 x 10MVA 66/11kV
Capacitor Bank	Nil
Number of Feeders	3 x 11kV
Ripple Control	Nil
Peak Load	5.5MVA
Number of Customers	2187

Table 9 - Summary of Substation Number 8 Data

4.10.2 Substation Number 8 Transformer Load Summary

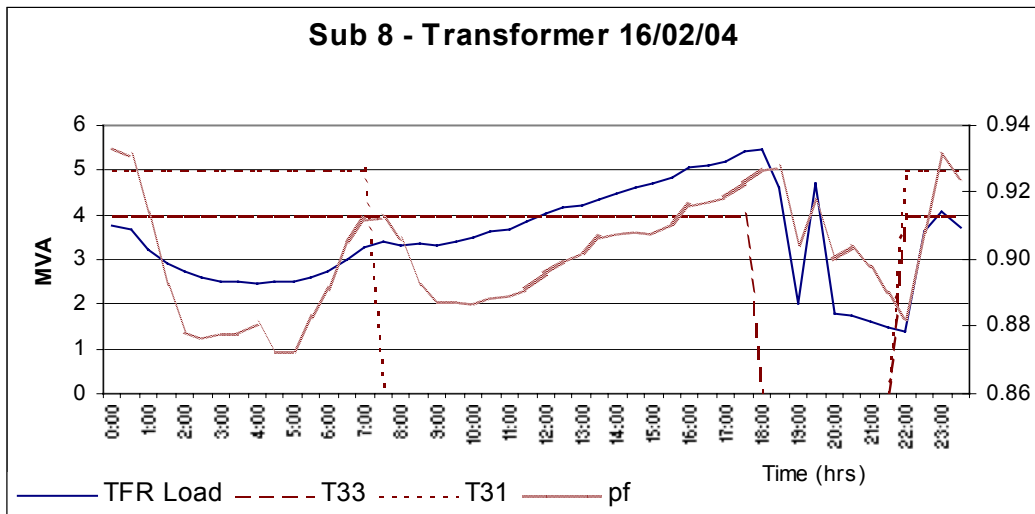


Figure 59 - Graph of the Total Summer Load on Substation 8

4.10.3 Substation 8 Transformer Summary

Load: Figure 59 shows there is a steady increase in load through out the day reaching 220% of its over night load. The outage at about 7pm and 8pm was caused by storms in the area of Feeder 1.

Power Factor: The power factor shown in Figure 59 is above approximately 0.87 however it is relatively unstable and ramps up with the load. This substation may benefit from a capacitor bank.

4.10.4 Substation Number 8 Example of Feeder

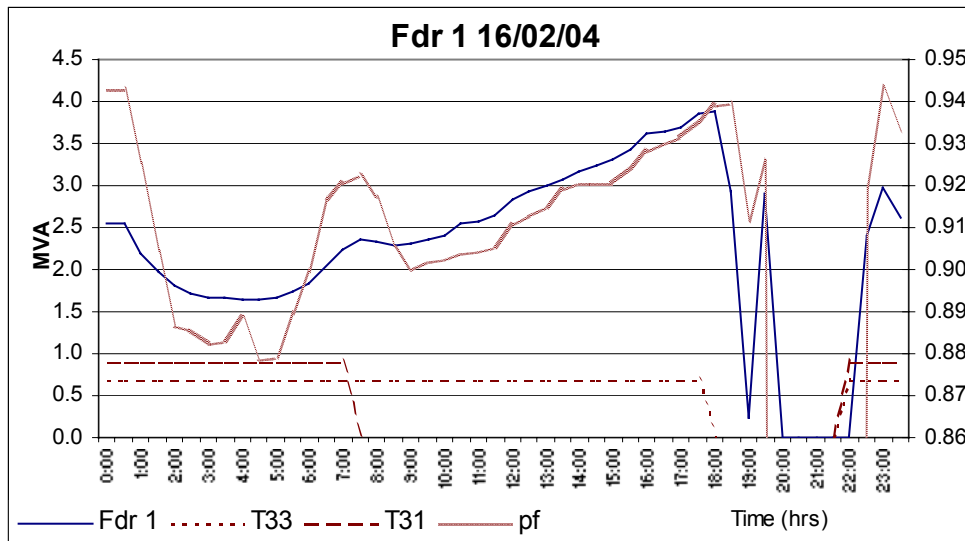


Figure 60 - Graph of the Summer Load on Substation 8 Feeder 1

4.10.5 Substation 8 Feeder Summary

Load: Figure 60 shows a similar path to the substation load as can be expected as this feeder on its own is carrying approximately 69% of the substation load. It would be advantageous from a reliability and operational perspective to spread the load over all feeders more evenly.

Power Factor: The power factor in Figure 60 follows the same path as the power factor demonstrated in Figure 59 and reaches approximately 0.87 however it is relatively unstable and ramps up with the load. This feeder may benefit from a capacitor bank on the feeder near the primary load source.

4.11 Substation Number 9 Data

4.11.1 Substation Number 9 Configuration

Substation 9 has the following configuration:

Transformers	2 x 20MVA 66/11kV
Capacitor Bank	1 x 5.4MVar at 13.5kV
Number of Feeders	5 x 11kV
Ripple Control	Nil
Peak Load	19.90 MVA
Number of Customers	5045

