Design and Development of Intelligent Computational Techniques for Power Quality Data Monitoring and Management

A thesis submitted

by

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To my (late) father

Abstract

The most important requirement of power system operations is sustained availability and quality supply of electric power. In Electrical Power Distribution System (EPDS), non-linear loads are the main cause of power quality (PQ) degradation. The PQ problems generated by these non-linear loads are complex and diversified in nature. The power system which is not capable to handle non-linear loads faces the problem of voltage unbalance, sag, swell, momentary or temporary interruption and ultimately complete outage of EPDS.

The PQ problems have motivated power system engineers to design and develop new methodologies and techniques to enhance EPDS performance. To do so, they are required to analyse the PQ data of the system under consideration. Since, the density of the monitoring nodes in EPDS is quite high, the aggregate analysis is computationally involved. In addition, the cost involved with the PQ shortcomings is significantly high (for domestic consumers and rises exponentially for industrial consumers), hence it also becomes mandatory to project /predict the undesired PQ disturbance in EPDS. This will provides power system engineers to formulate intelligent strategy for efficient power system operations.

This objective of the research is to identify and exploit the hidden correlation in PQ data with minimal computational cost and further use this knowledge to classify any PQ disturbance that may occur. The technique and the methodology developed in this research employ the actual PQ data of United Energy Distribution (UED) system in Victoria which is owned by Jemena Ltd. Australia. This power distribution network consists of 27 zone substations and is responsible for delivering electricity to over 600,000 customers in Melbourne Australia (United Energy Limited, Last updated 2002).

The techniques applied in this work analyse the PQ parameters for 66/22kV zone substations. The PQ data of the UED system is carefully pre-processed to highlight the principal determinants of undesired PQ disturbances with the help of principal component analysis (PCAT) technique model. The processed data is used for classification of major PQ disturbances such as power factor, sag, swell and harmonics in EPDS. The tool used for classification of these disturbances is Artificial Neural Network (ANN).

Further this research also investigates the power distribution system behaviour considering the relationship of main PQ disturbance harmonics in conjunction with the other major PQ parameters i.e. voltage unbalance, sag, swell and frequency. The work is aimed at applying fuzzy clustering techniques to marginalise out the undesired harmonics from the PQ data having multiple PQ attributes of the UED system.

The results reveal that the nuisance of dimensionality in PQ data can be evaded with the help of PCAT model. It also efficiently classifies the main PQ disturbances with appreciable accuracy of 93%-95%. The results establish the fact that in a resource constraint environment harmonics in EPDS can be used as single basis for PQ analysis.

This thesis aims to provide a framework for PQ data analysis. The methodology adopted here is not only helpful for united energy network but also applies to the EPDS across the board.

Declaration

"I, Zahir Javed Paracha, declare that the PhD thesis entitled "Design and Development of Intelligent Techniques for Power Quality Data Monitoring and Management" is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

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Zahir J. Paracha

Dated the 29th day of April, 2011

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I greatly acknowledge the initiative and drive of our new Head of School Associate Professor Iwona Miliszewska in fostering a culture of quality research in the School of Engineering and Science.

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List of Abbreviations and Symbols

AI	Artificial intelligence
ANN	Artificial neural network
ANFIS	Artficial Neuro-Fuzzy Inference Systems
CBEMA	Computer business manufacturer association
CI	Computational Intelligence
CFL	Compact fluorescent lamp
$\mathbf{C_v^l}$	Covariance matrix
$\mathbf{C_z^{\,v}}$	Cluster centers
$\mathbf{d^2}$	Eculidian distance
DG	Distributed Generation
DNMPQ	Distributed nodes monitor for power quality
EPRI	Electric power research institute
EPS	Electrical Power System
EMC	Electromagnetic compatibility
FFBP	Feed forward back propagation
f	Frequency
FACTS	Flexible AC transmission system
$\mathbf{F_{SC}}$	Normalized values of PQ attribute
$\mathbf{F_i}$	i^{th} feature
FCM	Fuzzy C mean
GK	Gustafson Kaseel
GUI	Graphical user interface
GPRS	General Packet Radio Service
HVDC	High voltage direct Current
ITIC	Information technology industry council
IPP	Independent power plant
LMSE	Least mean squared error
MOSFET	metal–oxide–semiconductor field-effect transistor
$\mathbf{m_{ik}}$	Membership matrix

N	number of desired clusters under study
PQ	Power Quality
p.f	Power factor
PQMS	Power quality management system
PSTN	Public switch telephone network
PCAT	Principal component analysis technique
RMS	Root mean square
RNN	Recurrent neural network
Sag	Voltage below standard defined limit
Swell	Voltage above a standard defined limit
Surge	Sudden peak in voltage
SMPS	switching-mode power supply
SCR	silicon-controlled rectifier
THD	Total Harmonic distortion
UPS	Uninterruptible power supply
$U_X(X,V)$	Objective function
V_k	Centriod of k^{th} attribute
$V_{(unb)}$	Voltage Unbalance
WAN	Wide area network
σ	Standard deviation of PQ attribute
μ	Mean of PQ attribute

Chapter 1

Thesis Overview

1.1 Introduction

Electrical energy is needed in almost every application of life. The major advantage of using this form of energy is cleanliness and ease of control with an improved efficiency as compared to the other type of available energy. The consumption of electricity is increasing at a rapid pace and so is the development of new electronic equipment.

With the increase in energy consumption, power utilities are forced to concentrate on enhanced performance of power system operation. Many factors contribute to shaping the consistency and quality of power in EPDS. These include: design, construction, operation and maintenance of distribution network.

The Electric Power Research Institute (EPRI) through its master plan for the next 10 years have identified several critical gaps that highlight specific needs for enhanced knowledge, capabilities and solutions in PQ. It stresses the need to continuously improve system operations, optimize customer satisfaction and minimize cost of business through intelligent collection, interpretation, and application of system data (Howe, 2007).

1.2 Motivation

Today, power quality (PQ) issues are there in all facets of power system including transformers, different drives for control circuits, rotating machines, power electronics, power supplies, capacitor switching, protection, power system faults, harmonics, signal analysis, measuring instruments and general power system operations. This makes the problem of PQ management complex and diversified.

In order to analyse and manage these PQ disturbances power utilities incorporate various PQ monitoring techniques. Conventional PQ monitoring techniques for recognizing PQ disturbances consist of collecting PQ data and inspecting the waveforms visually. This process of identification of PQ disturbance is not only slow but also involves lot of manual work. In addition, the power companies record the PQ data round the clock 365 days, which makes the PQ data size significantly large and highly dimensional. This causes extreme difficulty for power system engineers to filter out the correct information for important decision making.

The main motivation of this research is to formulate an intelligent framework for PQ data analysis for power utilities so that power system engineers are able to make critical decisions for sustainable and reliable power system operations.

1.3 Summary of Main Contributions and Publications

This thesis contributes to the area of energy efficiency and management in EPDS with special focus on electrical PQ. Following is the summary of research work and main contributions:

Chapter 2 presents the literature review for PQ monitoring in electrical power system and the main features of this work are:

1. Electrical power distribution system (EPDS)
2. PQ issues in EPDS
3. Importance of PQ
4. PQ data it's monitoring and standards.

Chapter 3 outline the PQ data monitoring in Victorian power distribution system, which includes following contributions:

1. PQ data monitoring in Victorian power distribution system
2. Principal component analysis technique (PCAT)
3. Development of PCAT model to pre-process the large PQ data having 15 different PQ attributes
4. Availability of 2-dimensional PQ refined data without loss of much information.

The **chapter 4** contributions are as follows:

1. Application of PCAT model
2. Implementation of neural networks
3. Estimation of PQ disturbances using feed forward back propagation (FFBP-NN) techniques
4. Estimation of PQ disturbances using recurrent neural networks (RNN) techniques
5. Result comparison of FFBP-NN and RNN techniques

Chapter 5 investigates the EPDS behaviour considering the relationship of harmonics in conjunction with main PQ disturbances. The major contributions of this chapter are outlined below.

1. Comprehensive analysis of EPDS
2. PQ feature selection
3. Intelligent PQ monitoring strategy
4. Application of Fuzzy C-mean to cluster undesired harmonics
5. Application of Gk based extended fuzzy clustering to cluster undesired harmonics
6. Comparison of Fuzzy c-mean and Gk based extended fuzzy.

These contributions have led to the following publications:

Journal Publications and Book Chapters

1. **Paracha Z. J.** & Kalam A., 2011, Intelligent techniques for the analysis of power quality data in electrical power distribution system, Handbook of Research on Industrial Informatics and Manufacturing Intelligence: Innovations and Solutions DOI: 10.4018/978-1-46660-294-6, ISBN13: 9781466602946, ISBN10: 1466602945, EISBN13: 9781466602953.
2. Hidayatullah N. A., **Paracha Z. J.** & Kalam A., 2011, Impact of Distributed Generation on Smart Grid Transient Stability, Smart Grid and Renewable Energy Journal, 2, 99-109.

3. **Paracha Z. J.** & Kalam A., 2010, Fuzzy clustering techniques for the analysis of PQ data in electrical power distribution system, International Review of Electrical Engineering, 5.

International Conference Publications

1. **Paracha Z. J.** & Kalam A., 2009, Power quality-a complex and diversified problem in power industry, The 3rd International Engineering and Optimization Conference (PEOCO 2009), Selangor, Malaysia.
2. **Paracha Z. J.**, Kalam A. & Ali R., 2009, A novel approach of harmonic analysis in power distribution networks using artificial intelligence, International Conference on Information and Communication Technologies (ICICT '09), Karachi, Pakistan, 157-160.
3. **Paracha Z. J.**, Kalam A., Mehdi A. M. & Amanullah M. T. O., 2009, Estimation of power factor by the analysis of power quality data for voltage unbalance, 3rd International Conference on Electrical Engineering (ICEE '09), Lahore, Pakistan, 1-4.
4. Hidayatullah N. A., **Paracha Z. J.** & Kalam A., 2009, Impacts of distributed generation on smart grid, International Conference of Electrical Energy and Industrial Electronic System (EEIES 2009), Penang, Malaysia.

National Conference Publications

1. **Paracha Z. J.**, Mehdi A. M. & Kalam A., 2009, Computational analysis of sag and swell in electrical power distribution network, Australasian Universities Power Engineering Conference (AUPEC 2009), Adelaide, Australia, 1-5.

Earlier Publications that facilitated this Research

1. **Paracha Z. J.** & Doulai P., 1998, Load management: Techniques and methods in electric power system, International Conference on Energy Management and Power Delivery (Proceedings of EMPD '98) Singapore, 213-217.

1.4 Outline of the Thesis

This thesis contains six chapters and is organized as follows:

Chapter 1 provides thesis overview of the research as well as the motivation behind this research. **Chapter 2** presents literature review of PQ issues, disturbances and their monitoring in electrical power system. It discusses the importance of PQ monitoring and various PQ monitoring standards. **Chapter 3** explains the real PQ monitoring system and the challenges associated with monitoring of PQ data for Victorian power distribution system. It includes details of the PQ monitoring set up and also gives the design and modelling of Principal Component Analysis Technique (PCAT) model to process the PQ data of UED network. **Chapter 4** implements the PCAT model to perform the intelligent computational analysis using neural networks. **Chapter 5** is aimed at applying fuzzy clustering techniques to cluster the undesired data with the aim of comprehensive analysis of power distribution network for UED. **Chapter 6** is the concluding chapter for this thesis and gives the summary of the thesis and future areas of research, which can be explored by signal processing techniques.

Chapter 2

An overview of PQ Monitoring in Electrical Power System

2.1 Introduction

This chapter provides the comprehensive literature review about the power system operations, the quality of supply power and its monitoring in electrical power distribution system. It also details and summarizes the key parameters which are essential for smooth operation of power system.

The increased usage of electricity to keep pace of advancements in the modern world challenges the economic operations of a robust electricity supply industry with greater focus on load management and optimization. The optimum utilization of energy leads to the management of load, which is defined as the set of objectives aimed at controlling or modifying the pattern of demands of various consumer of a power utility (Paracha & Doulai, 1998).

This deliberate effort to modify the pattern of demands of consumer gives rise to the issue of PQ, which has been acknowledged, as the most important area of research in recent times. PQ has different perspectives from user and utility point of view. This issue is expanded on a variety of fields of electrical engineering from electrical machines to power electroncis, from capacitor switching to protection circuits, etc., thus making it an important area of concern for power utilities, consumers and equipment manfacturers and society at large (Bollen, 1999, Collinson, 1999, Dugan *et al.*, 2002, Neumann & Burke, 2003, Stones & Collinson, 2001).

2.2 Electrical Power Distribution System (EPDS)

EPDS holds a pivotal position in entire electrical power system. An electrical power system consists of mainly three components:

1) Generating stations

2) Transmission systems

3) Distribution systems

These three components of electrical power systems are integrated together to supply electricity to consumer.

The typical EPDS consists of power distribution networks which consist of high voltage distribution lines having a rating of 11kV, 22kV or 33kV. The traditional power distribution network will have these high voltage lines as overhead lines coming out of the substation. With the modern power distribution network the overhead high voltage distribution lines are being replaced by underground lines to ensure safety, reliability and considering the environmental impact of the power distribution network. In addition to high voltage distribution lines power distribution network consists of transformers and other auxiliary equipment in substations to ensure smooth availability of quality supply power to consumers. PQ has become widely important and is a matter of concern to all of its stakeholders as it directly affects the running of their smooth operations.

2.3 PQ Issues in EPDS

The PQ problem can be defined as being "any power problem manifested in voltage, current, or frequency deviations that result in failure or mal-operation of customer equipment". Thus the PQ includes the frequency of the supply, it's voltage level as well as the presence of waveform abnormalities such as harmonic content, flicker or voltage transient (Collinson, 1999, Dugan *et al.*, 2002).

Modern world is changing at a rapid pace and new devices are coming in existence from companies around the world. In attempting to define PQ, the views of utilities, equipment manufacturers, and customers might be completely different. Utilities regard PQ from the system reliability point of view. Equipment manufacturers, on the other hand, consider PQ as being that level allowing for proper operation of their equipment, whereas customers consider good PQ that ensures the continuous running of processes, operations and businesses.

Use of power electronic based highly efficient devices has tackled the problem of power consumption in a significant manner. However, they pose threats to the quality of power. Furthermore, the deregulation in the regime of electrical generation, transmission and distribution has also created challenges for the electrical power companies, since the user can force the company to strictly follow the contract of electrical supply (Tao & Domijan, 2005).

The user needs a clean voltage waveform from utility within the limits defined by the regulatory body. However, the utility needs a smooth current waveform from user. Mostly the users are concerned with the energy savings without considering the aspects of PQ thus creating further problems in EPDS. For example, the use of

Compact Fluorescent lamps (CFL), instead of normal incandescent bulb or fluorescent tube light is advocated nowadays to cut down the electricity bill. There is no doubt that CFLs have proven to have huge impact on energy savings. However, several studies on CFL have proven that mass usage of CFLs in different power systems have generated the 3rd harmonic component and other negative effects on the equipment in the system. This harmonic component makes a long list of problems for utility engineers including the nasty one like false tripping of system components (Hunter, 2001, Jahanikia & Abbaspour, 2010).

PQ issues mainly arise with the use of non-linear devices by the consumers at the demand side of the EPDS. These devices include (Dugan *et al.*, 2002, Martin *et al.*, 2007):

- Uninterruptible power supply (UPS) systems
- Switch mode based power supplies for Personal Computers (SMPS)
- MOSFET / SCR based battery charging equipment CFL
- Mobile Phone chargers
- Power supplies of sensitive electrical devices like Television, Microwave Oven and printer etc.

Apart from the aforementioned devices PQ issues have also emerged by the switching of high power water pumps, power factor correction capacitor banks and loose connections at distribution network nodes.

Power distribution networks are ideally designed to tackle sinusoidal voltage and current waveforms. However, with the increased usage of modern power electronic equipment the situation has become difficult for power utility engineers to maintain PQ to its customers on sustainable basis. The existing power distribution network design in most cases is only capable of absorbing voltage distortion to a certain limit after which the effects of voltage distortion becomes evident in the distribution system. Some of the common effects associated with the distortion of voltage in power distribution network in an electrical power system are:

- Over voltage problems
- Circuit breaker tripping
- Equipment malfunction and failure
- Interference with communication
- Cable heating
- Data recording and metering problems
- Insulation failures

Over the years numerous techniques, methods and tools have been employed to measure the harmonic distortion in power distribution network (Baggini, 2007).

2.4 Importance of PQ

PQ has become widely important and is a matter of concern to all of its stakeholders as it directly affects the running of their smooth operations. However, it is interesting to note that different stakeholders view PQ in different ways.

2.4.1 Utility Perspective

Power companies and utilities are interested on the provision of sustained power supply to their customers. So, they focus on monitoring and troubleshooting of all those PQ issues which enable them to provide continuous power supply to their customers without any interruptions. With the liberalization of power industry and establishment of independent power plants (IPPs), their customers have the right to demand the higher quality of power at all times (Sakthivel *et al.*, 2003a).

2.4.2 Consumer's Perspective

The industrial and domestic customers view PQ in a different way. They judge good PQ to be in the level which conforms to running of their domestic and industrial rapid appliances. There has been growth in application of high efficiency adjustable speed drives which sometimes are the main cause of PQ problem (Brauner & Hennerbichler, 2001).

2.4.3 Equipment Manufacturers' Perspective

The equipment manufacturers who previously did not assume any responsibility are now considering how their equipment performs with increased awareness and the availability of various PQ standards. They are making efforts to produce excellent performance tools but unfortunately these tools are often more vulnerable to power disturbances and from time to time are the cause of extra PQ issues (Romano & Perli, 2005).

2.5. PQ Disturbances

PQ is gaining a lot of attention nowadays as the users are more conscious about the quality of electrical supply. However, most of the problems like harmonics, flicker, voltage sag and swell, voltage unbalance, etc., are caused due to the non-linear loads installed by the customers on the demand side of the electrical power system. These non-linear loads draw current that is rich in harmonics, thus making the voltage harmonically polluted (Integral Energy Power Qualitty and Reliability Center, 2008)

Power utilities across the board aim to maintain the voltage with constant amplitude and frequency without any distortion. For linear loads e.g. heaters, incandescent lamps and any equipment containing only resistive elements, the current drawn is also linear i.e. sinusoidal. However, when the customer's load gets non-linear the current drawn also gets non-sinusoidal which leads to harmonic distortion. For non-sinusoidal conditions the harmonically distorted waveforms are made up of harmonic frequencies with different amplitudes (Hossam-Eldin & Hasan, 2006).

The normal, sag and swell waveform for a power distribution network is shown Figure 2-1.