Table 10 - Summary of Substation Number 9 Data

4.11.2 Load growth for Substation Number 9

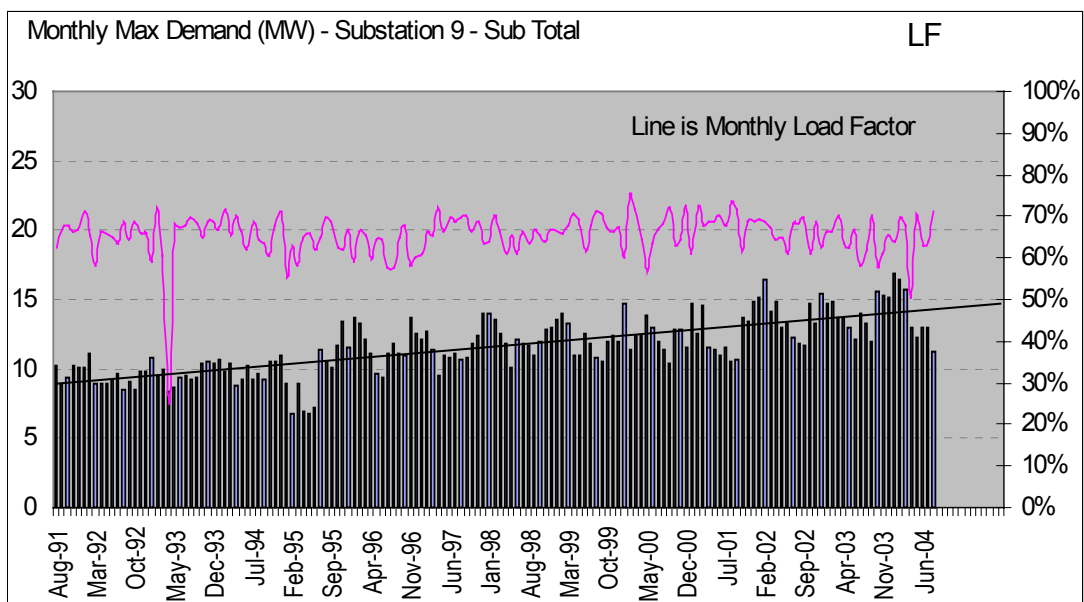


Figure 61 - Graph of Load Growth for 14 years for Substation 9

4.11.3 Substation Number 9 Transformer Load Summary

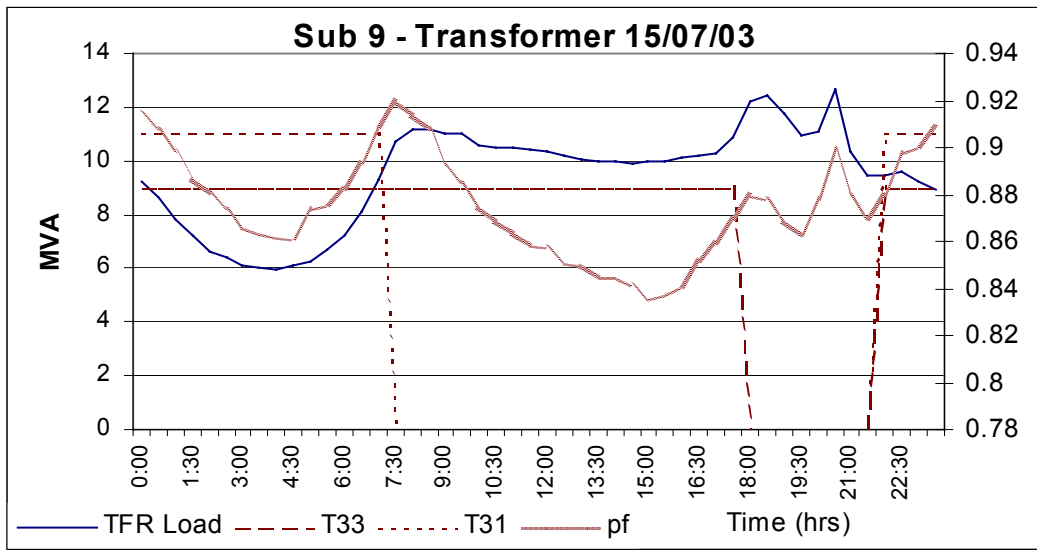


Figure 62 - Graph of the Total Winter Load on Substation 9

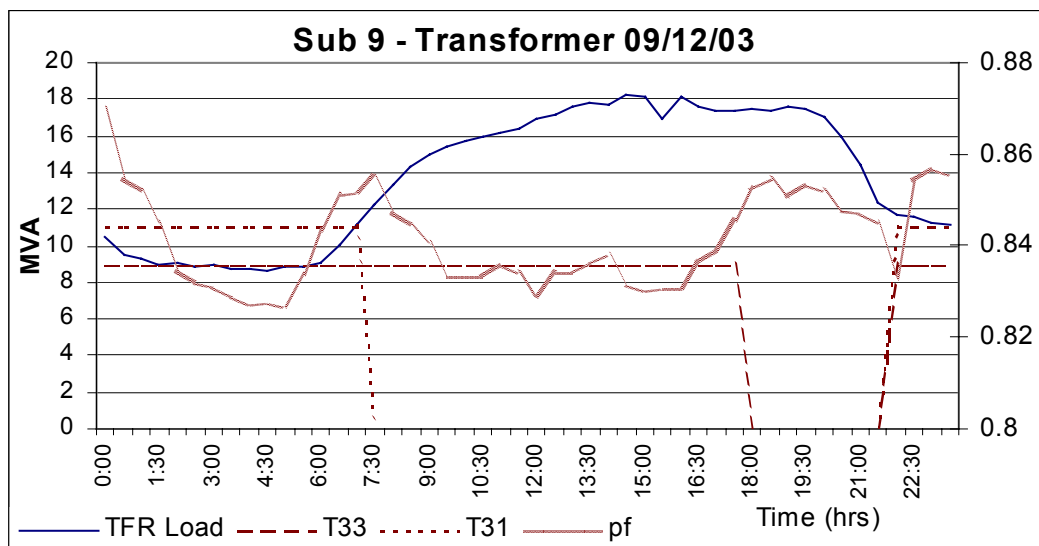


Figure 63 - Graph of the Total Summer Load on Substation 9

4.11.4 Substation 9 Transformer Summary

Load: The winter load profile in Figure 62 needs to be improved as there are peaks between 6pm and 8pm that show an increase of approximately 2MVA. Figure 63, the summer load is impacted predominantly by air-conditioning load and approximately 5MVA higher than winter.

Power Factor: The power factor in Figure 62 and Figure 63 is stable, however it does get as low as 0.83.

4.11.5 Substation Number 9 Example of Domestic Feeder

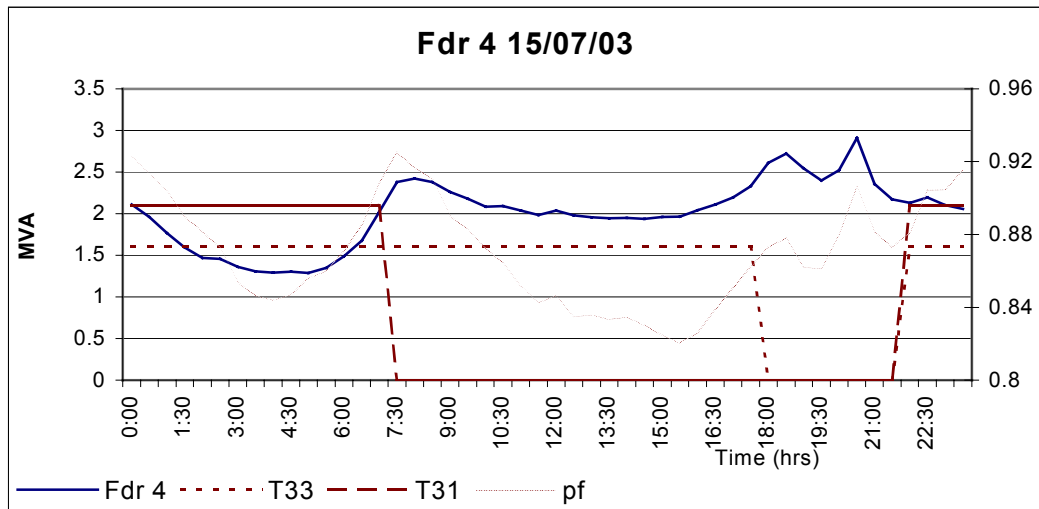


Figure 64 - Graph of the Winter Load on Substation 9 Feeder 4

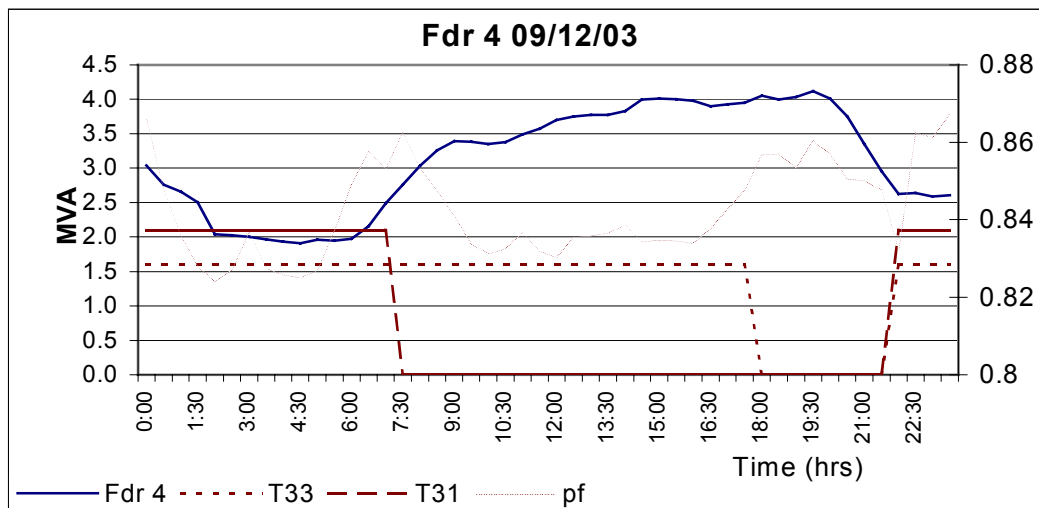


Figure 65 - Graph of the Summer Load on Substation 9 Feeder 4

4.11.6 Substation 9 Domestic Feeder Summary

Load: The feeder depicted in Figure 64 and Figure 65 is a miniature version of the transformer load profiles in Figure 62 and Figure 63 and the same issues need to be looked at.

Power Factor: The power factor in Figure 64 and Figure 65 is very similar to the transformer load profiles in Figure 62 and Figure 63.

4.11.7 Substation Number 9 Example of Domestic / Industrial Feeder

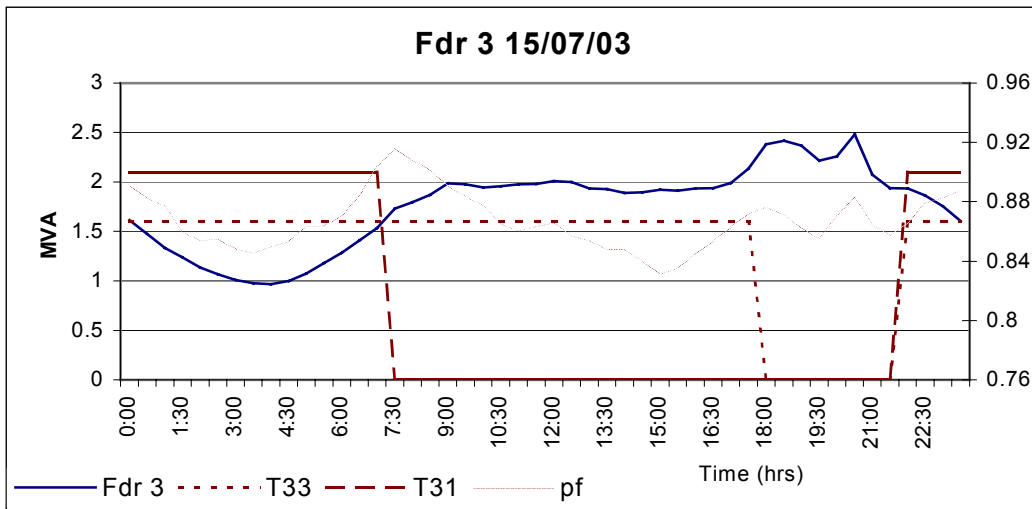


Figure 66 - Graph of the Winter Load on Substation 9 Feeder 3

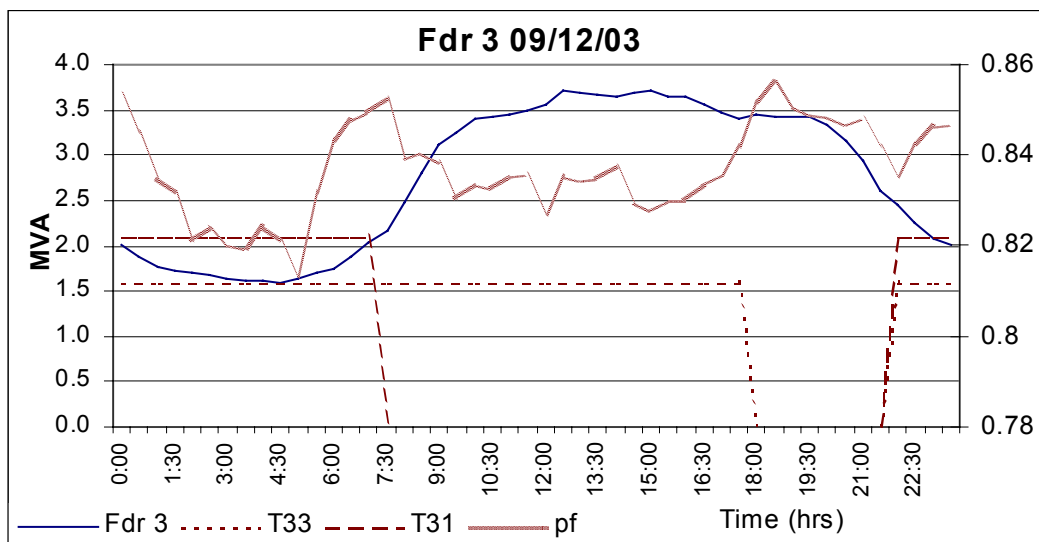


Figure 67 - Graph of the Summer Load on Substation 9 Feeder 3

4.11.8 Substation 9 Industrial Feeder Summary

Load: The winter load profile in Figure 66 peaks between 6pm and 8pm need to be addressed. The summer load profile in Figure 67 is approximately 1.1MVA higher than the winter load.

Power Factor: The power factor in Figure 66 and Figure 67 is relatively stable, however a slight improvement may help reduce load.

4.12 Discussion of Results

Overall the results in each of the substations were very similar and in general reasonably good, however listed below are some issue that may assist in improving the overall performance of each substation and the feeders in general.

- Load peaks between 6pm and 9pm.
- Low feeder power factor.
- Air-conditioning load.
- Improved demand-side management options.
- Capacitor banks effectiveness.

4.12.1 6pm Load peaks

The two peaks in load between 6pm and 9pm are generally at approximately 6.30pm and 8.30pm.

Code	Description	OFF	ON	OFF	ON	OFF	ON	OFF	ON
Bits 4,7,8,12-26 27 ON, 28 OFF	Hotwater – Economy Channel 1	18:30	21:00						
Bits 4,7,8,12-26 29 ON, 30 OFF	Hotwater – Economy Channel 2	18:00	19:30	20:15	21:15				
Bits 4,7,8,12-26 31 ON, 32 OFF	Hotwater – Economy Channel 3	18:15	20:15	21:00	21:45				
Bits 4,7,8,12-26 33 ON, 34 OFF	Hotwater – Economy Channel 4	18:45	20:45	21:30	22:00				
Bits 4,7,8,12-26 35 ON, 36 OFF	Hotwater – Economy Channel 5	18:30	19:15	20:15	21:00	21:30	22:00		
Bits 4,7,8,12-26 37 ON, 38 OFF	Hotwater – Economy Channel 6	18:15	18:45	19:15	19:45	20:15	20:45	21:15	21:45

Table 11 - Table of signal sent for Tariff 33 switching between 6pm and 10pm

As can be seen in Table 11 signals are sent to turn on all of the channels for tariff 33, between 6pm and 10pm. These turn on loads, which are hotwater, air-conditioning and any other form of load included on the tariff 33. I would recommend that a review be carried out to spread the above switching times out further to remove the peaks off the winter time loads.

4.12.2 Low feeder power factor

A few of the feeders exhibit low power factor down as low as approximately 0.7, whilst the impact on the substation is limited due to the capacitor banks providing correction. However it may be an option to consider including small shunt capacitors near the locations where the load is or where the predominate cause of the low power factor is.