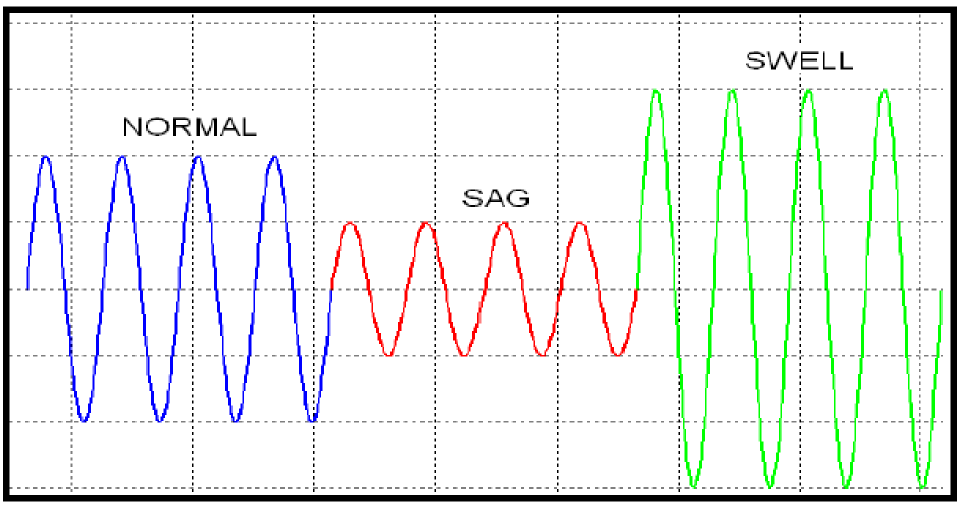

Figure 2-1 Sag, Swell and Normal waveform (Paracha & Kalam, 2009)

The Root Mean Square (RMS) value of voltage to detect variation in voltage is given as:

$$V_x^{rms} = \sqrt{\frac{1}{N}\sum_{y}^{V_y^2} V_y^2} \tag{2.1}$$

where N is the number of samples of voltage waveform, V_x^{rms} is the x^{th} sample and V_y is the y^{th} sample of the measured voltage respectively.

The most common issues on utility side are voltage sag and swell. They occur frequently in a power distribution network. Power utility engineers are concerned with these PQ disturbances as they can be disastrous for customer's equipment. Sag and swell noise and overvoltage disturbances are not strictly unaffordable, especially in industrial sector where the equipment is very costly. These voltage disturbances beside other abnormalities can cause permanent damage to the sensitive equipment, if they occur frequently or remain in the power distribution system for longer duration then the limits set by the power utilities (Shareef *et al.*, 2008).

There are several standards that define the condition for sag and swell in electrical power system. Voltage sag is also known as Dip in the International Electrotechnical Commission (IEC) standards. Various organizations like Institute of Electrical and Electronics Engineers (IEEE), Electric Power Research institute (EPRI), IEC and etc., have defined the limits for these conditions. IEEE defines sag as short term rms variation with duration of 0.5-30 cycles with typical voltage magnitude of 0.1-09 p.u. EPRI defines sag as a decrease of voltage smaller than 90% -92%. IEEE standard of recommended practice for monitoring electric PQ defines swell as a short term voltage imbalance where the voltage becomes 1.1-1.8 p.u. with a typical duration of 0.5-30 cycles. EPRI defines swell as the duration when the voltage increase is greater than 110% of nominal voltage. The magnitude of sag and swell depends mostly on the location in electrical network (Dorr *et al.*, 2000, IEEE Standards Board, 1995b, Mceachern, 2005).

However, the point of concern is that if the protection circuitry fails to respond and these conditions persist beyond a certain limit then the result may be very costly for the industrial user.

Other than the problem discussed earlier, there are also problems which are associated with the modern equipment based on power electronics. These loads like PC, stabilizers, drives, compact fluorescent lamps (energy savers), and UPS draw non-sinusoidal current and thus are a potential source of generation of harmonics.

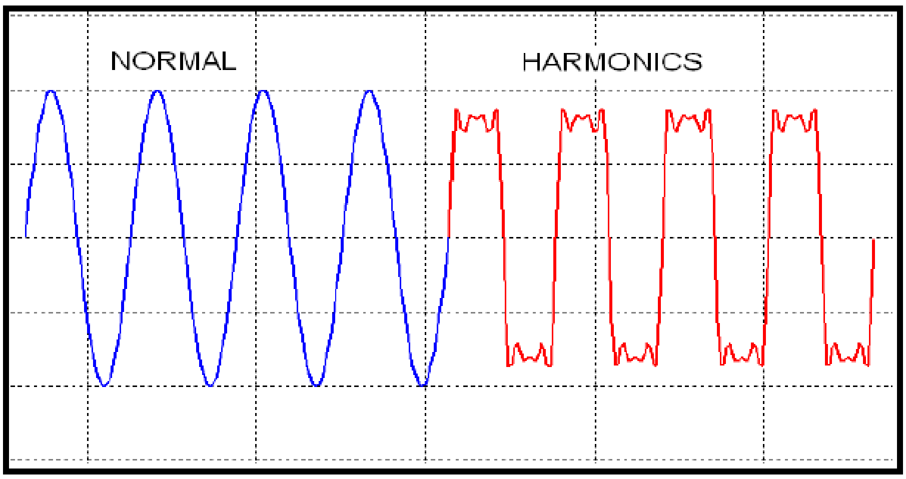

Figure 2-2 Normal and harmonic waveforms (Paracha & Kalam, 2009)

Non-linear loads not only draw fundamental current but also draw harmonic currents which inturns makes the voltage harmonically polluted. Most of the electrical equipment installed in distribution systems of almost all third world countries and even in some developed countries are designed to handle linear load.

In electrical power system the continuous supply of electrical power has become a challenge for the power utilities. The increased usage of switching devices and modern electronic circuitry by customers often disturbs the availability of power quality supply. This is due to the injection of undesired harmonics in power distribution network.

Harmonic distortion in the supply of electrical power from the utility is due to the increased magnitude of the currents generated by the non-linear loads. Thus it becomes essential for power utility engineers to analyse the wave shape of the current drawn by non-linear loads. These loads include modern electronic equipment like super computers, variable speed drives, modern electronic ballasts, and other equipment which operates on continuous switching mechanism.

Harmonic distortion is found in both the voltage and the current waveforms in power distribution networks and can be given as (Dugan *et al.*, 2002):

$$V_{rms} = \sqrt{\sum_{h=1}^{h_{\max}} \left(\frac{1}{\sqrt{2}} V_h \right)^2} = \frac{1}{\sqrt{2}} \sqrt{\left(V_1^2 + V_2^2 + V_3^2 + \ldots.. + V_{h_{\max}}^2 \right)} \quad (2.2)$$

$$I_{rms} = \sqrt{\sum_{h=1}^{h_{\max}} \left(\frac{1}{\sqrt{2}} I_h \right)^2} = \frac{1}{\sqrt{2}} \sqrt{\left(I_1^2 + I_2^2 + I_3^2 + \ldots.. + I_{h_{\max}}^2 \right)} \quad (2.3)$$

Equations (2.2) and (2.3) give the RMS values of voltages and currents for the non-sinusoidal waveforms where V_h and I_h are the amplitude of voltage and current respectively at the harmonic component *h*.

The total harmonic distortion (THD) which is a measure of the harmonic component present in a distorted waveform can be expressed as in equation (2.4)

(Dugan *et al.*, 2002):

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{max}} (M_h)^2}}{M_1}, \qquad (2.4)$$

where M_h is the RMS value of harmonic component *h*.

Figure 2-3 shows the fundamental sine wave and also shows 3rd and 5th harmonics on the same waveform.

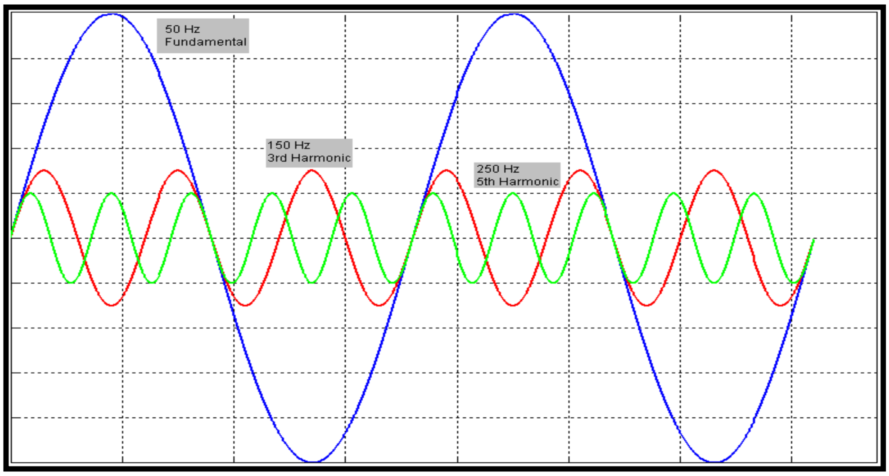

Figure 2-3 Waveforms of fundamental, 3rd and 5th Harmonic (Paracha *et al.*, 2009a)

The extra burden imposed by harmonics on such equipment results in overheating and malfunctioning thus making the equipment inefficient. IEEE standard 1159-2009 defines the harmonics upto 9 kHz with a typical voltage magnitude up to 20% of fundamental. In recent times, manufacturing companies specially the distribution transformer manufacturers are developing new techniques to handle the non-linear loads in electric EPDS.

The electrical power system in most cases is designed to handle only the fundamental or normal voltage and current waveforms. The injection of harmonics disturbs the operating capability and efficiency of the power system.

The effects of harmonic distortion become visible in form of continuous tripping of the network and ultimate malfunction or break down of the customer's equipment.

The customer's equipment fails because it was not designed to handle the abnormal voltage or current waveforms beyond a certain rating.

However, a matter of concern for power utility is the situation when there is temporary, momentary or sustained interruption in the power supply. Any unplanned failure can incur huge cost for the industrial customers. The time and again failure of the power supply financial loss can have great impact on their business. Figure 2-4 shows the normal, interruption and surge waveforms on the power distribution network.

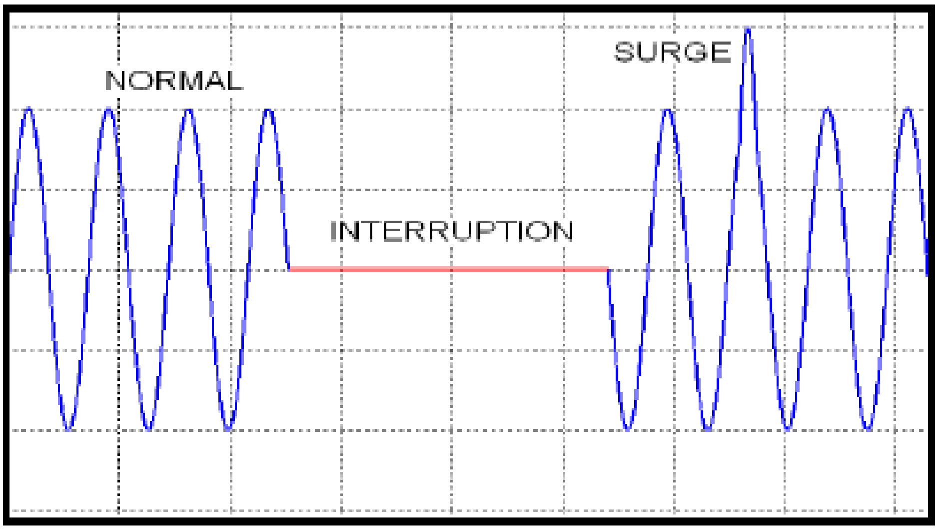

Figure 2-4 Normal interruption and surge waveforms (Paracha & Kalam, 2009)

Another major PQ problem which can lead to the total system shutdown is the surge of high magnitude on the power distribution network. Surge is a very dangerous condition and is capable of damaging the equipment installed in its way.

Table 2-1 PQ disturbances, their typical duration and voltage magnitude in per unit for electrical power system as defined in IEEE-1159-95 (Faisal, 2007)

s/no	PQ Disturbance	Typical duration	Typical voltage magnitude in per unit
1.0 1.1 1.1.1 1.1.2 1.1.3	Transients Impulsive Nanosecond Microsecond Millisecond	<50 ns 50 ns – 1 ms <1 ms > 1 ms	
1.2 1.2.1 1.2.2 1.2.3	Oscillatory Low frequency Medium frequency High frequency	0.3 – 50 ms 20 µs 5 µs	0-4 pu 0-8 pu 0-4 pu
2.0 2.1 2.1.1 2.1.2 2.1.3	Short duration variations Instantaneous Interruption Sag (dip) Swell	0.5 – 30 cycles 0.5 - 30 cycles 0.5 – 30 cycles	< 0.1 pu 0.1 – 0.9 pu 1.1 – 1.8 pu
2.2 2.2.1 2.2.2 2.2.3	Momentary Interruption Sag (Dip) Swell	30 cycles – 3s 30 cycles – 3s 30 cycles – 3s	< 0.1 pu 0.1 – 0.9 pu 1.1 – 1.4 pu
2.3 2.3.1 2.3.2 2.3.3	Temporary Interruption Sag (Sag) Swell	3s – 1 min 3s – 1min 3s – 1min	< 0.1 pu 0.1 – 0.9 pu 1.1 – 1.2
3.0 3.1 3.2 3.3	Long duration variations Interruption sustained Under voltages Over voltages	> 1 min > 1 min > 1 min	< 0.1 pu 0.1 – 0.9 pu 1.1 – 1.2 pu
4.0	Voltage unbalance	Steady state	0.5 – 2 %
5.0 5.1 5.2 5.3	Waveform distortion d.c. offset harmonics Inter harmonics	Steady state Steady state Steady state	0 – 0.1 % 0 – 20 % 0 – 2 %

In recent times the effort has been made to come up with new standards for equipment which can handle the undesired effects of harmonics at the customer's end.

The IEEE1159-95 categorises the PQ disturbances with their typical duration and voltage magnitude in per unit in electric power system. These are listed in Table 2-1 (Faisal, 2007).

The major cause of these problems are faults, dynamic operations, or non-linear loads which results in different types of PQ disturbances such as sags and swelling effects of input sources, switching transients, impulses, notches, flickers, harmonics, etc. These PQ problems can occur both on the demand side and the supply side of the electric power system. The sag, swell and harmonics are those PQ disturbances for which extensive research is in place.

2.6 PQ Monitoring

In electrical power system the monitoring and management of PQ data has become immensely important because of demand of continuous availability of quality power supply to consumers on sustainable basis. The main problem faced by modern power utilities today is the unpredictability of the power system behaviour due to unexpected PQ problems.

PQ monitoring is necessary to characterize the electric phenomenon at a particular location of the power distribution network. It is done by power utilities to run the power system operations with a view to provide quality power supply to customers without interruption on sustainable basis. With the increased customer completion and greater regulatory requirements more efficient and advanced signal processing techniques (Bollen & Gu, 2006) are required to monitor the PQ issues for enhanced system performance of the EPDS. PQ is measured and recorded by sensors installed at various locations of the utility networks. Mostly these sensors are modern sophisticated technology based equipment that can store the data for a very long time. Power utilities face the challenge to manage their large network for PQ monitoring and intelligent decision and separation of useful PQ data from the raw PQ data. Engineers and researchers are working towards the efficient data mining techniques to fetch useful data out of the huge recorded data (Price, 1993).

2.6.1 Conventional Methods of PQ Monitoring

The conventional methods of monitoring PQ data in electrical power system is based on collecting the power system operating data, inspecting the waveform visually and identifying the PQ disturbance that is present in that data. The greatest disadvantage of this methodology is that it is very slow and cannot address the requirement of modern electrical power system. Moreover, lot of manual work leads to inaccuracy and rectification of problems becomes a huge task for the power system engineer.

Today, PQ monitoring cannot be compromised and power utilities consider it as an essential service for their industrial and commercial customers (Gunther, 1999).

2.6.2 PQ Monitoring In Present Power Distribution Networks

PQ monitoring is becoming a necessity for every industry working in power transmission, distribution and generation, as load is becoming sensitive and is likely to be damaged by slight change in voltage parameters. The present day EPDS employ the technology i.e. installation of PQ meters are various point of the distribution network to do the PQ analysis.

Several researchers have devised and implemented indices for PQ monitoring in distribution networks (Nicholson *et al.*, 2008). Until recently the main focus of research was to perform statistical analysis and characterize typical quantities such as magnitude and duration of the disturbances. In essence, estimate/predict the tendencies of particular phenomenon as a function of historical indices. However, there is marked shift in present day research and the main focus is now on the reliability and performance enhancement of electric power system, while considering PQ disturbances (Mertens *et al.*, 2007).

2.6.3 PQ Monitoring in Future Power Distribution Networks

Over the years numerous techniques, methods and tools have been employed for PQ monitoring in power distribution network. However, newer systems based on intelligent techniques like Artificial Intelligence (AI), Fuzzy logic, Artificial Neuro-Fuzzy Inference Systems (ANFIS) based on computational intelligence are reducing the difficulty of data mining (Chuang *et al.*, 2005, Morsi & El-Hawary, 2009, Nath & Sinha, 2009, Njoroge, 2005).

In recent times the extensive use of non-linear loads especially in industry has made it quite difficult to achieve accuracy for the measurement of amount of harmonics generated by customer's equipment. Cheng-Long *et al.* worked on recognition of multiple PQ disturbances in two parts using wavelet-based neural networks (Chuang *et al.*, 2005). He was successful in implementing his technique by graphical user interface (GUI) computer program but the proposed intelligent system lacked the actual measurement of real PQ events. A. K. Chandel *et al.* in his research work has also developed a wavelet based artificial neural network classifier using MATLAB/SIMULINK to recognize PQ disturbances but his research also lacks the actual field results of different PQ problems encountered by electrical power distribution network (Chilukuri *et al.*, 2004).

In such a scenario, fast methods for measuring and estimating PQ disturbances through artificial intelligence techniques has produced excellent results and can be considered most efficient and reliable for PQ monitoring in future distribution networks. Different researchers have worked on the identification and classification of PQ problems with Artificial intelligence computational techniques in electrical power industry (Chilukuri *et al.*, 2004, Panigrahi *et al.*, 2009, Swiatek *et al.*, 2007a).

In developed countries utilities have already started looking at implementing Smart Grid (SG) and they are using sophisticated sensors and measuring instruments. In terms of SG environment sensors will help in mitigating the problems by predicting them in advance. SG by taking intelligent measurements and by the aid of sophisticated algorithms will be able to predict the PQ problems like harmonics and fault current in advance. This means that in coming years

Distributed Generation (DG) will be a part of total EPDS. DG is defined as a small scale power generation which is located near the consumer load, typically has rating <10MW and is not part of the major EPDS (Hidayatullah *et al.*, 2009). However, besides presenting an idea for remote control of all (DG) thus forming a virtual power plant the results of case study (Sikorski *et al.*, 2010) gives an indication that the integration of DG with main power system is still a prime concern in power industry. The virtual power plant will incorporate the forecast of energy usage, control of DGs and power market including all the area under the utility. The formation of virtual power plants will produce "smart" clusters that can play effective role in power outage handling (Sikorski *et al.*, 2010). The issues related to overcurrent relays and insulation coordination can be tackled using the modern instrumentation technology (Hussain *et al.*, 2010). It is pertinent to mention that the PQ monitoring using the ongoing 3G technologies has been implemented by Chinese researchers. This module of General Packet Radio Service (GPRS) communications is capable of analysing the real time data and its algorithm makes it intelligent enough to get the desired PQ information (Tang *et al.*, 2010).