This would reduce the impact on the load on the substation, by adding a 100kVAr capacitor into feeder; the feeder current can be reduced by approximately 10.7% as demonstrated below. The power factor can also be improved by approximately 5.5%.

Example 1:

Assuming a feeder has a load of 838kW and a reactive load of 763kVAr, this gives:

$$S = \sqrt{P^2 + Q^2} = \sqrt{838^2 + 763^2} = 1133kVA$$
$$pf = \cos(\arctan(763/838)) = 0.739$$
$$Current(A) = S / (22 * pf) = 69.69A$$

Example 2:

By inserting a 100kVA capacitor in the feeder and assuming that there is no impact on the resistive load of the feeder the following results:

$$S = \sqrt{P^2 + Q^2} = \sqrt{838^2 + 663^2} = 1069kVA$$
$$pf = \cos(\arctan(663/838)) = 0.784$$
$$Current(A) = S / (22 * pf) = 61.95A$$

Example 3:

As can be seen by reducing the kVA reactive of the feeder has a significant impact on the feeder. This was assuming there was no impact on the resistive load, however by assuming a 10kW increase in the resistive load the following results:

$$S = \sqrt{P^2 + Q^2} = \sqrt{848^2 + 663^2} = 1077kVA$$
$$pf = \cos(\arctan(663/848)) = 0.787$$
$$Current(A) = S / (22 * pf) = 62.13A$$

Whilst example 3 is not as good as example 2, it is clear that both are significantly better than example 1. In the case of this feeder to obtain a power factor of better than 0.9 approximately 400kVAr of capacitance would be required on the feeder.

4.12.3 Air-conditioning

As can be seen in most feeder and substations the impact of air-conditioning load on the feeders and substation is enormous. It is therefore suggested that demand-side management options be considered for reducing the impact of the air-conditioning loads on feeders and substations.

With the implementation of a congestion pricing arrangement, such that any air-conditioning load used during the summer demand times would be charged at a higher rate, would form part of a user pay system that is based on a fair system of use.

The cost of the congestion pricing used needs to reflect the real cost of upgrading feeders and old equipment due to the unexpected increases in load. The increases in load would have to take into account sudden changes and not those that should be accounted for in normal planning parameters.

4.12.4 Improved demand-side management options

Customers on Industrial feeders who consume large amounts of electricity load during the demand times need to be aware of their individual impact on the electrical network. It is recommended that further consideration be given to implementing a form of demand-side management that would improve the incentive of consumers to assist in the reduction of load during peak demand times.

4.12.5 Capacitor Bank effectiveness

In general the effectiveness of the capacitor banks in the substations that have been analysed has been good, however one of the substations had its capacitor bank out of service for approximately 12 months due to fire. This has been reflected back on the overall substation loads and system spares may be required to be kept to address this type of situation in the future.

CHAPTER 5

DISCUSSION

5. Discussion

5.1 Introduction

This section will discuss air-conditioning and methods of managing loads in detail. Air-conditioning will be discussed because it is one of the fast growing specific load types in Australia and around the world.

5.2 Air-Conditioning Load

5.2.1 Introduction

Air-Conditioning load is one of the fastest growing loads across Australia, this is mainly due to the reduced cost and size of the newer air-conditioning units. The newer split system air-conditioners are capable of air-conditioning large areas of a house, are reasonably efficient and inexpensive to operate. This in combination with a relative cheap purchase price has changed the perception of air-conditioning from one of a luxury to a necessity. It is estimated that about 50% of Sydney homes are air-conditioned. (Gillespie 2004).

With the increase in air-conditioner utilisation, there has been a larger than expect load growth in the energy consumption. As can be seen in the Chapter 4 of this report, there is a significant amount of difference between load patterns for winter and summer. A major proportion has to be contributed to air-conditioning. Research done by Enermet (Gillespie 2004) in Sydney into air-conditioning utilisation has been summarised in the graph below. Whilst this reflects the utilisation in Sydney it would be reasonable to expect that the utilisation of air-conditioning would be similar in the region where the data has been gathered.

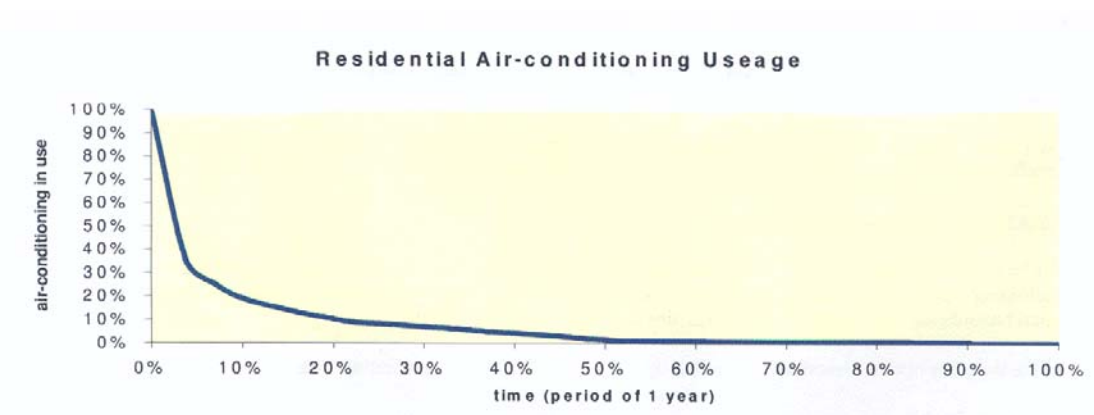


Figure 68 - Graph of Residential air-conditioning load curve

From this it is easy to see that the impact of air-conditioning load is significant and therefore needs to be managed. Various types of methods of managing air-conditioning load are proposed and will be discussed further below. Some of these are:

- Tariff Control
- Thermostat Adjustment
- Load Cycling
- Congestion Pricing

5.2.2 Tariff Control

Tariff control is the most common form of demand management of air-conditioning load. In this case customers are offered cheaper electricity, however the price is that they lose supply for set periods of the day. Currently most customers lose supply whether there is any constraints on the electricity network or not.

This is reasonably effective, however the down side is that customers are inconvenienced whether they need to be or not. For example customer choosing to go on tariff 31 would lose supply from 5-9pm every day. This has a tendency overtime to disenfranchise the customer and for them to look at going back to a tariff that does not impact on them at present that is tariff 11 for domestic customers.

5.2.3 Thermostat Adjustment

Thermostat adjustment is a method of adjusting the thermostat of a customer's air-conditioner by a few degrees. By raising the customer's air-conditioner a few degrees the air-conditioner will cycle less and therefore utilise less electricity.

The down side to this form of control is that there is a lot of infrastructure that needs to be included between the DNSP and the customer. In most cases it would require further interface with air-conditioning manufacturers as well.

5.2.4 Load Cycling

Load Cycling is a method that has been trialed in various states in the United States of America, and there are differing thoughts on how effective it is. Load cycling involves turning a customer's air-conditioner on and off during peak times, ie a customer might have supply for 20 minutes and no supply for 10 minutes. This allows for the area to be cooled for 20 minutes and then heat up for 10 minutes.

The disadvantages of this form of demand side management are that when the load is turn back on there is a high amount of energy consumption as the air-conditioner try's to cool the area back down. Over time customers also may become wise to this form of control and purchase larger air-conditioning units that would otherwise be necessary to speed up the cooling process when cycled back on. A third disadvantage is customers are more likely to set their thermostats lower than they would normally to take into account the rise in temperature when the supply is turned off (CRA 2003).

5.2.5 Congestion Pricing

Congestion pricing is similar in operation to tariff control, in that the whole process is managed automatically by a load control management system. The principle of operation of congestion pricing is the customer is offered a dual rate tariff arrangement. The normal tariff for off-peak load is lower than the normal tariff (tariff 11), similar to the tariff 31 or 33 pricing, and similar to tariff 31 or 33 the customer's air-conditioner is turned off at peak times. However unlike tariff 31 or 33 the customer is notified in advance of the impending peak load and then their air-conditioner is turned off, the customer then has the choice of overriding the outage and turning their air-conditioner back on at a high price. This price should reflect the cost of prematurely upgrading the electricity network due to sudden load increases and not to normal predictable load increases due to customer number increases.

This form of load management gives the customer the option to choose when and how much electricity they use and allows the DNSP to recoup costs on a user pay system. The other advantage of this system is for immediate load shedding for under frequency load shedding (this will be explained further later in section 5.3) (CRA 2003).

5.2.6 Conclusion

As can be seen air-conditioning is a considerable contributor to the sudden increase in electricity consumption and therefore must be considered a high priority contender for the implementation demand-side management strategies. As such it is recommended that Congestion Pricing be considered a good and fair option for managing peak demand encroachment due to air-conditioning load.

5.3 Under Frequency Load Shedding

Whilst not specifically a form of Demand Side Management for Substations, Under Frequency Load Shedding is currently a topical subject that relates to the management of overloaded situations. Under Frequency Load Shedding is where load is shed automatically in sizes as specified by the National Electricity Code. Currently all DNSP's are required to have 60% of their load capable of being shed in 5% blocks. Each of these blocks will be shed at specified frequencies and times. A copy of the times and frequencies for load shed arrangements is attached below in Table 12 (NECA 1994).

Block No.	Frequency (Hz)	Time(s)
Q1	49.0	8.0
Q2	49.0	0.3
Q3	48.8	25.0
Q4	48.95	40
Q5	48.9	0.45
Q6	48.8	0.45
Q7	48.6	0.45
Q8	48.4	0.45
Q9	48.2	0.45
Q10	48.0	0.45
Q11	47.9	0.45
Q12	47.8	0.45
Q13	47.7	0.45

Table 12 - Table of frequency and timings for Under Frequency Load Shedding

The purpose of Under Frequency Load Shedding is to attempt to maintain the stability of the Electricity Network, when a set of generators from a large power station are suddenly tripped off line for what ever reason there may be more load on the system than generation. In this situation the system frequency will drop, when the frequency drops all other generators on the electrical system are affected and depending on the situation all the other generators on the electrical network can quickly follow the generator's that tripped off. If not managed this can cause a cascade effect where all generation in the state can be ground to a halt in a matter of a few minutes. This can then lead to a situation similar to the one that occurred in the United States of America in February 2004.

To purpose of the shed blocks is to quickly get rid of load and to allow the electrical network to stabilise, once stabilised the system can then be quickly restored to normal.

5.4 Rotational Load Shedding

Rotational Load Shedding is similar in many ways to peak demand side management and under frequency load shedding. However, Rotational Load Shedding is where load is shed on a rotational basis and manually managed by a control room operator. The amount of load that is shed depends on the situation, and can range from minor feeder loads at the single substation level to a state-coordinated load shed that is managed by NEMMCO.

A two-transformer substation that has been designed to N-1 capability means that the substation has been designed to handle the loss of one transformer for 99% of the time. However 1% of the time a single transformer may not be able to safely supply the full substation load. Therefore load needs to be moved off the substation so that the single transformer will not fail or be damaged. One of the methods that can be utilised to manage the load is rotational load shedding. In this case one or multiple feeders out of the substation or part of a feeder is turned off to reduce the load on the transformer to a safe limit. The rotational side of this means that after a period of time the feeder is turned back on and another feeder is turned off until the situation has been stabilised (Ergon Energy 2004).

5.5 Voluntary Load Shedding

Voluntary Load Shedding is a method of reducing peak load with short notification, normally less than 24 hour and is more suited to industrial customers who can defer their operations or are flexible with their load or a portion thereof. Manufacturing plants with energy intensive processes that are not time sensitive are good contenders for this form of Load Shedding. These plants can defer a large amount of energy consumption. If a single plant or multiple plants can defer enough loads at peak times then substation upgrades can be delayed.

The customers are only paid when they actually defer their operations, however some form of tariff or cheaper electricity price is often included as compensation for participation in the process. There are often limitations on the number of times and duration's by which a customer can be requested to reduce or defer energy consumption.

A Demand-Side Management program was undertaken to defer a \$1.7 million network augmentation from 1998 to 2003. The project required the construction of a zone substation, due to increases in summer demand. The program began in 1998 and was essentially an agreement with a major industrial customer that had a peak load of 12MVA. The program required that the customer be given 24 hours notice to shed load between 1pm and 5pm the next day. The customer was able to achieve this load shift by speeding up production prior to the event and slowing it down during the required time. The customer managed to achieve peak load reductions of between 3.5 and 4.5 MVA. The majority of the cost of the program involved payments to the customer for shifting their loading times. (CRA 2003)

5.6 Retail Pricing

Customers who are in Tier 1, 2 or 3 are customers who are able to choose their own retailer. These customers through voluntary load shedding when the price is high can reduce their load during peak times and therefore also reduce the cost of energy. Appendix 4 shows a typical day of variation in retail pricing.

5.7 Energy Conservation

Irrespective of which type of load management philosophy is employed by customers and electricity entities, the most important method of Demand-Side Management is energy conservation. Energy conservation can be achieved in many forms, several of which are listed below:

- Energy efficient light globes.
- Ceiling and wall insulation.
- Solar power – this includes photovoltaic cells and hotwater systems.
- Use of gas and other renewable energy sources for heating, cooking and electricity generation.
- Energy efficient appliances, ie. Appliances that have a high-energy efficiency star rating.
- Correctly rated energy efficient air-conditioning, like inverter air-conditioners. Inverter air-conditioners use less power by ramping the motor speed up and down to maintain a steady speed rather than stopping and starting the air-conditioner motor.

5.8 Energy Storage

There are several forms of energy storage that are commonly used, hotwater storage systems and cooling systems.

Hotwater storage systems are in common use through out the world and enable a customer to have hotwater at almost anytime of the day or night at a relatively low cost. The hotwater is heated during a low demand period and then later used.

Cooling or air-conditioning storage systems work in a similar manner, where ice is generally manufactured during the low demand period and then used later to cool large office areas down. The major drawback with this system of air-conditioning is that it requires large storage areas that must be insulated. Also space in an office or shop situation is a precious commodity and therefore the storage system eats into precious space that could be returning a profit (CRA 2003).

5.9 Temperature Effects on Plant

One of the issues that need to be taken into account during any discussion about demand-side management is the impact of ambient temperature on plant such as transformers and conductors.

For the purpose of this project all plant that is associated with a transformer shall be included in determining the limitation of the transformer. For example the cables that connect a transformer to the electricity network shall be included as part of the transformer for limitation purposes. So bearing the above definition in mind transformers can be limited by up to 30% due to factors such as temperature. An example of this is a substation has a 6.5MVA transformer, however during summer the cable that connects the substation to the electricity network is only rated at 4.7MVA. This effectively has de-rated the transformer capacity to 71% of its capability.

A feeder conductor can be even worse than most plant as plant is often designed to meet high temperature conditions. However, most distribution feeders have been designed some 30-40 years ago. For example a 110kV feeder has a winter evening current rating of 289 A, however the same feeder has a summer day rating of 93 A. That is the feeder is de-rated to approximately 32% of its winter rating due to effects of temperature. In some cases a feeder can have a summer rating of as much as 15% of its winter rating (Ergon Energy 2004).