2.7 PQ Standards

As stated earlier, there are many power system communication protocols employed by power utilities. PQ standards restrict the user and the utility to improve the PQ. Users in a sense to restrict the amount of harmonic injection by using products of good quality are improving the power factor. PQ standards worldwide may have different allowable limits but they are common in the sense that they follow the same fashion in the journey of identification to the mitigation of problem. The only difference lies in the techniques suggested for mitigation and the allowable limits. These are different in the sense that standards are defined using the geographical conditions of the area, the nature of load, the type of production of electrical energy and the kind of transmission system. For instance, it may happen that a country with HVDC system allows somewhat a tolerable harmonics up to 10%. However, there are some international committees like IEC, IEEE and IET that defines standards for worldwide usage (Psl World Leader in Power Quality and Energy Monitoring).

2.7.1 IEEE 1195 Standards

The United States (ANSI and IEEE) do not have such a comprehensive and complete set of PQ standards as the IEC. IEEE is well known in engineering community and has devised over 200 standards on various aspects in the field of Electrical engineering. Some researchers claim that they have a very comprehensive and complete set of PQ standards. It is true to some extent since most of the PQ standard work is on allowable limit of harmonics, IEEE defines the allowable limits for transients both impulsive and oscillatory, short duration variations including the sag, swell and short duration interruption. IEEE also take into consideration the PQ problems of long duration interruptions, undervoltage, overvoltage, voltage imbalance, frequency distortion and waveform distortion that includes notching, harmonics, inter-harmonics, DC offset and noise (Abdel-Galil *et al.*, 2002). IEEE standard 519 defines the harmonics limit for different voltage levels that is at maximum 5% for voltages up to 68.9kV.

2.7.2 IEC 61000 Series of Standards

Electromagnetic Compatibility (EMC) is the ability of equipment or system to function in its electromagnetic environment without introducing intolerable disturbances to anything in that environment (IEC 61000-1-1). IEC has a very comprehensive set of standards as far as the PQ is concerned. It covers the PQ standards related to electromagnetic issues. IEC standard series 61000 is all about EMC. It describes in detail the limits for general issues, the characteristics of environment where the equipment is to be used and the limits of disturbances that can be caused by a system. It also defines the tolerable limits for a power system. These disturbances may be harmonics, flicker, or inter-harmonics at different levels of power transmission network. IEC 61000 series further covers the measurement issues and provide adequate guidelines for the monitoring and measurement of PQ. It also provides the user ways of installation methods for the mitigation of identified problems. IEC 61000-6-x is a generic standard and as certain specified standard for certain category of equipment for certain environments.

As mentioned earlier in this Section above IEC 61000 standard series is a comprehensive attempt of defining the PQ problems. IEC 61000-3-2 elaborates this fact. This part of the PQ standard series outlines PQ problems with respect to the type of equipment. IEC committee has bounded the equipment in four distinct classes stated as Class A, B, C and D. Class A deals with all the balanced 3 phase equipment. Class B has definitions and standards for portable tools. Class C includes the lighting equipment whereas Class D is for low power equipment ranging between 75-600W. Class D also deals with the wave shaping equipment. All other equipment that cannot be classified under Classes B, C and D fall under the umbrella of Class A.

2.7.3 New Zealand Standards

New Zealand was one of the first countries to pass regulations in 1981 to limit the harmonic levels in the electrical network (Limitation of Harmonic Levels Notice 1981, issued by the Office of the Chief Electrical Inspector, Ministry of Commerce). New Zealand Electrical code of practice 36 is cited in electricity regulations 1997 defines the limits of harmonics in their system. For voltages less than 66kV the limit of harmonics is defined separately for even and odd harmonics. So for even harmonics the limit is 2% and for odd harmonics it is 4%. The THD is confined to 5%. For all the voltages above 66kV, the percentage limits for different harmonics have been defined. As an example, the 3^{rd} harmonics the percentage phase to neutral value is 2.3 (harmonic voltage limit). As the limit decreases the harmonic order goes up. For 5^{th} harmonic it is 1.4 and for 7^{th} it is 1.0. It keeps on defining the limits till the 29^{th} harmonic where its value is 0.3. As in the case of voltages under 66kV here also the NZ authorities have defined the even harmonics limits separately and have given the harmonic voltage limit for 2^{nd} harmonics to be 1.2 at the maximum. It keeps on rolling till the 50^{th} harmonic for which case the limit is 0.2.

2.7.4 Commonly used PQ Standards in Saudi Arabia

In Saudi Arabia there exists a regulatory body that defines the permissible limits and standard operational procedures for electricity transmission, distribution and generation. This body is known as Electricity and cogeneration regulatory authority (Saudi Electricity Company, 2007) they too follow some standards defined by UAE Power distribution companies (Al Ain *et al.*, 2005a, Al Ain *et al.*, 2005b, Al Ain *et al.*, 2005c). Most of the standards are made according to the regional requirements of the country, whereas few are based on the global needs and requirements. IEEE standards are widely cited for their capability to address issues of all the regions in the world. There are more than 1000 standards in engineering fields, which have been devised by IEEE. IEEE standards are the main inspiration here. IEEE standard on harmonic control in electrical power system was published in 1992 and it covers all aspects related to harmonics in EPDS (IEEE Standards Number 519-1992, 1993). It defines the maximum harmonics distortion up to 5% on voltage levels ≤69kV. However, as the voltage levels are increased the allowable limits for harmonics in this standard are decreased to 1.5% on all voltages ≥161 kV. It is also worth mentioning that individual voltage distortion starts from 3% and ends at 1.0% for voltage levels of ≤69kV and ≥161kV respectively. Harmonics limit set by the Saudi authorities is almost the same as IEEE standard but with a bit of flexible limit such as, 3% THD for all networks operating within the range of 22kV-400kV.

IEEE standard for voltage distortion defines the value for allowable change of amplitude and shape of supply voltages (Al Ain *et al.*, 2005b). For voltage flicker it follows the GE curve reproduced here for clarity in Figure 2-5 (IEEE Standards Number 141-1993, 1994). The Saudi electric supply industries have some specified values for voltage unbalances and flicker. For voltage unbalances it is around 5% for voltages up to 380kV and for over voltages of over 30 min it is up to ±10% of the input voltage.

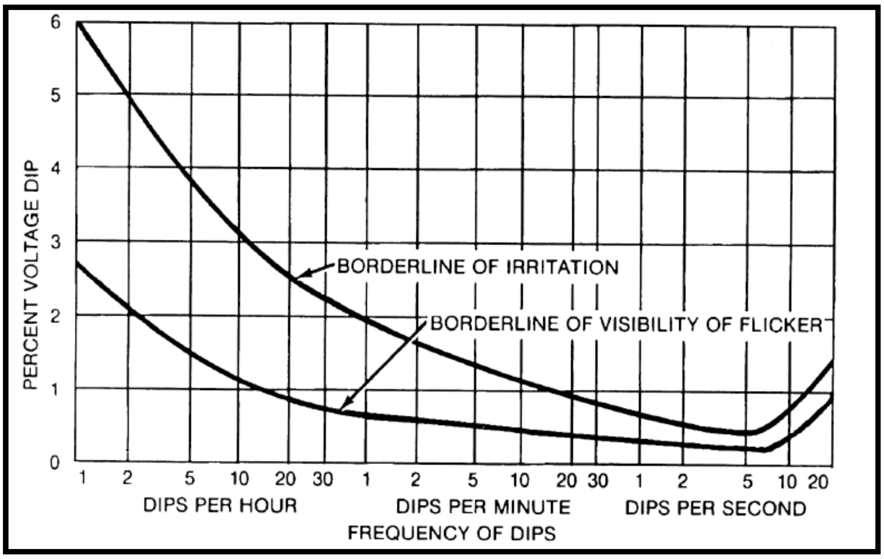

Figure 2-5: GE Curve for Voltage Flicker (IEEE Standards Number 141-1993, 1994)

Table 2-2 Details the standards for various PQ indices in Saudi Arabia

PQ Disturbances	**ECRA (Electricity and Cogeneration Regulatory Authority Limits) Kingdom of**	**Abu Dhabi Distribution Company**	**Comments**
Power Frequency Limits	58.8-60.5 For 60Hz fundamental		Continuous Operation
	57.5-61.5 for 60 Hz fundamental;		For a period of 30 min
	57-62.5 for 60 Hz fundamental		For a period of 30 secs
Voltage limits	From 110 kV to 380 kV the normal range is ±5 %. However the over voltage limit less than 30 Min the range may have ±10 % of input	Unbalance at individual loads/ connections 1.3 % Unbalance at PCC is 2 %	
Voltage Fluctuation	Short term flicker sensitivity ≤0.5	Short term flicker sensitivity ≤0.5	
Harmonics Limits	THD limit is 5% for 400 V system, and 4% and 3 % for 6.6-20kV and 22kV-400kV respectively	THD limit is 5% for 400 V system, and 4% and 3 % for 6.6-20kV and 22kV-400kV respectively	Details in IEEE standard 519-1992

2.8 Conclusion

In this Chapter comprehensive literature was reviewed to understand the PQ monitoring in electrical power system.

Advancements in electrical engineering have posed threats for the PQ engineers. For example previously the techniques devised for managing interruptions for overhead AC transmission line may not be applicable for tackling problems in modern HVDC systems. Similarly, the techniques for HVDC may not be valid for FACTS systems. Furthermore, the use of HVDC and FACTS devices has produced the problem of waveform distortion. Moreover, in a deregulated environment the IPP may be using the renewable energy as a power source which imposes the PQ problems like voltage instability and distortion (Distributed Nodes Monitor for Power Quality (DNMPQ) is proposed for PQMS in deregulated environment. New systems are coming along with the technological advancements and a PQ engineer is always seen to catch the remedies and meet the specified criteria for customer satisfaction. Distributed generation is also playing an important role in power systems. DGs make a power system more reliable but even in DG there may be PQ problems. So, in a nut shell conventional distribution systems are being replaced by Smart Grid environment in various countries. The aspect of provision of reliable quality of power supply has challenged engineers to design and develop new methodologies and techniques to enhance the performance of electric power system.

PQ monitoring is done by power utilities round the clock; hence the size of PQ data being recorded is huge. As the size of the recorded PQ data by monitors at substations is huge, it has become imperative for power utilities to think of new ways to separate the useful data from the huge raw data.

The next Chapter will explain in detail the real PQ monitoring system and the challenges associated with monitoring of PQ data for Victorian EPDS in a 66/22kV zone substation of UED system, which is part of Jemena Power Network in Melbourne, Victoria.

Chapter 3

PQ Monitoring: Victorian Power Distribution System

3.1 Introduction

An overview of PQ monitoring in EPDS was presented in the previous Chapter. This Chapter will detail the real PQ monitoring system and the associated challenges in PQ data monitoring of Victorian EPDS. The experimental analysis of PQ monitoring is carried out for a 66/22kV zone substation of United Energy Distribution (UED) Company, which is part of Jemena Power Network based in Melbourne, Victoria. The main aspect of this analysis was to investigate the management strategies which can mitigate the adverse effect of PQ problems on distribution system performance.

PQ monitoring is necessary to characterize the electric phenomenon at a particular location of the power distribution network. It is done by power utilities to run the power system operations with a view to provide quality power supply to customers without interruption on sustainable basis. PQ monitoring is done by power utilities round the clock; hence the size of PQ data being recorded is huge. As the size of the recorded PQ data by PQ monitors at substations is huge, it has become imperative for power utilities to thinks of new ways to separate the useful data from the huge raw data (Mcgranaghan & Santoso, 2007). With the increased customer completion and greater regulatory requirements more efficient and advanced signal processing techniques (Bollen, 1999) are required to monitor the PQ issues for enhanced system performance of the EPDS. Power utilities face the challenge to manage their large network for PQ monitoring and intelligent decision and separation of useful PQ data from the raw PQ data.

This chapter is organised as follows:

Section 3.2 discusses the PQ monitoring system and PQ data download at 66/22kV zone substations for the UED system. Section 3.3 explains the experimental set up of the PQ data for the EPDS. Section 3.4 gives the PQ data being recorded at site. Section 3.5 explains the steps involved in pre-processing of this data by the techniques of principal component analysis. The experimental results, discussion and development of PCAT model is presented in section 3.6. The conclusions are done in Section 3.7.

3.2 PQ Monitoring System

The PQ monitoring set up at UED is based on reliability of the function of the EPDS and supply of quality of power on continuous bases. It focuses on the performance of the electrical equipment when connected to the electrical supply power.

Figure 3-1 shows the PQ monitoring set up for the 66/22kV zone substation of the UED system. The PQ meter is installed at the 22kV bus. PQ monitors are installed at the 22kV side of the zone substation and also at the end of the feeder after the distribution substation on LV side to analyse the maximum variance of PQ data. The PQ meters record the average values of different PQ attributes of the distribution network on hourly basis round the clock.

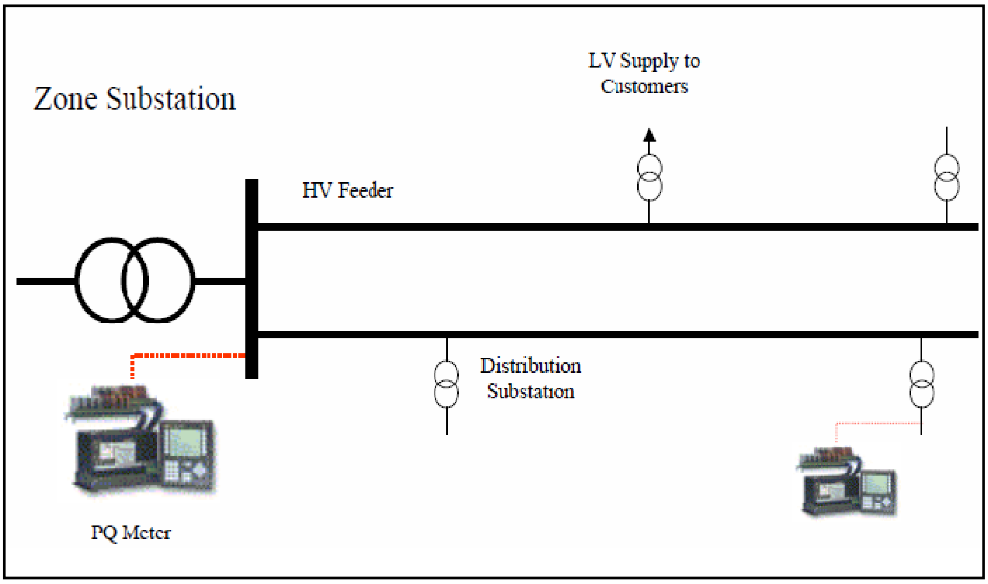

Figure 3-1 PQ Monitoring Set-up (Jemena Electricity 2008)

The main PQ parameters include voltage sag and swells, flickers, harmonics, voltage unbalance and transients. The UED distribution network consists of:

- 27 zone substations
- All zone substations are installed with PQ meters
- One feeder end out of every zone substation is monitored
- Voltage excursions outside Electricity Distribution Code limits are reported to the Essential Services Commission (ESC).

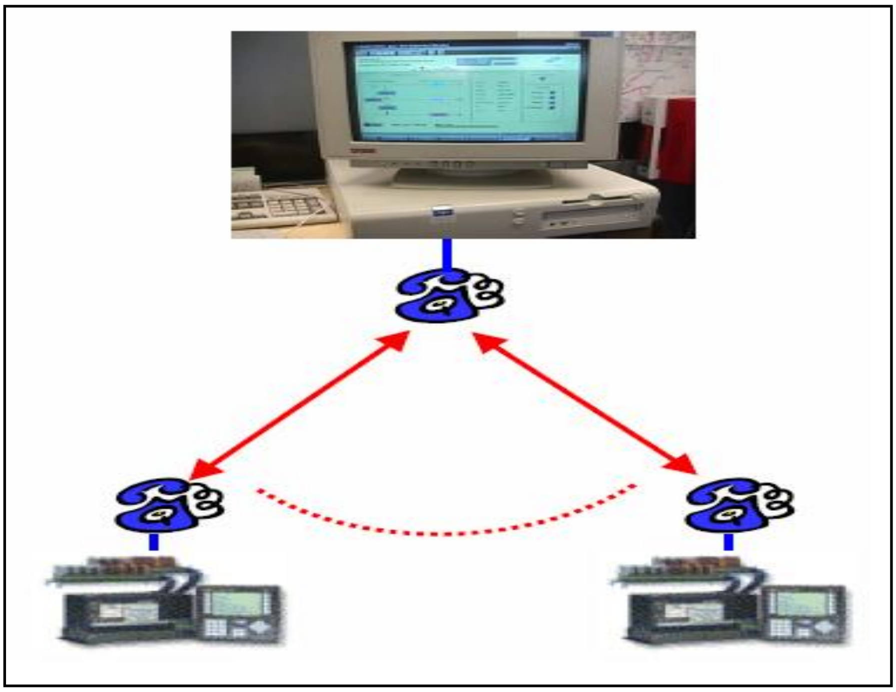

Figure 3-2 PQ centralised recording system (Jemena Electricity 2008)

The PQ data is downloaded into a central computer from the PQ meters installed at the zone substations as shown in Figure 3-2.

The automated modems are used to download the PQ information into centralised recording system. The recording of PQ data at the host end is through Public switch Telephone Network (PSTN) with the help of dial up modem or through Ethernet for the zone substations which are connected through the wide area network (WAN).

The detailed communication of recorded PQ data by the PQ meters at the 66/22kV zone substations with the host end is shown in Figure 3-3. The node 'Host End' interacts with its parent node, 'zone substation End' through public switch telephone network (PSTN) or wide area network (WAN) network to record the PQ data.