5.10 Issues and Assumptions

There have been relatively few issues throughout the project, however one of the substations had no data for the chosen dates so a single day of data was chosen in February 2004 for one feeder only for that specific substation. The date that was chosen in February 2004 was chosen because Rockhampton experienced its highest temperature in one week during the summer period.

The assumption that have been made to complete this project are:

- ◆ Feeders are classed as domestic or industrial based on their load profile as compared to the draft profiles given in section 3.3.1.
- ◆ The representation of the tariff switching in the graphs did not take into account the minor switching signals that were sent as described in section 4.12.1.

CHAPTER 6

CONCLUSIONS

AND

RECOMMENDATIONS

6. Conclusions and Recommendations

6.1 Project Objectives

The aim of this project was to determine the actual impact that of Demand-Side Management in a substation, this was achieved by analysing the load profiles of various substations. The analysis was done utilising the tariff switching times. This was achieved and the analyses has successfully determined that there are problem areas that if addressed could lead to improvements in substation load profiles and therefore reduce the impact of load on a substation.

6.1.1 Review of Demand-Side Management Options

The Demand-Side Management options that are currently being utilised are tariff control and power factor correction. Tariff control is extremely effective at managing a load, however can lead to customer dissatisfaction if it is not managed correctly. To reduce the overt impact of tariff control on customers it should be primarily used for storage based loads such as hotwater.

Power factor correction has been shown to be very effective and discussions with Ergon Energy Corporation planning staff suggest that more capacitor banks within the Central Region area. This will further enhance power factor correction and improve demand management at the substation level, however further work needs to be conducted on the viability of placing capacitor banks closer to the problem area, in particular on industrial feeders.

Other methods of Demand-Side Management have been reviewed some of these include:

- ◆ Congestion Pricing
- ◆ Voltage Reduction
- ◆ Embedded Generation
- ◆ Voluntary Load Shedding
- ◆ Energy Conservation
- ◆ Energy Storage

Of these the two main options that need to be considered further are Congestion Pricing and Voluntary Load Shedding. However the most important option it is the responsibility of the individual and that is to actively practice Energy Conservation.

6.1.2 Assessment of current documentation

There are multitudes of current documentation however the biggest problem is that most common methods of Demand-Side Management are controlled by legislation that has been enacted in parliament. Therefore any changes to the options are long and drawn out having to go through the parliamentary legislative process to be changed.

6.1.3 Gathering and Analysis of data

The data gathered for analysis was achieved with the assistance of Malcolm Adkin from the planning department. Malcolm's extensive knowledge of the metering data system and how to obtain the required information was invaluable. Even with Malcolm's assistance data for one of the substations was missing for the chosen dates, so data from the 16th February 2004 was chosen. Rockhampton experienced its hottest week for the summer period in February with the peak demand coinciding to the 16th February 2004.

All in all the data successfully showed that some changes are required in the tariff switching times and also that there is a significant increase in load between winter and summer periods.

6.2 Recommendations/ Further Work

It is recommended that the further work listed below be undertaken to assist in making improvements to the Ergon Energy Corporation network. This further work will also assist the corporation in reducing the peak demands and may also assist in delaying some works, thereby deferring capital expenditures until necessary.

6.2.1 Tariff switching time changes

It is recommended that the tariff 33 hotwater switching times need to be reviewed to spread out to make sure that there are no hotwater peaks over the winter period. This may be achieved by having a summer and winter switching regime all tariff 33 loads, as this will include both hotwater and air-conditioners.

6.2.2 Congestion Pricing

It is recommended that Ergon Energy Corporation consider carrying out a detailed study into rolling out Congestion Pricing for air-conditioning load. It is also recommended that the issue of Congestion Pricing be raised with the Ergon Energy Corporation shareholders and Executive Management.

6.2.3 Voluntary Load Shedding

It is recommended that Ergon Energy Corporation consider carrying out a detailed study into rolling out Voluntary Load Shedding for larger industrial customers.

6.2.4 Customer Liaison

It is recommended that customer focus groups be implemented to discuss the options above in section 6.2.2 and 6.2.3. These discussion and focus groups will better enable Ergon Energy Corporation to identify with the customer requirements and to inform the customer on why these requirements are needed.

6.3 Conclusion

As a result of the analysis carried out in this project it is evident that there is a direct relationship between the load profiles of customers, Demand-Side Management, the overall impact on substations and the overall state load.

It must also be noted that failure of Demand-Side Management methods will occur when the customer does not support the options available. So it is imperative that any Demand-Side Management methods presented to customers must be effective, meet the customers needs and also meet the requirements of the energy provider.

Irrespective of the Demand-Side Management options available it is beholden on the customer (domestic and industrial), the electricity entity and government to promote, use and encourage energy conservation as this is the key factor in long term sustainability.

Reference List

ABB – refer to Asea Brown Boveri

Asea Brown Boveri 1994, *LCM-500 Master Station System Description*, ABB Power Transmission Pty Limited

Australian Greenhouse Office, (Accessed on 04 October 2004), *+2% Renewables Target*, URL: http://www.greenhouse.gov.au/markets/mret/pubs/6_solar.pdf

Australian Science and Technology Heritage Centre, (Accessed on 20 February 2004), *Technology in Australia 1788 – 1988*, URL: <http://www.austehc.unimelb.edu.au/tia/803.htm>

Bureau of Meteorology, (Accessed on 17 May 2004), *Climate Averages for Rockhampton Aero*, http://www.bom.gov.au/climate/averages/tables/cw_039083.shtml

California Energy Commission, (Accessed on 15 January 2004), *Buildings End-Use Energy Efficiency*, URL: <http://www.energy.ca.gov/pier/buildings/projects/400-99-011-1-3.html>

Charles River Associates (Asia Pacific) Pty Ltd 2003, (Accessed on 2 March 2004), *DM Programs for Integral Energy*, URL: <http://www.efa.com.au/>

CRA – refer to Charles River Associates (Asia Pacific) Pty Ltd

Crossley, D., (Accessed on 20 February 2004), *DSM and Energy Efficiency in the Australian Competitive Electricity Market*, URL: <http://www.efa.com.au/cphen96.pdf>

Crossley, D. & Gordon, N., (Accessed on 20 February 2004), *Pricing Regulation to Promote Energy Efficiency in Australia*, URL: <http://www.efa.com.au/preregrev.pdf>

Electricity Industry Association, (Accessed on 14 January 2004), *Electric Utility Demand-Side Management 1999*, URL: http://www.eia.doe.gov/cneaf/electricity/dsm99/dsm_sum99.html

Ergon Energy Corporation Limited 2003, (Accessed on 20 February 2004), *Network Price Book*, URL: http://www.ergon.com.au/resources/Ergon_Network%20Price%20Book%202003-04_24June.pdf

Ergon Energy Corporation Limited 2003, *Ergon Energy Tariff Manual*, Ergon Energy Corporation, Queensland

Ergon Energy Corporation Limited 2003, *Load Management Controllable Load Test - CA*, Ergon Energy Corporation, Queensland

Green Power Services Pty Ltd, Mark Ellis and Associates & Poole, M. 2001, (Accessed on 2 March 2004), *Development Options Involving Demand Side Management and Local Generation in Advance Energy Area*, URL: [http://www.countryenergy.com.au/internet/cewebpub.nsf/Content/TR2238/\\$file/GPS_Revised_Report.pdf](http://www.countryenergy.com.au/internet/cewebpub.nsf/Content/TR2238/$file/GPS_Revised_Report.pdf)