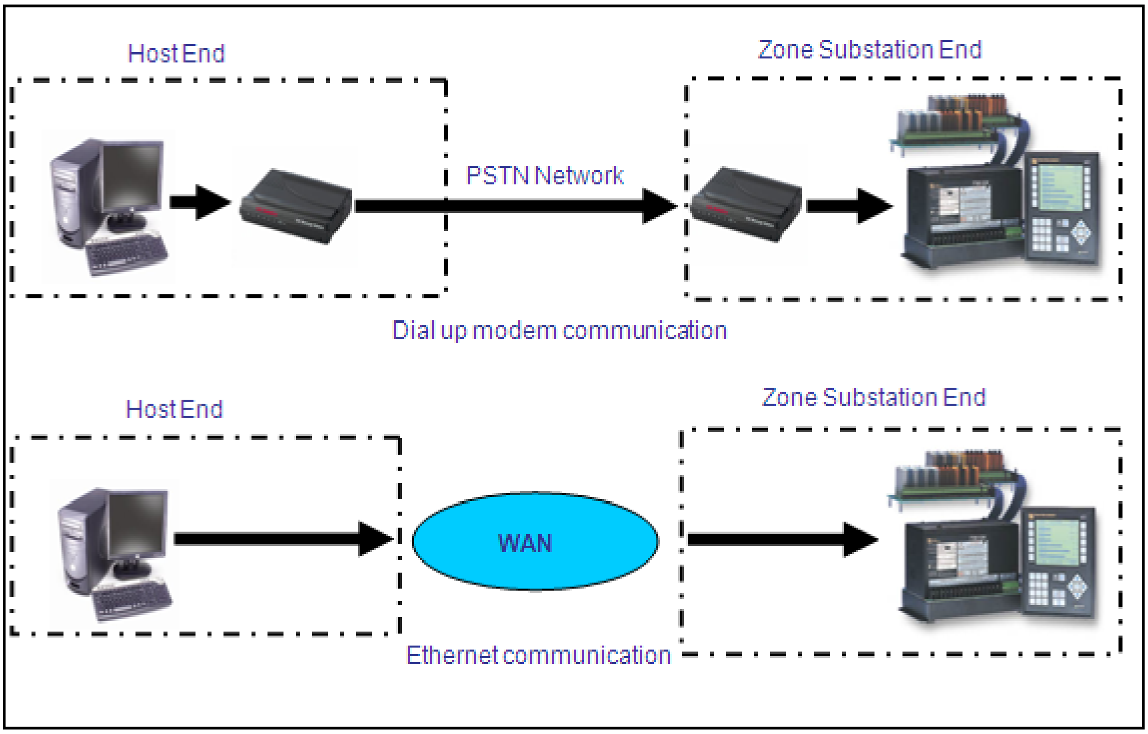

Figure 3-3 United Energy Distribution PQ Monitoring (Jemena Electricity 2008)

According to the Victorian Distribution Code, sag/swell and transient events of a voltage signal in a distribution system are triggered by their threshold limits. These limits are programmed for all zone substations in the United Energy ION PQ Host system. The threshold limits for Sag/Swell and transients are listed below:

- Sag/Swell limits: +/- 6%
- Sag Limit: 94%
- Swell Limit: 106%
- Nominal Voltage: 11500V or 22500V
- Transient Limit: 130% of nominal voltage.
- Nominal Voltage: 11500V or 22500V

Transient event is basically an over voltage or a step rise in the voltage signal. Sag is a reduction in voltage and a swell is an increase in voltage, sag/swell and transient events are expressed as percentage of the nominal voltage.

3.3 Experimental Setup for Measurement of Power Quality Disturbances

The experimental setup in Figure 3-4 was used to measure various PQ disturbances for the 66/22kV zone substation of UED.

A small part of the real data recorded by the PQ meter at 66/22kV Box Hill substation is shown in Table 3-1. The table only shows the values of the PQ data for sag, swell and transients at the 22kV side of the zone substation.

The recorded data is for the three different phases of the EPDS. It can be seen from the Table 3-1 that the PQ meter has recorded the sag, swell and transients events when the PQ disturbances occurred at the network beyond the threshold limits. These threshold limits have been set according to the Victorian electricity distribution code and have been explained in Section 3.2. These limits have been programmed in the PQ meters ION 7700 enterprise software.

Figure 3-4 Experimental set up of 66/22kV zone substation in Melbourne Victoria

The data in the Table 3-1 indicates that the sag/swell and transient events at different phases of voltages e.g. V1, V2 & V3 were picked up by the PQ monitors installed at the 22kV side of the Glen Waverley zone substation. As an example, at incident 9 a sag event was recorded on the voltage (V1) phase on 21 Feb 2010 at 21:56:49 hrs, where the voltage was reduced to 91% of the nominal voltage. Note that the sag alarm limit is programmed as 94% in the ION UED PQ system hence the event was recorded as the signal had reached the alarm limit (94%).

Table 3-1 Sag/swell and transients for 66/22kV Glen Waverley zone substation

Worst Disturbances

Incident	Meter	Time	Type	Phase	Duration (s)	Magnitude (%)
Incident 39	ZSS.GW	2010-Mar-29 04:20:11.962	Sag *Exceeds Tolerance	V1	1.404000044	52.00
Incident 3	ZSS.GW	2010-Feb-11 16:14:04.403	Sag *Exceeds Tolerance	V1	0.801999986	32.00
Incident 24	ZSS.GW	2010-Mar-13 13:14:41.548	Sag *Exceeds Tolerance	V3	0.760999978	30.00
Incident 32	ZSS.GW	2010-Mar-20 22:57:33.002	Sag *Exceeds Tolerance	V2	0.481999993	29.00
Incident 28	ZSS.GW	2010-Mar-16 06:24:59.091	Sag	V1	0.920000017	83.00
Incident 14	ZSS.GW	2010-Feb-27 10:07:22.185	Sag	V3	0.74000001	86.00
Incident 21	ZSS.GW	2010-Mar-07 13:13:47.973	Sag *Exceeds Tolerance	V3	0.100000001	32.00
Incident 9	ZSS.GW	2010-Feb-21 21:56:49.818	Sag	V1	0.32100001	91.00
Incident 43	ZSS.GW	2010-Mar-31 20:27:29.206	Sag	V2	0.180000007	91.00
Incident 13	ZSS.GW	2010-Feb-27 08:47:52.668	Sag	V2	0.079999998	86.00
Incident 16	ZSS.GW	2010-Mar-01 07:54:46.650	Sag	V2	0.059	86.00
Incident 15	ZSS.GW	2010-Feb-28 22:37:52.264	Sag	V1	0.039999999	86.00
Incident 2	ZSS.GW	2010-Feb-11 16:12:11.282	Sag	V3	0.039999999	92.00
Incident 25	ZSS.GW	2010-Mar-14 06:43:41.342	Sag	V3	0.02	93.00
Incident 45	ZSS.GW	2010-Apr-04 08:06:59.373	Trans	V2	0.001872	142.00
Incident 40	ZSS.GW	2010-Mar-29 05:58:44.230	Trans	V3	0.001872	137.00
Incident 44	ZSS.GW	2010-Apr-03 09:04:34.599	Trans	V2	0.00156	142.00
Incident 29	ZSS.GW	2010-Mar-17 05:48:52.338	Trans	V2	0.001716	138.00
Incident 19	ZSS.GW	2010-Mar-04 06:42:11.882	Trans	V1	0.00156	139.00
Incident 26	ZSS.GW	2010-Mar-14 09:17:43.411	Trans	V3	0.001716	135.00
Incident 12	ZSS.GW	2010-Feb-26 06:04:36.893	Trans	V1	0.001404	141.00
Incident 37	ZSS.GW	2010-Mar-27 06:53:51.903	Trans	V2	0.001248	144.00
Incident 33	ZSS.GW	2010-Mar-21 11:44:10.403	Trans	V1	0.001248	136.00
Incident 7	ZSS.GW	2010-Feb-17 07:42:50.850	Trans	V3	0.001248	131.00

These sag/swell and transient events are plotted on the CBEMA (Computer Business Electrical Manufacturer Association) voltage tolerance curve as shown below in Figure 3-5 (Information Technology Industry Council, 2008).

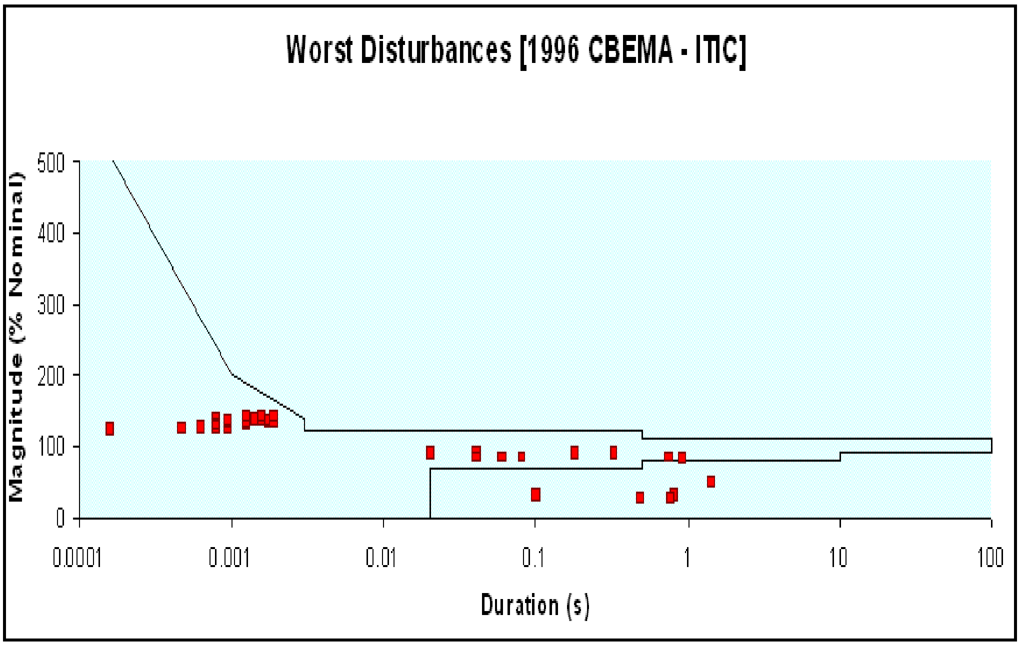

Figure 3-5 Quality disturbances at 66/22kV Glen Waverley zone substation (Information Technology Industry Council, 2008)

CBEMA has been renamed as ITIC (Information Technology Industry Council) curve. This curve describes the tolerance of the equipment in all types of PQ or voltage disturbances.

The solid lines represent the maximum and minimum voltages that can be tolerated without malfunction plotted against time. The curve was originally produced to help users of IT equipment in resolving PQ problems with electricity suppliers. By standardising the requirements of equipment it became much easier to determine by site measurement whether the supply was adequate or not (Information Technology Industry Council, 2008).

3.4 Power Quality Data

The power quality real is taken from a power utility in Victoria Australia. The PQ data consists of 15 attributes. Each attribute consists of 2208 data sets and the experiment was carried out by recording data for three months.

The different parameters being measured for the electrical power distribution system are sag, swell, harmonics, power factor, frequency, voltage unbalance, real power, apparent power, reactive power and total harmonics distortion for the power distribution network under investigation. The raw average values of different parameters after each hour of power quality data on all the three phases of the electrical power distribution system were recorded. Due to larger number of attributes being monitored for the power quality data containing multiple parameters it becomes very difficult to analyse the power system behaviour by processing all the attributes. Moreover because of high correlation in the available power quality data, it becomes impossible to separate those parameters, which are significantly affecting the voltage and current disturbances in the power distribution system. Hence the technique of principal component analysis to pre-process the raw power quality data for intelligent computational analysis will be used.

3.5 Pre-processing of PQ Data

The experimental setup in Section 3.3 reveal that PQ meters installed by the power utilities are recording raw PQ data which is huge in size with many PQ attributes. These attributes give information about steady state value of the system voltage/current. They also record the voltage unbalance, harmonics, fluctuations, sags, swells, transients and other unexpected PQ disturbances. As the size of data is huge with multiple PQ attributes there is an extensive need for management of such a data base so that useful information can be separated from the huge raw data.

3.5.1 Principal Component Analysis Technique (PCAT)

Principal Component Analysis Technique (PCAT) is used to pre-process the large PQ data of the EPDS. The recorded PQ data consists of huge number of attributes (e.g. sag, swell, voltage unbalances). The main objective of PCAT is to reduce the dimensionality of raw PQ data while maintaining the core relationship between different PQ attributes. PCAT will figure out all those attributes of PQ data, which are based on maximum variance. The goal is to describe this dataset with a smaller set of new, synthetic variables. These variables will be linear combinations of the original variables, and are called Principal Components. It is often expected that reducing the number of variables used to describe data will lead to some loss of information. PCA operates in a way that makes this loss minimal, in a sense that will be given a precise meaning. Therefore, PCA is regarded as a dimensionality reduction technique. This is confirmed by calculating the Eigen values and vectors in Section 3.5 of the experimental results and discussion.

3.5.2 Steps for Implementation of Principal Component Analysis

The steps used for the implementation of PCAT are summarized below:

(a) Plot of PQ data and Calculation of data Mean

The first step is to plot the PQ data as shown in Figure 3-6. After the plot of PQ data, the mean value is calculated as shown in Figure 3-7.

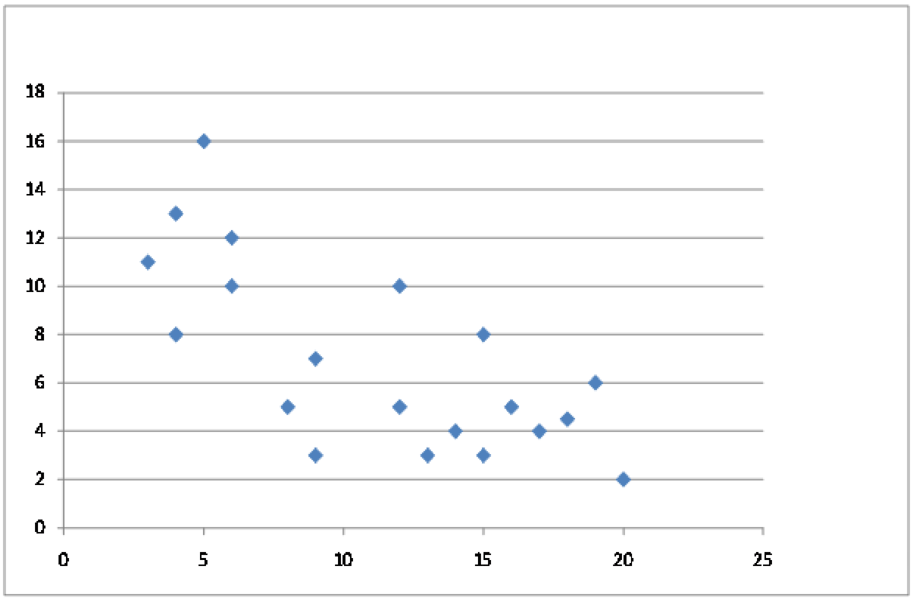

Figure 3-6 Plot of PQ data in two dimensions

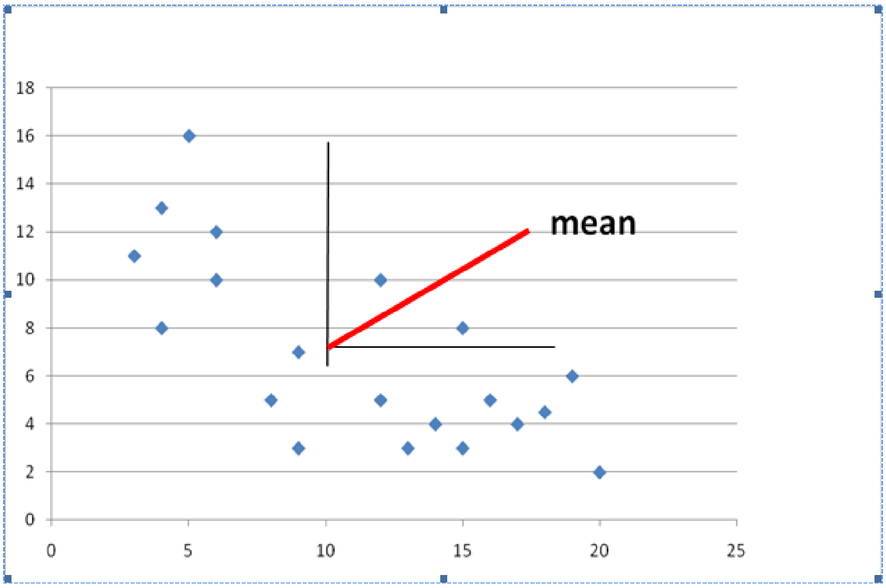

Figure 3-7 Plot of mean of PQ data

(b) Shifting of PQ Data to Mean

The second step is to shift the zero axes to the new mean; the mean value has to be subtracted from the value of each feature. Figure 3-8 represents the new axis after shifting the data.

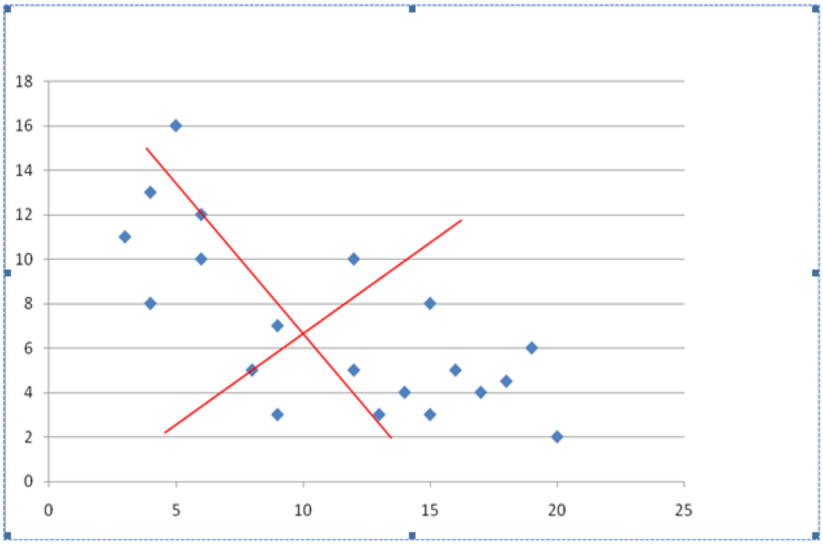

Figure 3-8 New axes showing the maximum variation of PQ data

Figure 3-8 gives the maximum variation of the plotted PQ data.

(c) Establishment of New Data Axis

A new data axis of interest uses the mean value as a reference (origin) point of new axis. Therefore, the final dimension based on Eigen vectors is shown in Figure 3-9 showing principal components of PQ data.

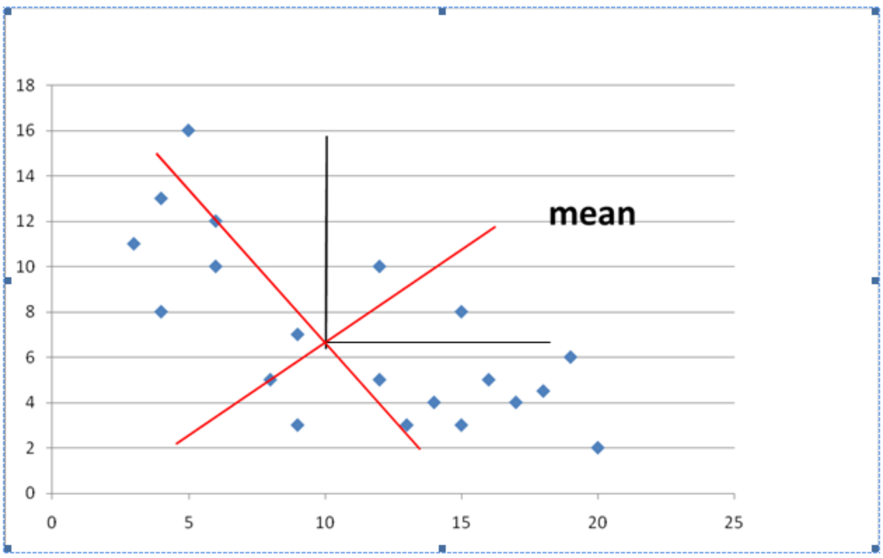

Figure 3-9 Final dimension of PQ data based on Eigen vectors

(d) Calculation of Data Covariance

The important step in finding the principle components is to find the covariance matrix using equation (3.1). This will give those components of PQ data where the variance of the data is found to be highest.

$$C_{xy} = \frac{\sum_{i=1}^{N}(X_i - \mu_x)(Y_i - \mu_y)}{N-1} \qquad (3.1)$$

where, C_{xy} show the covariance of the attributes i.e. X_i and Y_i, N is the total number of data values and μ is the mean of data.