Gillespie, A. 2004, *Mitigating Domestic Air-conditioning Effects on Electricity Networks*, Enermet Pty Ltd, Brisbane

Grainger, J. & Stevenson, W 1999, *Power Systems Analysis*, McGraw-Hill Book Co., Singapore

National Electricity Code Administrator 1994, *National Electricity Code*, National Electricity Code Administrator

National Electricity Code Administrator (Accessed on 1 March 2004), *Survey of Demand-Side Participation in the national market*, URL: <http://www.efa.com.au>

National Electricity Code Administrator Limited 2000 (Accessed on 20 February 2004), *Demand-side Participation Report*, URL: http://www.neca.com.au/Files/C_Code_Change_Panel_report_Demand_side_participation.pdf

National Electricity Market Management Company limited 2002 (Accessed 20 February 2004), *NEM Retail Market Development Plan*, <http://www.nemmco.com.au/operating/metering/610-0059.pdf>

National Electricity Market Management Company limited (Accessed 29 September 2004), *Queensland 5 minute Metering Data*, <http://www.nemmco.com.au/meteringandretail/700-0158.htm>

National Electricity Market Management Company limited (Accessed 29 September 2004), *Queensland Electricity Price*, http://www.nemmco.com.au/data/GRAPH_5QLD1.htm

New South Wales Government, (Accessed on 1 March 2004), *Code of Practice -Demand Management for Electricity Distributors*, URL: <http://www.efa.com.au/>

Queensland Government 2003, *Queensland Government Gazette No.47*, Queensland Government Printer, Brisbane.

U.S. Department of Energy, (Accessed on 14 January 2004), *Demand Side Management*, URL: http://www.eere.energy.gov/EE/power_dsm.html.

Appendix 1 - Project Specification

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

Unit ENG4111, PROJECT, 2004
PROJECT SPECIFICATION

FOR: David GRAY

TOPIC: IMPACT OF DEMAND SIDE MANAGEMENT ON
SUBSTATIONS

SUPERVISOR: Ron Sharma

ENROLMENT: Commence January 2004 (Enroll S1 – 2004) and complete in
November 2004.

PROJECT AIM: This project seeks to determine the impact of Demand-Side
Management Loads on the overall substation load and how this can
be minimised. This could involve making recommendations for
changes to current Load Control practices.

PROGRAMME: Issue A – January 2004

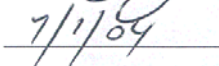
1. Review current methodologies and processes for managing Demand-Side Load on Substations.
2. Access and document current standards and/or codes relevant to Demand-Side Load Management.
3. Devise a set of tests to determine the amount of load switched under current Load Management practices.
4. Gather the required data by performing the tests mentioned in 3 above.
5. Determine whether the current Demand-Side Management (Ripple Control) signaling is being adequately utilised.

As time permits:

6. Determine the impact of feeder restoration after Demand-Side Management (i.e. Load shedding).

AGREED:  (Student)

 (Supervisor)

DATE: 

Copies: Mr. David Gray
Ron Sharma
ENG4111 Records

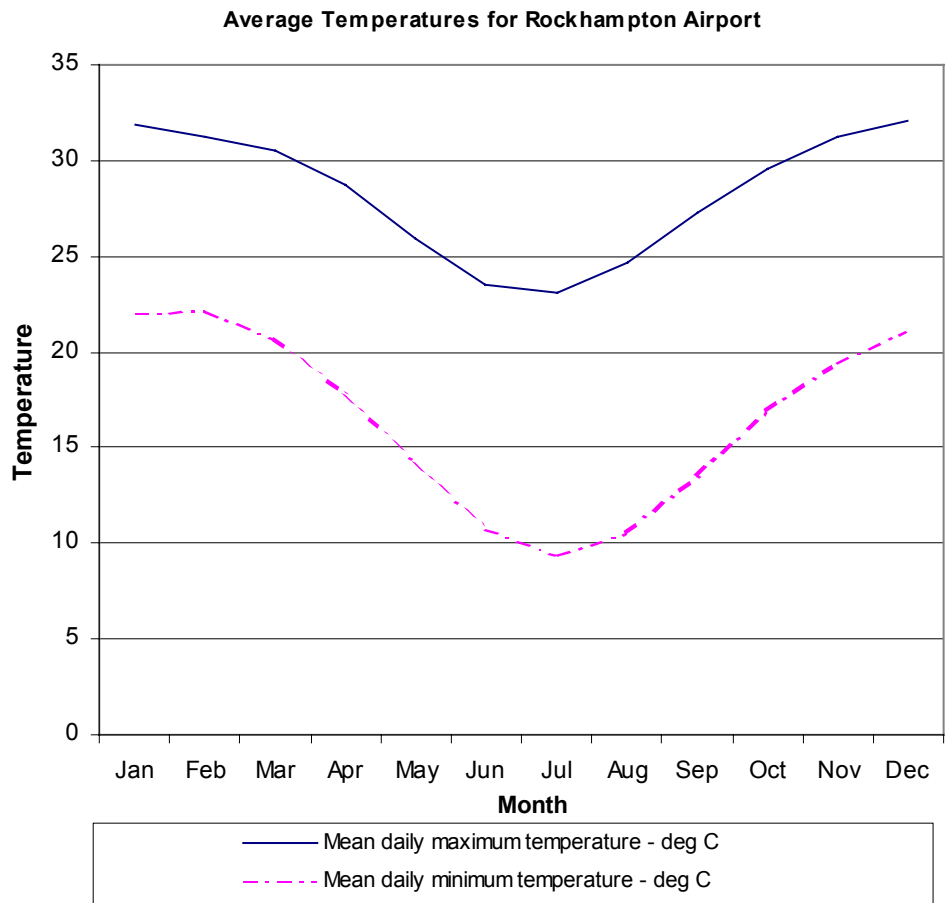
Appendix 2 - Summary of the Queensland Tariff Arrangement

TARIFF CODE	TARIFF	APPLICATION
11	Domestic	Lighting, power and continuous water heating in domestic residences
20	General Supply	Lighting & power used by medium size commercial enterprises – newsagents, offices, farming equipment where majority of power is used during the week days
21	General Supply	Enterprises the same as for tariff 20 with usage less than 330 kWh/month – All new installations of this nature should be connected to this tariff initially and let FACOM change to tariff 20 if least expensive
22	General Supply Time of Use	Customers with 30% or greater of consumption used between 9pm & 7am Monday to Friday and on the weekends
31	Night Rate	Specific water heaters and other permanent connected loads designed to meet the customer's needs with a daily, 8 hour availability of supply between 10pm & 7am or an 8 hour block as determined by Ergon
33	Controlled Supply	Specific water heaters and other permanent connected Domestic loads
37	Non Domestic Heating Time of Use	Non-domestic heating load greater than 4kW as well as other load (up to a maximum of 10% of the connected heating load) that forms an integral part of the heating process.
41	Low Voltage General Supply Demand	For customers with a monthly usage of approximately 18 000kWh and a load factor of 35%.