(e) Calculation of Eigen Values and Eigen Vectors from Covariance Matrix

The Eigen values represent the number of principle components and their significance in the data. While the Eigen vectors represent the dimensions in which the variance of the given data is maximum. This maximum variation of data is helpful for extracting the knowledge of new attributes (dimensions) in dataset (Smith, 2002).

3.6 Experimental Results and Discussion

The PQ is taken from the experimental set up of Section 3.3. The PQ data consists of 15 attributes. Each attribute consists of 2208 data sets and the experiment was carried out by recording data for consecutively 92 days. The raw average values of different parameters after each hour of PQ data for the EPDS were recorded. Due to larger number of attributes being monitored for the PQ data containing multiple parameters it becomes very difficult to analyse the power system behaviour by processing all the attributes. Moreover, because of high correlation in the available PQ data, it becomes impossible to separate those parameters, which are significantly affecting the voltage and current disturbances in the EPDS.

In many practical applications, principal component analysis technique (PCAT) is employed for finding dimensions of the PQ data where the spread of data is found to be greatest.

Figure 3-10 is the block diagram which shows the complete method to obtain the processed data. This data is further used in Chapter 4 for advanced computational analysis.

As the size of data is huge with multiple attributes and different operating conditions the techniques of principal component analysis to get the processed data for research work was used.

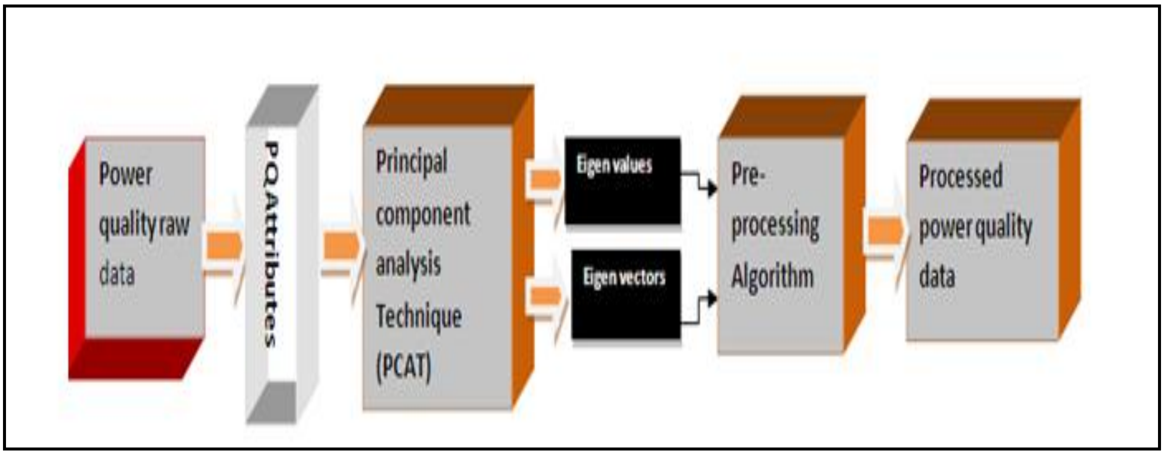

Figure 3-10 Block diagram of PCAT model for processed PQ data

Figure 3-11 shows the plot of Eigen values for reducing the attributes of the PQ data. Each Eigen value corresponds to one new dimension of the real PQ data taken for this research work.

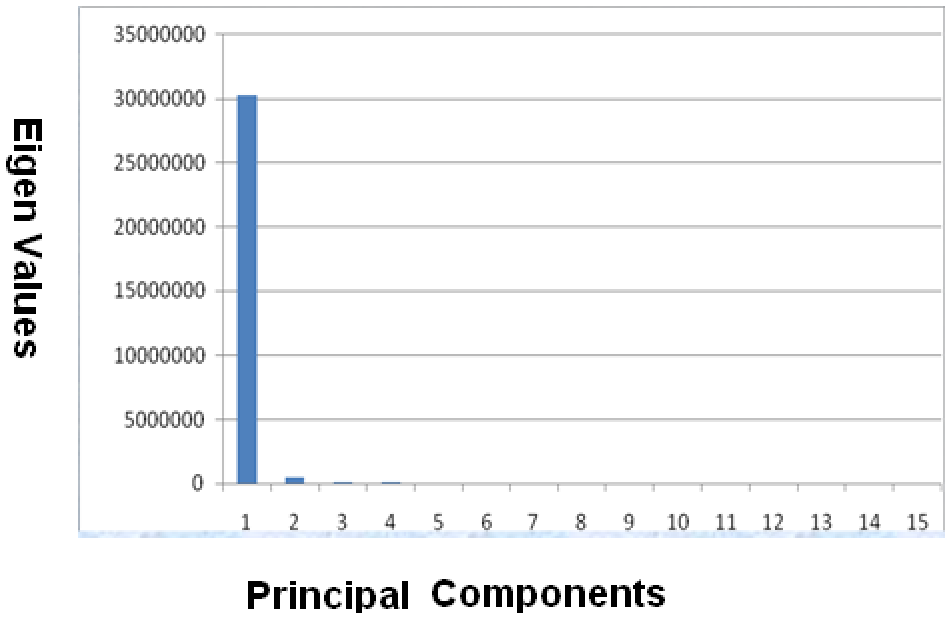

Figure 3-11 Plot of Eigen Values Vs Principal Component

To get the desired result the PCAT shifts the zero axis of the PQ data to a new axis by taking the mean values of the total PQ data for the three months period. The covariance between all the 15 PQ data attributes are calculated to find the Eigen vector. Each Eigen vector corresponds to new dimensions of the real PQ data. The pre-processing algorithm is applied at the Eigen Values and Eigen vectors to get the final two dimensional processed data. The algorithm is explained in Figure 3-12.

The code:

```
VECTOR=NULL
J=0
FOR X: 1 TO N
IF EIGEN_VALUE (X) > THRESHOLD
VECTOR (J) = EIGEN_VECTOR (X) + VECTOR (J)
END FOR
IF VECTOR NOT EQ NULL
NEW_DATA= VECTOR * OLD_DATA
ELSE
NEW_DATA=OLD_DATA
```

Figure 3-12 The code for final 2-dimensional processed PQ data

PQ data can be represented by two new dimensions without the loss of any data as shown in Figure 3-13.

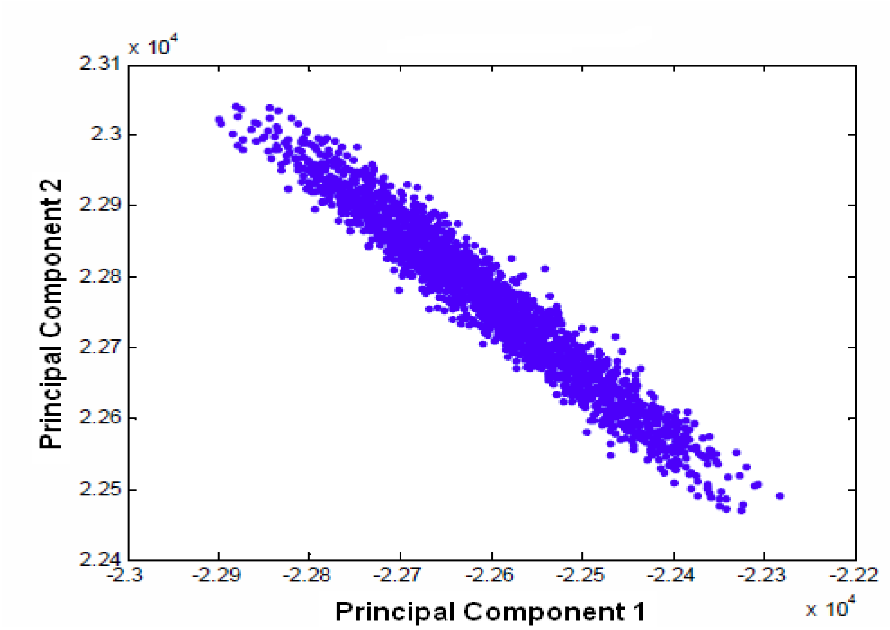

Figure 3-13 Plot of PQ data in 2 dimensions (Paracha *et al.*, 2009c)

The loss of the final 2 dimensional processed PQ data is shown in Figure 3-14. It clearly confirms that 0% data is lost by considering two principal components of the PQ data.

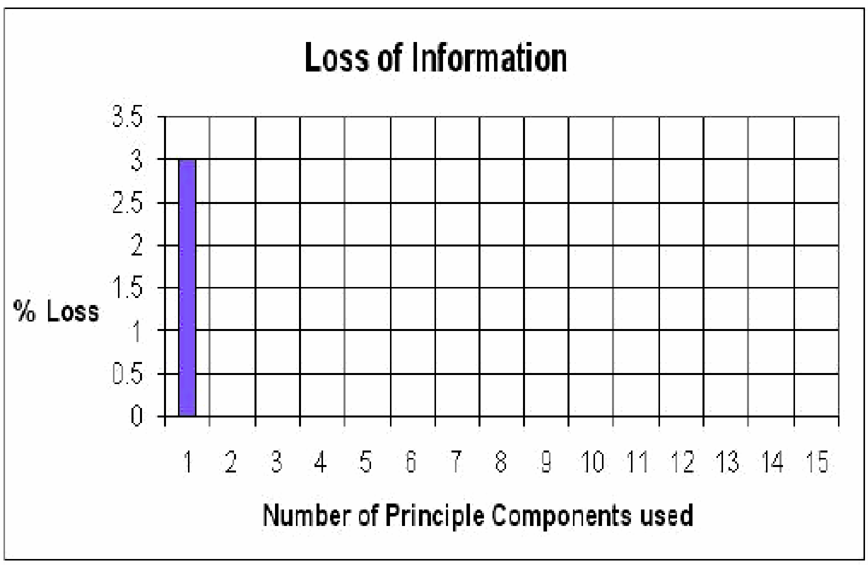

Figure 3-14 Loss of PQ data (Paracha *et al.*, 2009c)

3.7 Conclusion

In this Chapter PQ monitoring for a Victorian power distribution company was discussed in detail. The experimental work revealed that the recording of PQ data is not only huge but it is complex and diversified. Thus it becomes essential to apply some intelligent methodology to separate the raw data with multiple PQ attributes to filter out useful information for monitoring and management of PQ problems in EPDS. The chapter discusses the technique of principal component analysis which is employed on raw PQ data to extract the useful information for future work. The developed model in Section 3.5 for processing the PQ data with multiple attributes will be used in Chapter 4 to perform the intelligent computational analysis of UED system by neural networks.

Chapter 4

Computational Analysis of PQ Data Using Neural Networks

4.1 Introduction

The Chapter 3 developed the PCAT model to pre-process the PQ data. In this chapter firstly this developed PCAT model will be used to refine the multi-dimensional PQ data and then neural networks intelligent techniques will be implemented to classify the major PQ disturbance of the UED system.

The chapter is organised as follows:

Section 4.2 explains the neural network methodology and intelligent computational techniques of feed forward back propagation (FFBP) and recurrent neural network (RNN) for efficiently predicting the PQ disturbances. Section 4.3 explains the major PQ disturbances which are encountered in EPDS on day to day basis. Section 4.4 details the implementation of neural network on the refined PQ data using FFBP and RNN intelligent techniques and also lists the test results for the predicted PQ disturbances. Finally the conclusion is drawn in Section 4.5.

4.2 Neural Network Methodology

Neural network is a black–box method approach which works on the principle of biological nervous system. The neural network processes the information in a similar way as human brain does. They consider the behaviour of the brain as the network of units called neurons. (Abu-Siada, Islam and Mohamed., 2010)

Neural networks have proved to be very effective in solving complex problems (Latorre *et al.*, 2011) and have the following main advantages:

- Neural networks can handle complex problems which are difficult to analyse with mathematical models
- Neural networks are very effective when the data is non-linear and is of huge size
- Neural networks can handle noisy training data
- Neural networks have emerged as a major paradigm for Data Mining applications

4.2.1 Feed Forward Back Propagation (FFBP)

In this chapter FFBP is used to estimate the PQ disturbances in the power distribution network of the UED. The FFBP algorithm is one of the most widely used techniques in Artificial Neural Network (ANN).

In this algorithm supervised techniques are employed. The training errors for the estimated harmonics are calculated using the "Least Mean Squared Error (LMSE) technique" (Abrar *et al.*, 2002). The algorithm is summarised as follows:

a. Randomly initialize the weight matrix
b. Train the network depending on the initial weight matrix
c. Calculate the LMSE by comparing the network output and the desired output

d. Update the weight matrix by back propagating the result obtained to reduce the error

e. Repeat all steps from b to d, to achieve convergence. (In this research convergence is taken as 0.01).

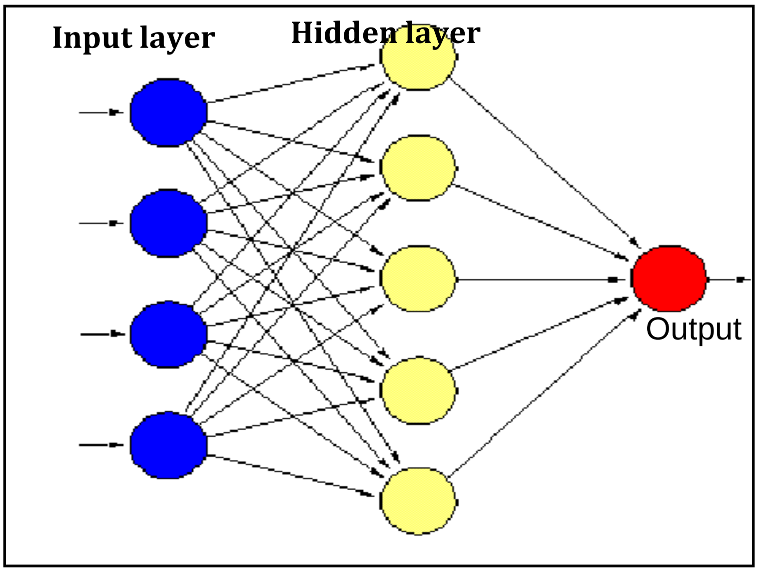

Figure 4-1 A simple architecture of FFBP-NN

Due to the non-convergent behaviour of Multilayer Perceptron for available PQ dataset, the FFBP algorithm is proposed.

The error in the PQ disturbances under consideration is calculated using LMSE algorithm (Abrar *et al.*, 2002). The weight at each node of FFBP is calculated using equation (4.1)

$$\Delta w_{ij}^{\ n} = -\frac{\eta \partial E_r}{\partial \Delta w_{ij}^{\ n}} \quad , \qquad (4.1)$$

where $w_{ij}^{\ n}$ is the weight from i^{th} to j^{th} node of $(n-1)^{th}$ $(m-1)^{th}$ layer, η is the learning rate of neural network and E_r shows the LMSE. A simple architecture of

FFBP (given in MATLAB) is shown in Figure 4-2.

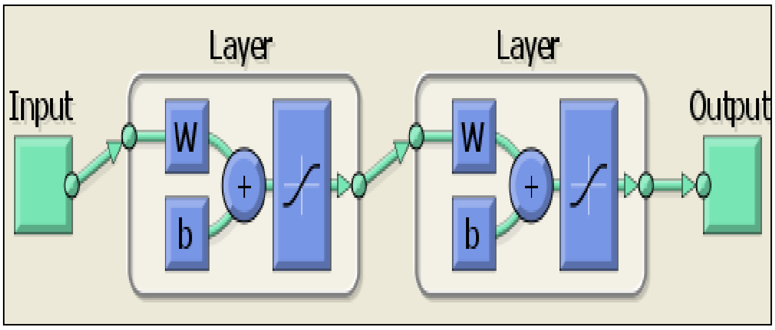

Figure 4-2 The architecture of Feed Forward Back Propagation NN

4.2.2. Recurrent Neural Network

The Recurrent neural networks (RNN) have random topologies. The models using RNN can be developed using their internal states. In this model, training of neural network is very difficult as compared to other. Because of its inherent nature of internal states, delays are linked with different specific weights of neural networks.

It has activation feedback (Boden, 2001) as shown in Figure 4-3, which helps this network to remember the past inputs.

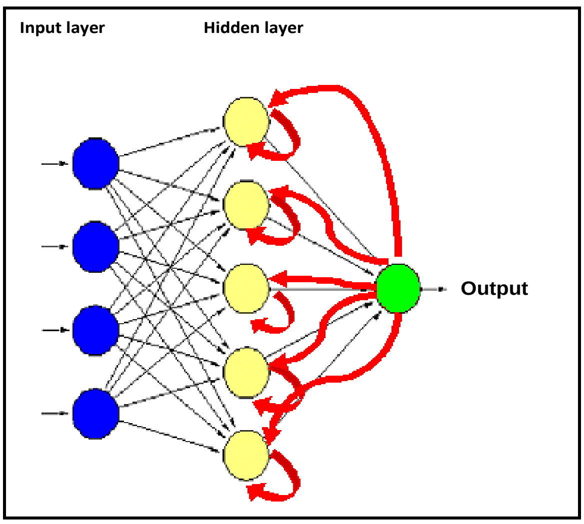

Figure 4-3 A simple architecture of recurrent layer neural network

The blue coloured nodes represent the input nodes. The yellow coloured nodes represent the hidden nodes. The feedback loops are drawn in red colour and final output is given in green colour node.

All other steps are similar to FFBP algorithm. The difference between RNN and FFBP neural networks is that the feedback is available at the input. A simple architecture of recurrent neural network (given in MATLAB) is shown in Figure 4-4.

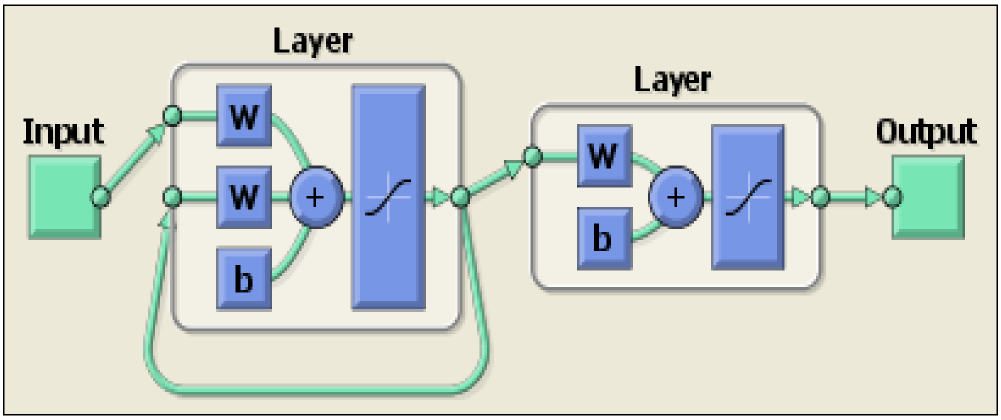

Figure 4-4 The architecture of recurrent neural network (RNN)

4.3 PQ Disturbances in EPDS

In electrical power system the monitoring and management of PQ disturbances is of prime importance for provision of quality supply of electric power. The PQ disturbances in EPDS are not only restricted to only technical problems in a power utility but are also concerned with economics for both power utility and its customers. In recent years, there has been lot of emphasis on the provision of reliable and quality electric power supply to domestic and industrial consumers. The aspect of provision of reliable quality of supply power has challenged engineers to design and develop new methodologies and techniques to enhance the performance of the electric EPDS. The proper analysis of PQ problems requires a high level of engineering expertise.