TARIFF CODE	TARIFF	APPLICATION
43	Low Voltage General Supply Demand - Time of Use	For customers using 200 000kWh per month with a load factor between 35 to 85% & off-peak usage between 20 & 75%
53	High Voltage General Supply Demand - Time Dependant	A tariff for very large consumers where the network charges are too high for entering into a contestable contract with an Electricity Retailer.
62	Farm - Time of Use	Rural Customers with 30% or greater of consumption used between 9pm & 7am Monday to Friday and on the weekends. For situations where power is metered on a central metering point and includes domestic as well as consumption related to the farming enterprise.
63 (obsolete)	Farm - Time of Use	For existing customers only – no new customers
64 (obsolete)	Irrigation - Time of Use	For existing customers only – no new customers
65	Irrigation - Time of Use	Only for irrigation pumps where the 12 hour “High” & “Low” times match the irrigation strategy of the farm
66	Irrigation	Only for irrigation pumps with a consistent usage pattern during the year
67	Farm	Only applicable to existing customers who have taken supply under the Rural Subsidy Scheme.
68	Irrigation Pumping (Drought)	A special tariff for farmers effected by drought
91	Watchman	Applicable to Watchman Security lights provided, installed and maintained by Ergon in some of the Regions

Table 13 - Table of Ergon Energy Corporation Tariff Arrangements

**Appendix 3 – Graph of Average
Maximum and Minimum
Temperature**



(Bureau of Meteorology, 2004)

Figure 69 - Graph of Average Temperature Maximum and Minimum

Appendix 4 - Example of a Daily Electricity Price Schedule

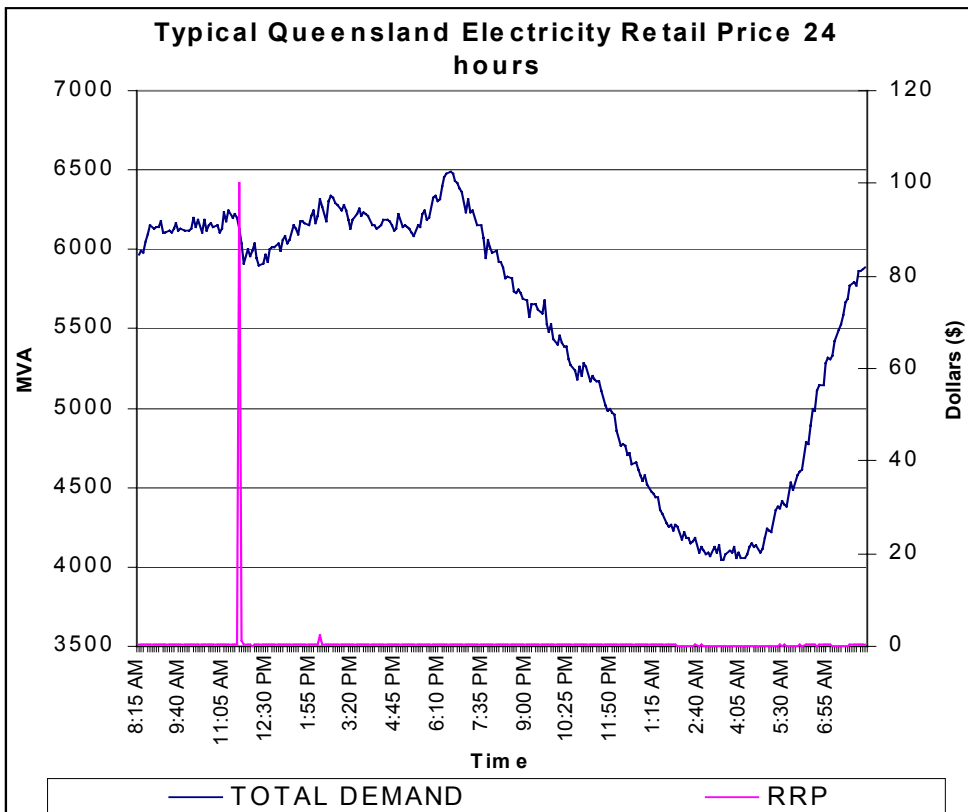


Figure 70 – Graph of Typical Retail Electricity Prices for 24 hour

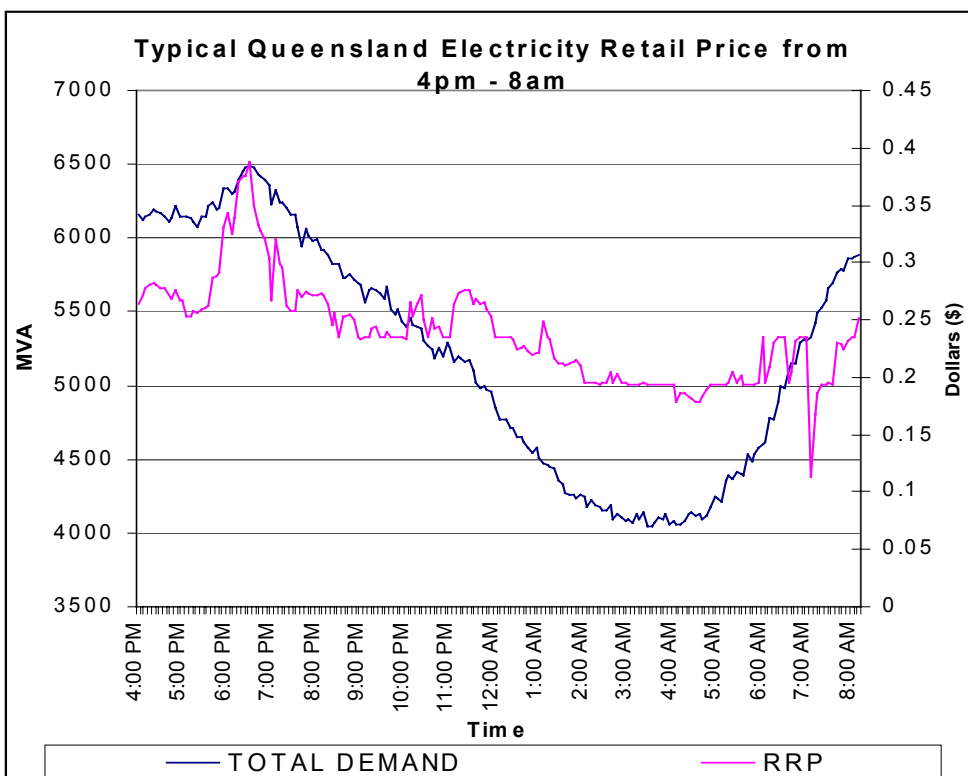


Figure 71 – Close up graph of Typical Electricity Prices

Appendix 5 - Workplace Health and Safety

Introduction

Workplace Health and Safety issues cover more areas than just field-based or industrial situations. Some of the more common places where good Workplace Health and Safety practices are generally overlooked are in the office.

Some of the areas of concern in an office environ are:

- ◆ Wrist and shoulder strain from desk/ seat height
- ◆ Back pain from bad posture or seating arrangements
- ◆ Eye strain from either too long in front of computers or not enough periods of rest

Having a correctly designed and layed out workspace can reduce the probability of being affected by these ailments. This type of issue is generally covered under the Workplace Health and Safety Act 1995.

Another issue that is often either overlooked or not considered is workplace bullying this is covered under the Workplace Health and Safety Act 1995 and may include any or all of the following behaviours:

- ◆ Physical actions
- ◆ Verbal actions
- ◆ Non-verbal actions (eg. Ostracising and isolating a person in the workplace).

In any case it is the responsibility of all employees and persons within a workplace to:

- ◆ Ensure there workplace behaviour and conduct is professional at all times
- ◆ Ensure that they perform work in a safe manner
- ◆ Report any breaches of Workplace Health and Safety practices