The PQ disturbances in EPDS have already been discussed in detail in Chapter 3. In this Section, the impact of the major PQ disturbances which are important for the electric power utilities is analysed.

4.3.1. Power Factor

The power utility engineers aim to reduce the electrical costs by improving the power factor and also to prevent equipment malfunction due to poor PQ. Power companies aim to maintain power factor of the power system close to unity. The power factor (P.F) is a relation between the actual power and the apparent power and is given by equation (4.2)(Emanuel, 1993):

$$P.F = \cos\phi \tag{4.2}$$

Equation 4.2 stands for a balanced system whereas in case of unbalanced system, the power factor can be expressed by considering the harmonics power components of the current (Marafao *et al.*, 2002) as shown in equation (4.3)

$$P.F = \frac{VI\cos\phi_1 + \sum V_x I_x \cos\phi_2}{V} \tag{4.3}$$

In equation 4.3, $VI\cos\phi_1$ is related to fundamental frequency whereas the second term, $\sum V_x I_x \cos Ø_x$ relates to harmonics and voltage unbalances. This makes the estimation of power factor a difficult task as the harmonic components identification cannot be calculated completely.

The voltage unbalance contributes to poor power factor in EPDS. With the increase of non-linear loads, it becomes difficult practically to eliminate the voltage unbalance in the distribution network (Von Jouanne & Banerjee, 2001). There may be one or more reasons for the voltage unbalance at one time in a power distribution network (Paranavithana, Perera & Koch, 2009).

The voltage unbalance can be due to the changes in the voltage values at different phases. The deviation in phase angle also causes the voltage unbalance. According to IEEE definition (Bollen, 2002, Singh *et al.*, 2007) , the voltage unbalance can be expressed by equation (4.4)

$$\%v = 100 \frac{\max(\overline{\nabla v})}{\bar{v}} , \tag{4.4}$$

where $\%v$ *is the* phase voltage, $\overline{\nabla v}$ is the average change in voltage, $\bar{v}$ is the average phase voltage of a distribution system.

There are power companies which impose a penalty to its customers if their load contributes towards poor power factor and voltage unbalance in electrical distribution networks. The close monitoring of power factor calculations by power companies forces the industrial customers to take all adequate steps to maintain their power factor close to unity.

4.3.2. Sag and Swell

In electrical power system other than the addition of customers' non-linear load on continual basis the dynamic operation of power system, faults and continuous switching operations result in PQ problems frequently faced by the electrical distribution network. These frequent PQ problems faced by electrical power distribution network are harmonics, voltage unbalance, transients and voltage variations leading to sag, swell and temporary or long-term interruptions (Gosbell *et al.*, 2001).

Among the common PQ problems, sag and swell are few of the main concerns for power companies. They can damage and can create severe losses for industrial consumers including costly equipment.

Sag and swell are those specific PQ disturbances, which can frequently occur in a power distribution network. Power utility engineers are concerned with these PQ disturbances as they can be disastrous for customer's equipment.

The RMS value of voltage to detect variation in voltage is given as:

$$V_x^{rms} = \sqrt{\frac{1}{N}\sum_{y}^{x+N-1} V_y^2}\ , \qquad (4.5)$$

where N is number of samples of voltage waveform, V_x^{rms} is the x^{th} sample of calculated RMS voltage and V_y is the y^{th} sample of the recorded voltage.

The IEEE 1159-95 standard on monitoring of Electrical PQ defines sag as the reduction in voltage/current between 0.1-0.9 per unit in the actual voltage/current, while swell as a boost in the voltage/current between 1.1-1.8 per unit. These changes are analysed in a period of 0.5 cycles – 1 min. The detail of PQ disturbances with their duration as per IEEE 1159-95 standards are given in Table 4-1:

Table 4-1 IEEE Standard 1159-1995 for Sag and Swell (IEEE Standards Board, 1995a)

No#	PQ Disturbances	Duration
1	Instantaneous Sag or Swell	0.5 cycles – 30 cycles
2	Momentary Sag or Swell	30 cycles – 3 seconds
3	Momentary Interruption	0.5 cycles – 3 seconds
4	Temporary Sag, Swell	3 seconds – 1 minute
5	Long Duration	> 1 minute

4.3.3. Harmonics

The PQ monitoring and management has become the main focus for power utilities across the globe. In such a scenario precise detection of PQ problems can help avoid the unpleasant situation of black outs.

Harmonic distortion is found in both the voltage and the current waveforms in power distribution networks and can be given as (Dugan *et al.*, 2002):

$$V_{rms} = \sqrt{\sum_{h=1}^{h_{\max}} \left(\frac{1}{\sqrt{2}} V_h \right)^2} = \frac{1}{\sqrt{2}} \sqrt{\left(V_1^2 + V_2^2 + V_3^2 + \ldots\ldots + V_{h_{\max}}^2 \right)} \qquad (4.6)$$

$$I_{rms} = \sqrt{\sum_{h=1}^{h_{\max}} \left(\frac{1}{\sqrt{2}} I_h \right)^2} = \frac{1}{\sqrt{2}} \sqrt{\left(I_1^2 + I_2^2 + I_3^2 + \ldots.. + I_{h_{\max}}^2 \right)} \qquad (4.7)$$

Equations (4.6) and (4.7) give the root mean square values of voltages and currents for the non-sinusoidal waveforms where V_h and I_h are the amplitude of voltage and current respectively at the harmonic component h.

The total harmonic distortion (THD) which is a measure of the harmonic component present in a distorted wave form can be expressed as (Dugan *et al.*, 2002),

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{\max}} (M_h)^2}}{M_1}, \qquad (4.8)$$

where M_h is the root mean square value of harmonic component h.

Power distribution networks are ideally designed to tackle sinusoidal voltage and current waveforms. However, with the increased usage of modern power electronic equipment the situation has become difficult for power utility engineers to maintain supply of quality power to their customers on sustainable basis.

The existing power distribution network design in most cases is only capable of absorbing harmonic distortion to a certain limit after which the effect of harmonic distortion becomes evident in the distribution system.

Over the years, numerous techniques, methods and tools have been employed to measure the harmonic distortion in power distribution network. The extensive use of non-linear loads especially in industry has made it quite difficult to achieve accuracy for the measurement of amount of harmonics generated by customer's equipment. In such a scenario, fast methods for measuring and estimating harmonic signals through artificial intelligence techniques have produced excellent results (Swiatek *et al.*, 2007b).

The conventional power system is not designed to accept the behaviour of non-linear loads and thus afore-mentioned mentioned PQ problems of poor power factor, voltage unbalance, sag/swell, harmonics and other associated problems cost the electric power utility both in terms of reliability and sustained availability of quality supply power for their consumers.

4.4 Implementation of Neural Networks on PQ Data

The conventional methods for estimation or prediction of PQ problems were restricted to only collection of the PQ data with the aim of identifying the PQ problems from the available PQ data. This method is very tedious and slow and is often not very accurate.

In times intelligent computational techniques like neural networks and fuzzy logic systems have proved to be very accurate and fast in classification of the PQ problems in EPDS.

They have proved to be very efficient because of their high performance and the complexity of the electric power distribution system and recoding of huge non-linear PQ data round the clock.

In this Section the technique of neural networks to classify the main PQ problems in the network of UED system will be used. Neural Networks (NN) have been proven to produce appreciable results and have the capability to accurately model the system. The neural network has great ability to deal with random alteration of different values of PQ data.

4.4.1 Use of PCAT MODEL for data refining

As discussed in Chapter 3, the real PQ data of UED system consisting of 15 PQ attributes is recorded for the three phases of the UED system. The developed PCAT model converts the high dimensional into 2 dimensions with minimal or no loss of information.

After the data is processed by PCAT model neural networks are invoked for classifying the major PQ disturbances on the UED system. For predicting each main PQ disturbance (i.e. power factor, voltage sags and swell and harmonics, the whole PQ data eliminating the target disturbance will be pre-processed. For each case study, the PCAT is applied separately, prior to implementing the neural network algorithms.

4.4.2 Estimation of Power Factor

ANN techniques have been used to efficiently predict the power factor of the distribution system which is close to unity. The feed forward back propagation (FFBP) neural network has been found to have an inherited error tolerance for PQ real data used in this research. FFBP has proven to be the simplest method that can be employed for estimation of real PQ data with good predictable efficiency. 10% of the data was reserved for testing purposes. On the average 93% of accuracy was achieved. The Neural network consists of two layers as shown in Figure 4-5.

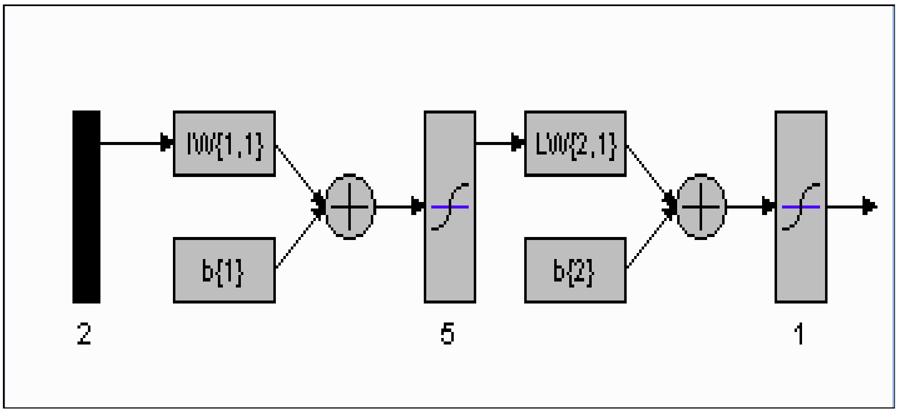

Figure 4-5 Architecture of 2 Layer Feed Forward back Propagation Neural Network

The transigmoid function was used in the first layer whereas the hidden layer employed logsigmoid function. The output layer was the estimated power factor at different parametric values of PQ disturbances of the power distribution network. The training curve is shown in Figure 4-6. The network achieved the convergence in 100 epochs.

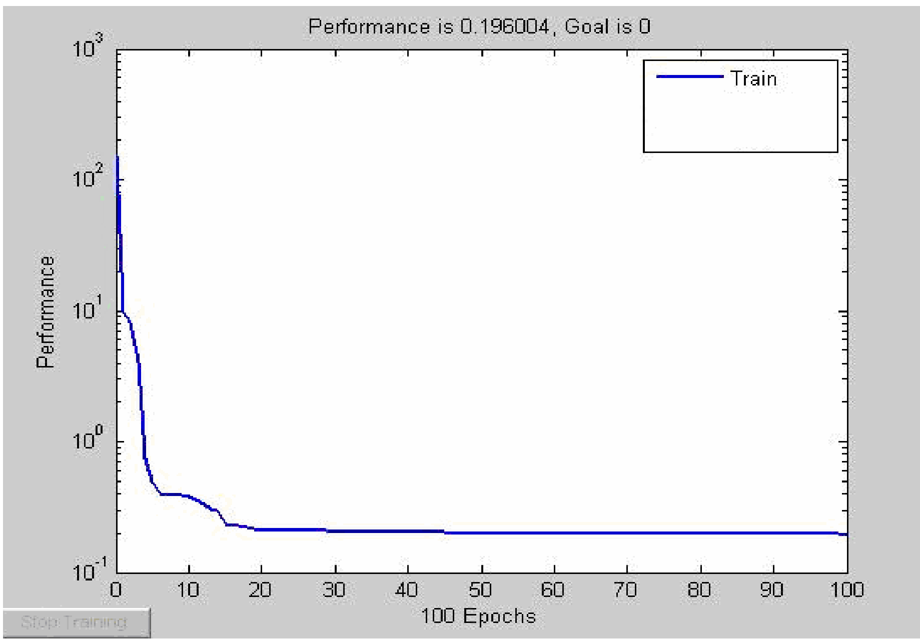

Figure 4-6 The training error curve for estimation of power factor using FFBP-NN (Paracha *et al.*, 2009c)

Table 4-2 shows the estimated and actual values of the power factor and their differences. The accuracy of estimated power factor helps in achieving the desired objectives of availability of quality supply of power to customers on sustainable basis.

Table 4-2 Predicted and Actual Values of Power Factor (Paracha *et al.*, 2009c)

Test No.	Predicted Values of PF	Actual Values of PF	Difference
1	0.9240	0.9939	0.0699
2	0.9262	0.9931	0.0669
3	0.927	0.9925	0.0655
4	0.9278	0.9911	0.0633
5	0.9184	0.9811	0.0627
6	0.9287	0.9712	0.0425
7	0.9211	0.9965	0.0754
8	0.9281	0.9983	0.0702
9	0.92	0.9988	0.0788
10	0.9292	0.9992	0.0700

4.4.3 Estimation of Sag and Swell

The first task in for the computational analysis of sags and swells of distribution system is to find those attributed which have maximum variation using PCAT model. Only two major components (non-zero Eigen values) were found which could represent the whole dataset. Thus these two highly correlated attributes (principal components) were used to train the neural networks. After the pre-processing using PCAT, the capability of two different neural networks was tested to perfectly estimate the sag and swell values of a distribution network. In feed forward back propagation algorithm, the PQ data is trained from input (pre-processed data) to the outputs (Sag and Swell). The Sag and Swells values are estimated/ predicted through the model. The training, testing and validation error curves are shown in Figure 4-5 and Figure 4-6 respectively. The FFBP estimated the sags and swells values with an overall accuracy of 94%. For sag estimation, the sensitivity was calculated to be 95% and the specificity of 78% was observed, whereas the sensitivity and specificity of swell estimation were 93% & 76% respectively. The area under region of convergence (ROC) curve using FFBP neural network for sag and swell was calculated to be 0.945 and 0.935 respectively.

The PQ data was also trained with RNN and convergence is applicability. In this case the network was trained for both sag and swell estimation at the same time. The RNN achieved convergence after thirty epochs. The training, cross validation and testing mean squared training error curves are shown in Figure 4-7.

The PQ monitoring and management has become the main focus for power companies across the globe. In such a scenario precise detection of PQ problems can help power utilities to take adequate steps to tackle the situation and avoid the unpleasant situation of black outs or shut down of customer's equipment.

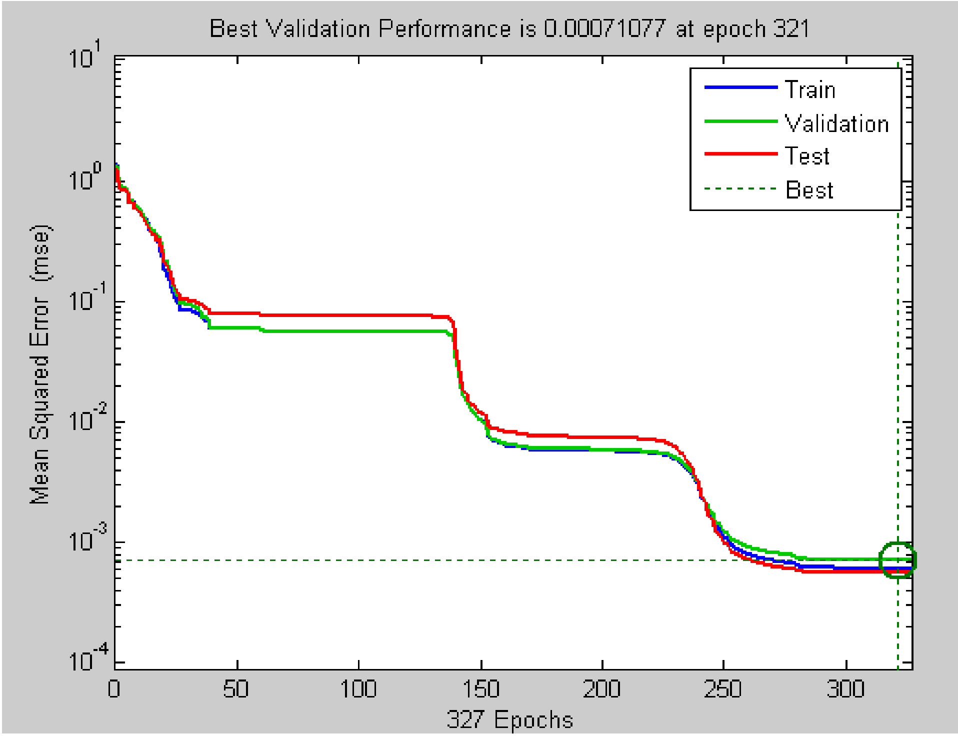

Figure 4-7 The training, testing and validation error curves for swell using FFBP-NN (Paracha *et al.*, 2009d)

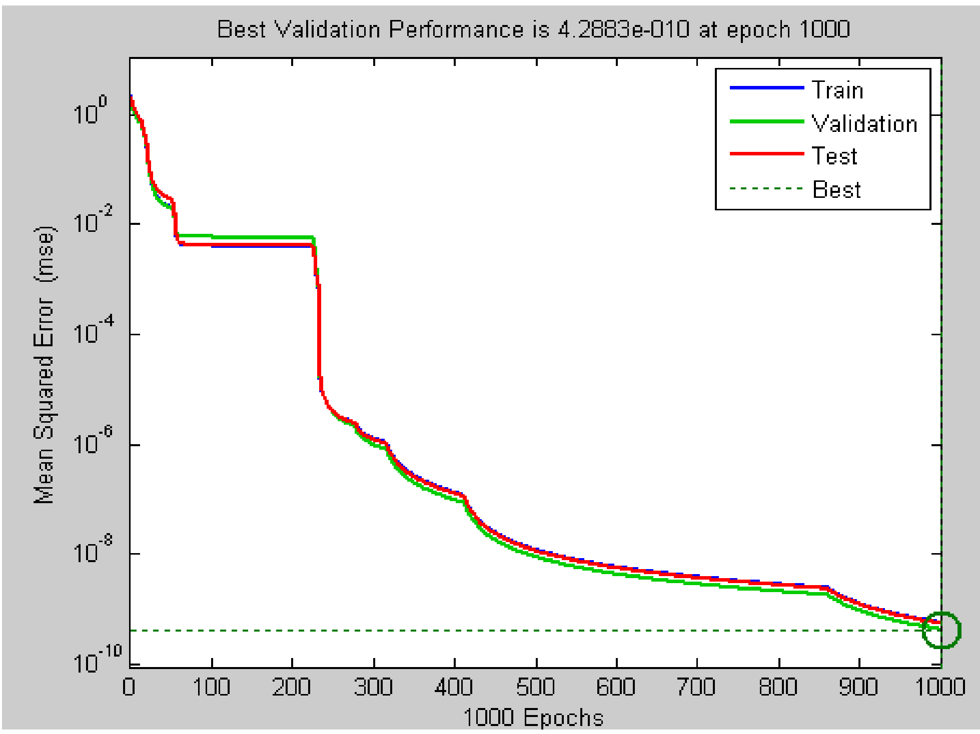

Figure 4-8 The training, testing and validation error curves for sag using FFBP-NN (Paracha *et al.*, 2009d)

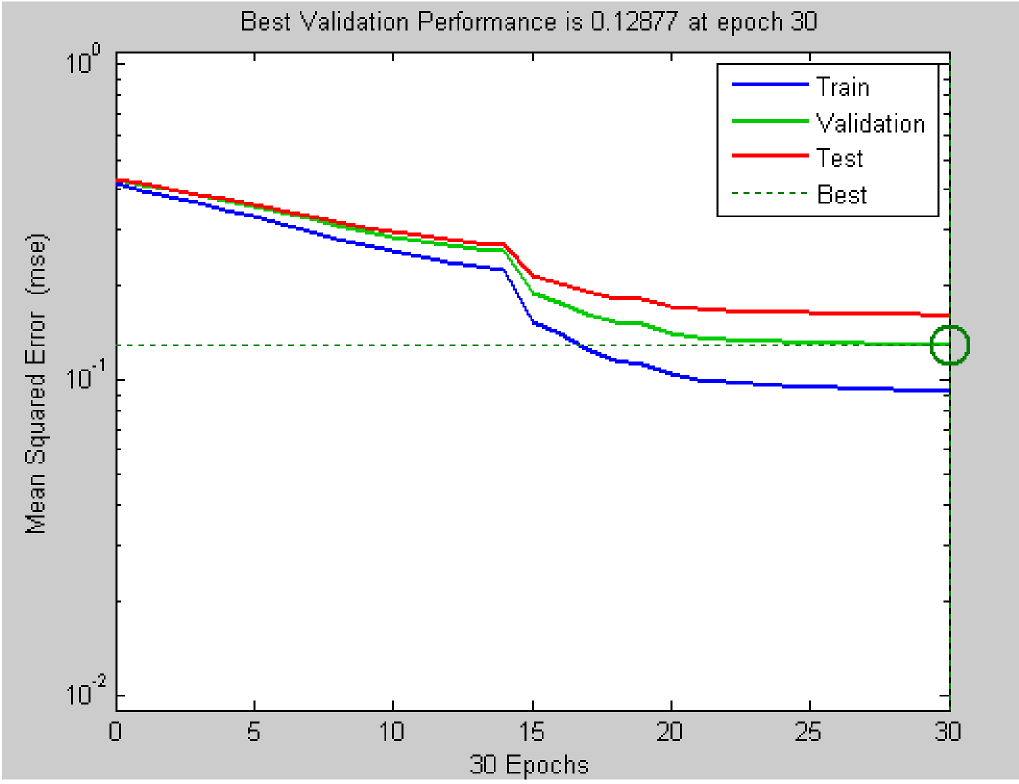

Figure 4-9 The training, testing and validation error curves for sag and swellusing RNN (Paracha *et al.*, 2009d)

4.4.5 Estimation of Harmonics

In the analysis for estimation of power factor, sag and swell only 10% data is used for training purposes and harmonic distortion data was not considered. In this experiment, 20% of the available data for testing purpose.

A two layer neural network is used with tan sigmoid in the hidden layer and log sigmoid in the output layer. The output layer estimates the harmonic values on the three phases of a distribution network. The estimated and desired values of harmonics are listed in Table 4-3 to 4-5.

Table 4-3 Predicted values of Phase A (Paracha *et al.*, 2009b)

Test No.	Predicted Values (PV)	Actual Values (AV)	Difference (PV-AV)
1	5.2438	5.150000095	0.093799905
2	5.44 16	5.409999847	0.031600153
3	5.9725	5.909999847	0.062500153
4	6.3115	6.25	0.0615
5	6.558	6.519999981	0.038000019

Table 4-4 Predicted values of Phase B (Paracha *et al.*, 2009b)

Test No.	Predicted Values (PV)	Actual Values (AV)	Difference (PV-AV)
1	6.8151	6.76999998	0.045100019
2	6.3271	6.230000019	0.097099981
3	4.7180	4.639999866	0.078000134
4	3.4399	3.529999971	-0.090099971
5	2.8528	2.670000076	0.182799924

Table 4-5 Predicted values of Phase C (Paracha *et al.*, 2009b)

Test No.	Predicted Values (PV)	Actual Values (AV)	Difference (PV-AV)
1	5.11151	6.769999981	-1.65848998
2	6.1232	6.230000019	-0.10680001
3	5.7238	4.639999866	1.08380013
4	3.4444	3.529999971	-0.08559997
5	2.3456	2.670000076	-0.32440007

On average 94.5% of accuracy was achieved for predicting the harmonic values of the distribution network. This can help the power utility to attain some precautionary measures against high value of harmonics.

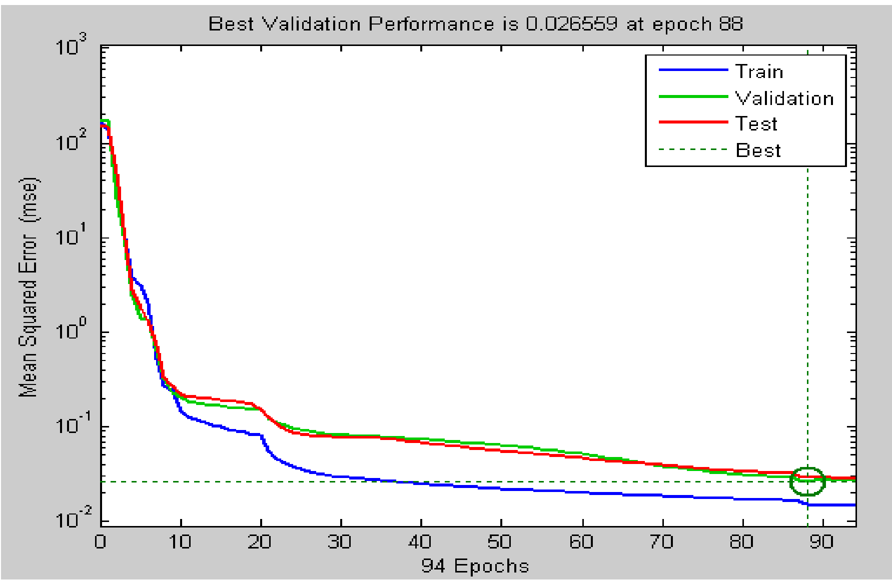

Figure 4-10 The training, cross validation and testing error curves for harmonic currents in Phase A (Paracha *et al.*, 2009b)

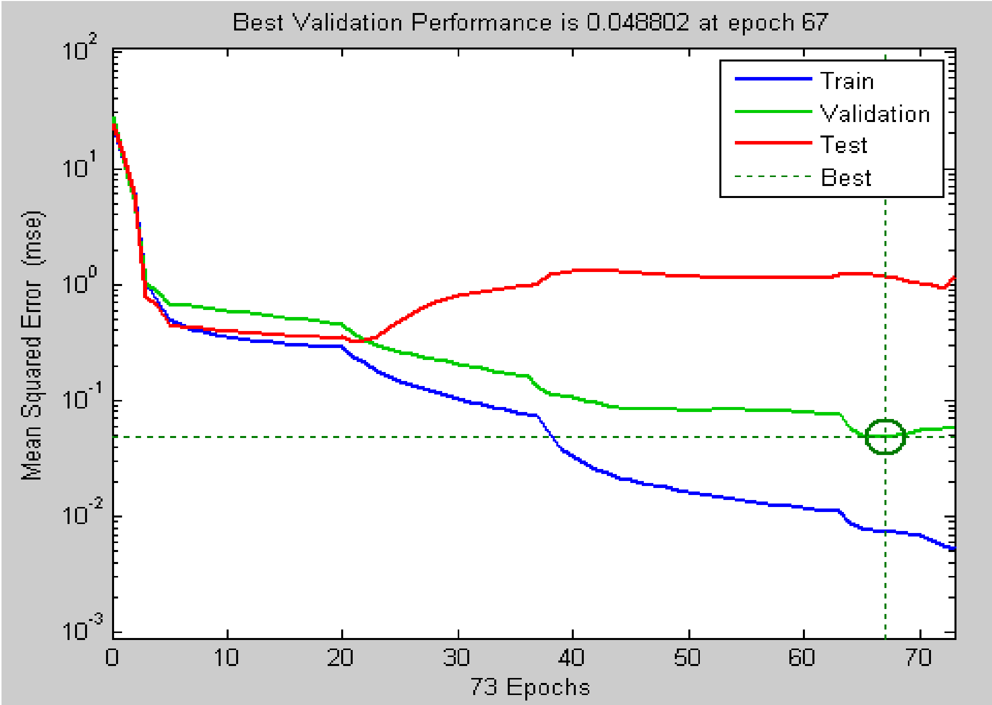

Figure 4-11 The training, cross validation and testing error curves for harmonic currents in Phase B (Paracha *et al.*, 2009b)

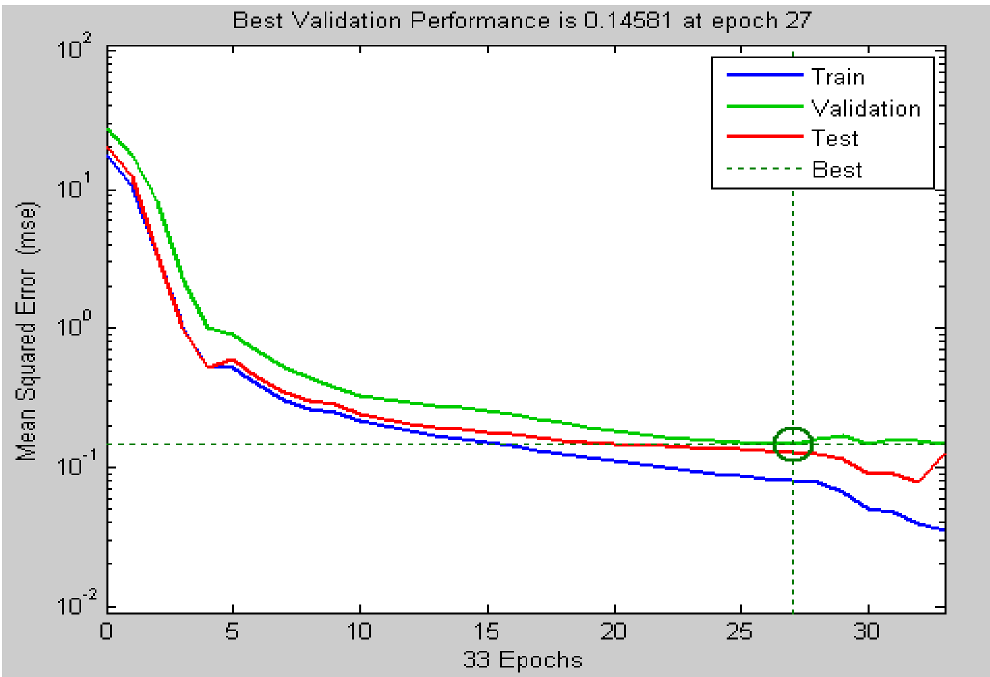

Figure 4-12 The training, cross validation and testing error curves for harmonic currents in Phase C (Paracha *et al.*, 2009b)

The training, testing and cross validation error curves are shown in Figures 4-10-4-12 respectively. The harmonics on phase A achieved convergence in 88 epochs. The harmonics on phase B achieved convergence in 67 epochs while on phase C, the convergence was achieved in 27 epochs.

4.5 Conclusion

In this chapter the PQ data was firstly processed by the PCA model developed in Chapter 3. Each time the PCAT model was implemented by eliminating the target PQ disturbance i.e. power factor, voltage sag and swell and harmonics. After the data is processed for each main PQ disturbance neural network techniques are invoked to predict the main PQ disturbance for the UED.

PQ is a diversified issue and needs a lot of attention in computational analysis. In this research an appreciable accuracy of 93% for power factor estimation is achieved on voltage unbalances of a PQ data by applying the technique of feed forward back propagation neural network (FFBP-NN).

For sag and swell, FFBP-NN and RNN are used separately. The technique of FFBP predicted sag with accuracy of 93.5%, swell with accuracy of 91.5% whereas the technique of RNN classified sag and swell with accuracy of 96%. It is being found that although the technique of RNN gave higher accuracy of 96% as compared to accuracy of sag (93.5%) and swell (91.5%) with FFBP, but RNN has more time complexity.

In case of harmonics only FFBP-NN is used. For this experiment 20% data was reserved for testing purpose and 80% data was used to train the neural network. In this case 94.5% accuracy was achieved for predicting the harmonics for the power distribution network.

The proper estimation of power factor, sag and swell, and harmonics help in safety, reliability and economical efficiency of the power system on long term basis. Problems related to PQ disturbances faced by industrial customers and power utilities can be controlled by efficiently estimating/predicting their values and comparing them with allowable standards. This means that artificial intelligence techniques can easily monitor the PQ data and precautionary measures can be taken in advance. In this Chapter it has been shown that, simple artificial neural networks techniques can be used for the estimation of major PQ problems with appreciable accuracy. The computational analysis of PQ data for the power distribution system under investigation can help in protection, reliability and economical efficiency of the power distribution network.

In the next chapter fuzzy clustering techniques for comprehensive analysis of power distribution system for UED will be used.

Chapter 5

Clustering of Undesired PQ Data using Fuzzy Algorithm

5.1 Introduction

The classification of PQ disturbances in EPDS was presented in Chapter 4 using neural network techniques. In this chapter fuzzy clustering techniques will be used to investigate the power distribution system behaviour, while considering PQ disturbances of voltage unbalance, sag, swell and harmonics of the UED system. The chapter highlights how best computational intelligence approaches can be integrated for efficient prediction /estimation of PQ parameters in electrical power distribution system.

Section 5.2 discusses the PQ measurement and feature selection process to meet the challenge of the accurate analysis. The intelligent PQ monitoring strategy is presented in Section 5.3. The mathematical algorithm and experimental results are presented in Section 5.4 and 5.5 respectively. Conclusion is made in Section 5.6

5.2 PQ Measurement and Feature Selection

The PQ monitoring by taking measurements of different PQ attributes is a common practice adopted within the power industry especially by the privatised power utilities. This has become important for them primarily to retain their customer by supplying them good quality power supply and mainly to maintain minimum standards as prescribed by their electricity regulators.

There are no uniform standards of PQ monitoring and power utilities adopt different technology and standards to maintain the quality of supply power (Sakthivel *et al.*, 2003b). However, there is a mandatory condition that if their supply system is not able to maintain the quality of supply power within the given parameters then as per requirement they have to report all undesirable PQ data back to the regulators. There can be various trends of monitoring and management of PQ problems (Putrus *et al.*, 2007).

Due to diversified and complex nature of PQ problems and huge size of data recorded by power utilities conventional methods of tackling PQ problems by studying the recorded data of electrical power system have been replaced by modern Computational Intelligence (CI) approaches (Saxena *et al.*, 2010).

(Cao *et al.*, 2001, Masoum *et al.*, 2002, Shikoski *et al.*, 2000) have proposed active filters for improvement of electric PQ. Mitigation of PQ disturbances and placement of capacitors banks at the right location is done to enhance the performance of electrical power system.

In recent years the applications of computational intelligence techniques have stressed the need for the management of large database of power utilities so that useful information can be extracted irrespective of their formats and standards. (Lai, 2007, Waraphok & Saengsuwan, 2007) and (Manke & Tembhurne, 2008).

5.2.1 PQ Measurement

The installation of numerous PQ meters at various points of the network recording the data round the clock make the life miserable for PQ engineers and the power utilities as it becomes very tedious to separate the useful PQ data from the raw PQ data because of its huge size. A sample of real power quality data is attached at appendix1.

As mentioned in previous chapters, the PQ data consists of fifteen attributes of the recorded real PQ data. Each attribute contains 2150 datasets. The dataset consists of hourly average values of different parameter of voltage unbalance, voltage sag, voltage swell and power system frequency for consecutive ninety two days.

5.2.2 PQ Feature Selection

The selection of different available features of PQ data is one of the challenging tasks for the analysis of PQ data and plays an important role in classification in electrical power distribution system.

In the following sections the relationship between different PQ data features will be established and then fuzzy clustering techniques will be applied to investigate the behaviour of the EPDS.

Figures 5-1 to 5-3 (Paracha & Kalam, 2010) shows the relationship between sample real data of the THD of power distribution network and values of other important features of PQ data.

The total harmonic distortion and voltage unbalance data relationship is shown in Figures 5-1.

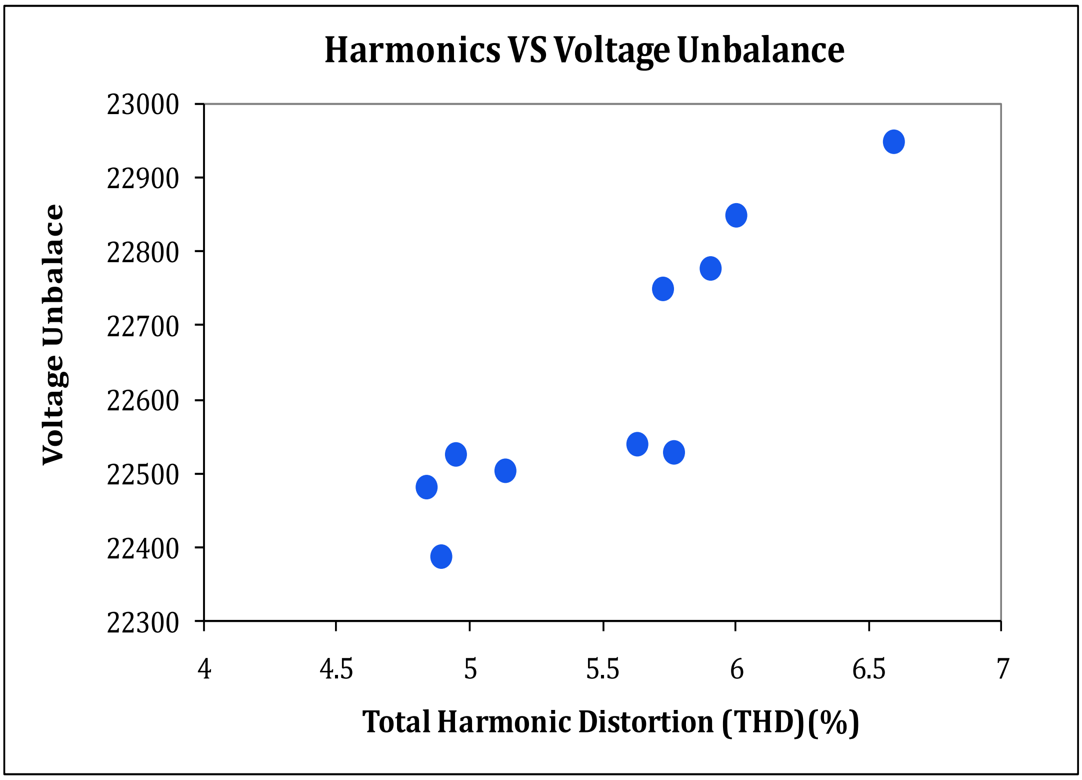

Figure 5-1 Total harmonic distortion and corresponding voltage unbalance

The graph shows that the variations of the voltage unbalance in power distribution network with the variation of THD values. This is an important analysis as it warrants that in order to have a 3-phase balanced power system, this relationship should be analysed further for better supply of power. Thus the first feature set for mathematical algorithm is harmonics and voltage unbalances and the relationship is denoted as <*harmonics::voltage unbalances*>.

Secondly, the THD and sag/swell of electrical power distribution system under study is plotted in Figure 5-2. The graph clearly gives a relationship between total harmonic (THD) distortions and sags & swells values. Thus these features need to be analysed and this second set of features is denoted as <*harmonics: sag-swell*>.

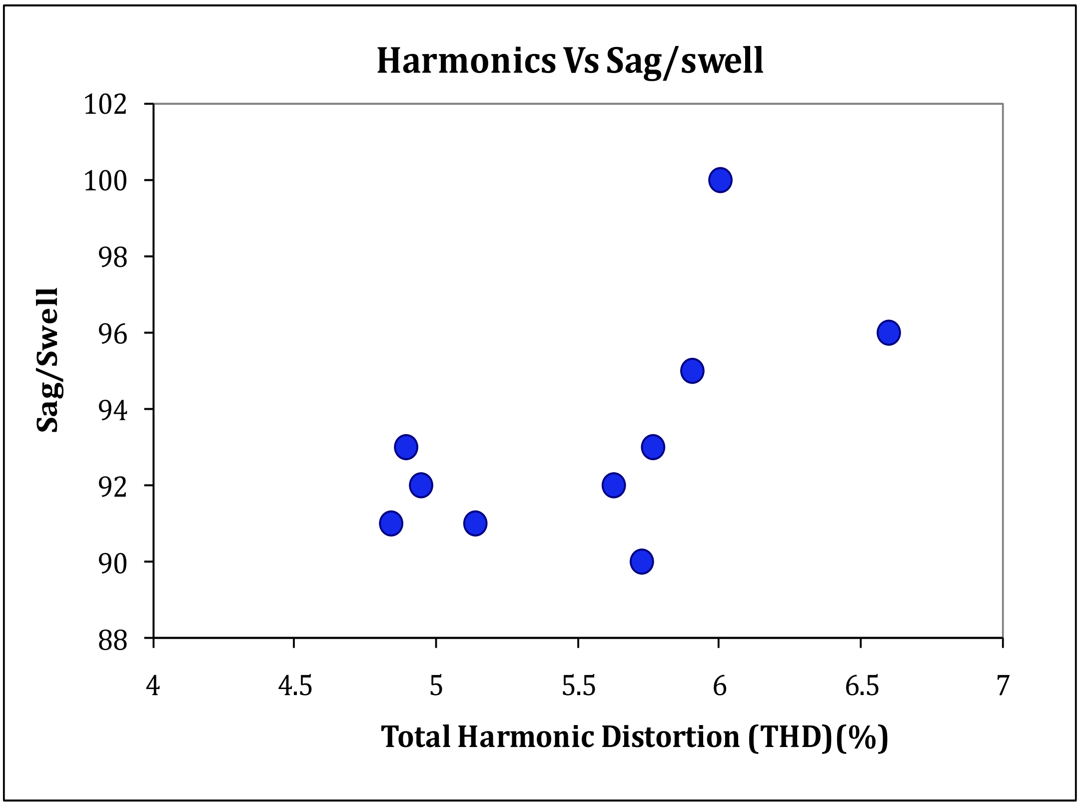

Figure 5-2 Total harmonic distortion and corresponding voltage sag and swell

The relationships between THD and power system frequency is also investigated which give some indication that harmonics has relationship with power system frequency. These are shown in Figure 5-3 and the third feature is denoted as <*harmonics: frequency*>.

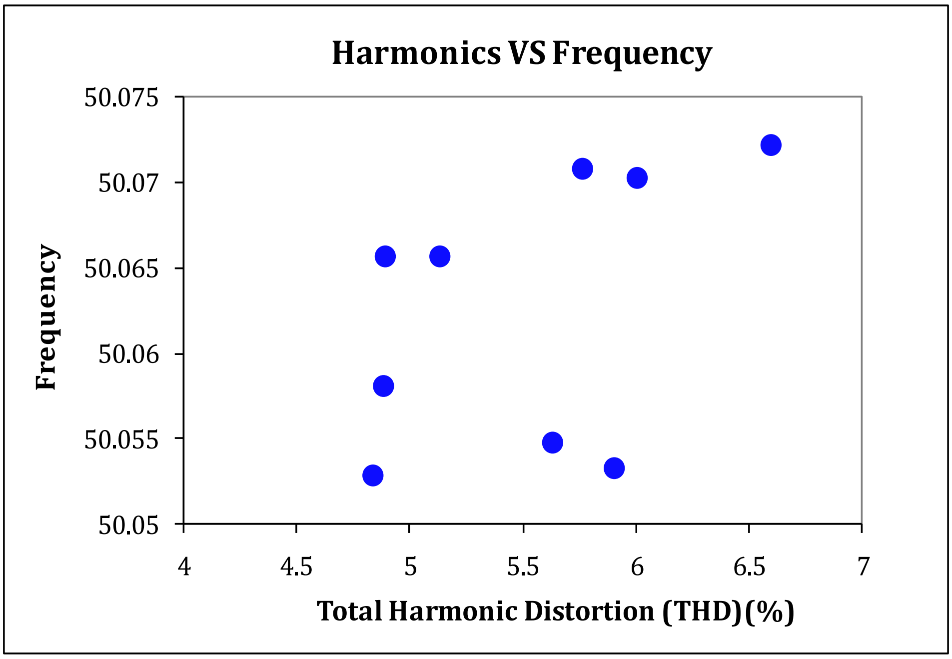

Figure 5-3 Total harmonic distortion and corresponding values of frequency

Section 5.2 explains the relationship between the important parameters of the PQ

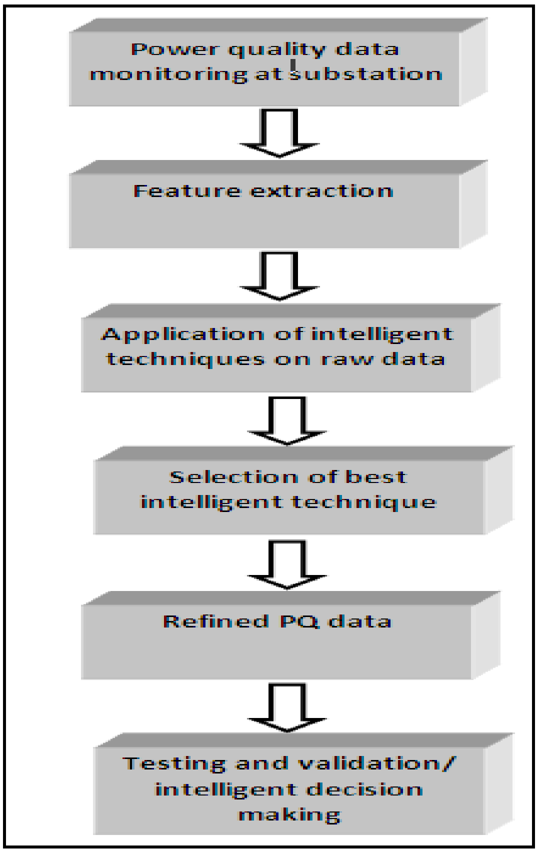

Figure 5-4 Intelligent PQ monitoring strategy (Paracha & Kalam, 2010)

The numbers of stages involved in this PQ monitoring strategy are shown in the block diagram of Figure 5-4. As the data is being recorded 24 hours a day so its size is huge and it needs extensive literature survey to select the correct attribute to extract the useful PQ information on the electrical power system (Ibrahim & Morcos, 2003).

The strategy adopted for feature selection is to take the harmonic raw data and analyse it with each set of data for different PQ attributes being recorded for the power system. Accordingly, the current and voltage harmonics on the electrical power system are analysed with the data for sag, swell, voltage unbalance and frequency of the electrical power system. The main reason for adoption of this approach is to analyse the power system behaviour in a unified framework for the various PQ disturbances in the electrical power system.

As shown in Figure 5-4, the intelligent PQ monitoring strategy extracts features that are responsible for generating PQ disturbances. In this case harmonics are selected as the main feature and analysed using its relationship with other major PQ parameters which can cause disturbance in electrical power system. The main selected feature i.e. harmonics is analysed with the changes of sag, swell, voltage unbalance, and frequency of the electrical power system. The intelligent PQ monitoring strategy not only extracts those features which are responsible for undesired harmonics but also applies computational intelligence techniques to cluster and separate non-useful data. As different computational techniques generate different results so by using referencing based AI technique which gives the maximum accuracy for sorting out the useful information is selected. The refined data from this process is then tested and validated with the actual field results of the electrical power system. The information out of the refined useful data is then used to critically analyse the power system behaviour and important decision making at the power utility side. The output of the best-selected data is tested and validated with the real PQ data.

5.4 Mathematical Algorithm

To guarantee a sensible combination in the variation of data, the normalization procedure is adopted by making the scaled variance to be 1. By employing this procedure the problem of overriding of any principal component attribute is overcome. In this procedure, the mean of different data attributes (i.e. harmonics, sag, swell, frequency, and voltage unbalances) is subtracted from the corresponding values of their real data. Finally the result is divided by standard deviation of that attribute. These steps are explained in equations (5.1)-(5.3).

$$\mu = \frac{\sum_{i=1}^{M} F_i}{M} , \tag{5.1}$$

$$\sigma = \frac{\sqrt{\sum_{i=1}^{M} F_i - \mu}}{M} , \tag{5.2}$$

$$F_{sc} = \frac{F_i - \mu}{\sigma} , \tag{5.3}$$

where μ is the mean of a particular attribute, σ is standard deviation of that attribute, F_i is the data set of M values and F_{sc} is the final normalized or scaled values.

5.4.1 Fuzzy C- Mean Clustering

The clustering techniques organize the data under study in well-defined clusters therefore the probability of detecting a specific data points within a cluster increases and the likelihood between data points of non-similar cluster decreases. A degree of ranking using membership function is assigned to different clusters. The membership function is the main difference between a hard clustering (e.g. K-means clustering) and soft clustering (e.g. Fuzzy clustering) (Asheibi *et al.*, 2009). Fuzzy clustering usually does the deviation between different clusters. To perform this task the objective function of fuzzy algorithm is usually minimized. This is shown in equation (5.4).

$$U_x(X,V) = \sum_{i=1}^{N}\sum_{k=1}^{M} m_{ik}{}^{x} d^2(F_i, V_k) \ , \tag{5.4}$$

where, F_i is the i^{th} feature, V_k is the centroid of k^{th} feature and N is the number of cluster under study, $d^2(F_i, V_k)$ is calculated through measuring of Euclidean distance. The fuzzy C-mean algorithm is explained as follows:

a) Select the optimal number of clusters.

b) Randomly select the centroid for each cluster.

c) Compute the membership function for each cluster.

d) Verify that the sum of memberships should equal to 1.

e) Calculate the new cluster centroid for all clusters.

f) Revise the membership matrix.

g) Stop all iterations till convergence is achieved.

5.4.2 GK based Clustering

To analyse the PQ data using advance fuzzy clustering techniques, Gustafson Kaseel (GK) based fuzzy algorithm is employed. The GK algorithm assigns a positive definite matrix (Salarvand *et al.*, 2010) to each cluster in addition of making the membership matrix. In addition to this GK based extended fuzzy clustering algorithm also identifies each cluster by its cluster centre and a co-variance matrix and therefore circular clusters are generated. The covariance matrix is generated as shown in equation (5.5).

$$C_v^{\,l} = \frac{\sum_{i=1}^{M} m_l^{(v-1)}}{\sum_{i=1}^{M} m_l^{(v-1)}} \; I_i - C_z^{\,v} I_i - C_z^{\,vT} \quad , \tag{5.5}$$

where $m_l^{(v-1)}$ is the membership matrix.

5.5 Experimental Results

The PQ data consists of 15 attributes. In order to gather those attributes which are responsible for generating undesirable harmonics, a manual assessment by selection of three features namely <*harmonics::voltage unbalances*> ,<*harmonics::sag-swell*>, and <*harmonics::frequency*> out of the fifteen is performed (See Figures 5-1 to 5-3).

After the selection of different set of features, the two different types of fuzzy clustering techniques are employed i.e. fuzzy C-mean clustering & GK based extended fuzzy clustering after the normalisation of data. (Refer section 5.4).

The results of fuzzy C-mean clustering for the first feature harmonics and voltage unbalance analysis <*harmonics::voltage unbalance*> are shown in Figures 5-5.

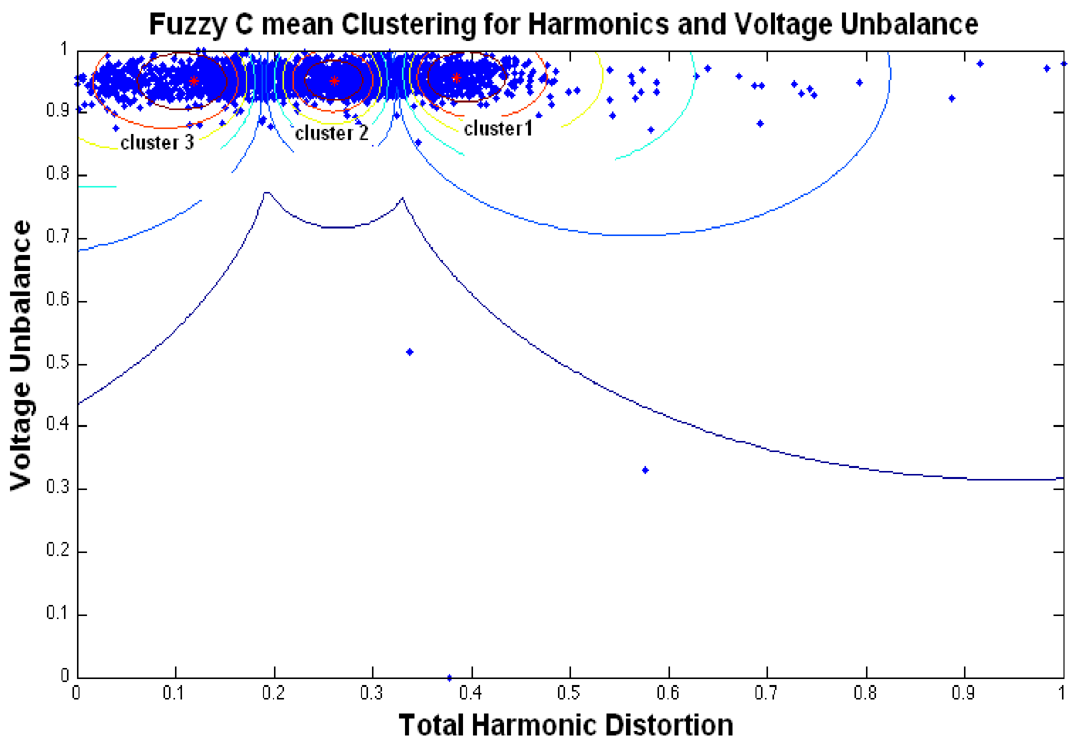

Figure 5-5 FCM clustering for harmonics and voltage unbalance

For fuzzy C-mean clustering better results were obtained if the size of cluster number is taken as 3. The cluster 1 generated by this algorithm gathers the non-useful harmonics and voltage unbalance data with a testing accuracy of 95.3% for fuzzy C-mean while the data which are not clustered by any of the clusters comes in the group of marginally undesired data set.

The results of GK based extended fuzzy clustering for the first feature harmonics and voltage unbalance analysis <*harmonics::voltage unbalance*> are shown in Figures 5-6.

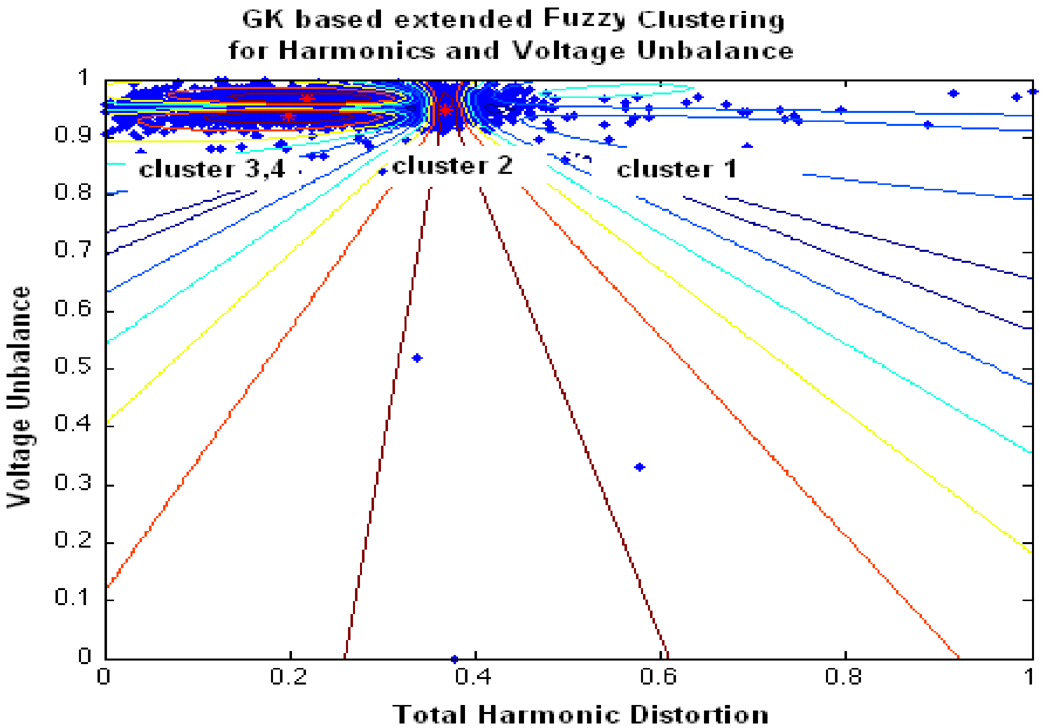

Figure 5-6 GK based extended fuzzy clustering for harmonics and voltage unbalance

In Figures 5-7 and 5-8 the cluster analysis for <*harmonics:sag-swell*> feature set is done. These results showed almost the similar behaviour as that of <*harmonics::voltage unbalance*>*.* In this case data set was only available for 50 days instead of three months. The fuzzy C-mean clustering and GK based extended fuzzy clustering predicted the undesired harmonics and corresponding sag/swell with equal testing accuracy of 96.4%.

The cluster analysis given in Figure 5-9 and Figure 5-10 show the results generated by both type of fuzzy techniques for <*harmonics::frequency*> feature analysis. In case of fuzzy C-mean clustering, the undesired harmonics are gathered by cluster 1 while undesired frequencies of a power system are partially gathered by cluster1 and 2. A similar results were obtained through GK based extended fuzzy clustering, where frequency (undesired) is gathered both by cluster 1 and 2. While in case of undesired harmonics, 93.3% of them is collected by cluster1 (using fuzzy C-mean) and 96.8% of the undesired harmonics data is contained by cluster1. (Using GK based fuzzy clustering).

From the above results it can be seen that GK based fuzzy clustering out performed fuzzy C-mean clustering (Paracha & Kalam, 2010).

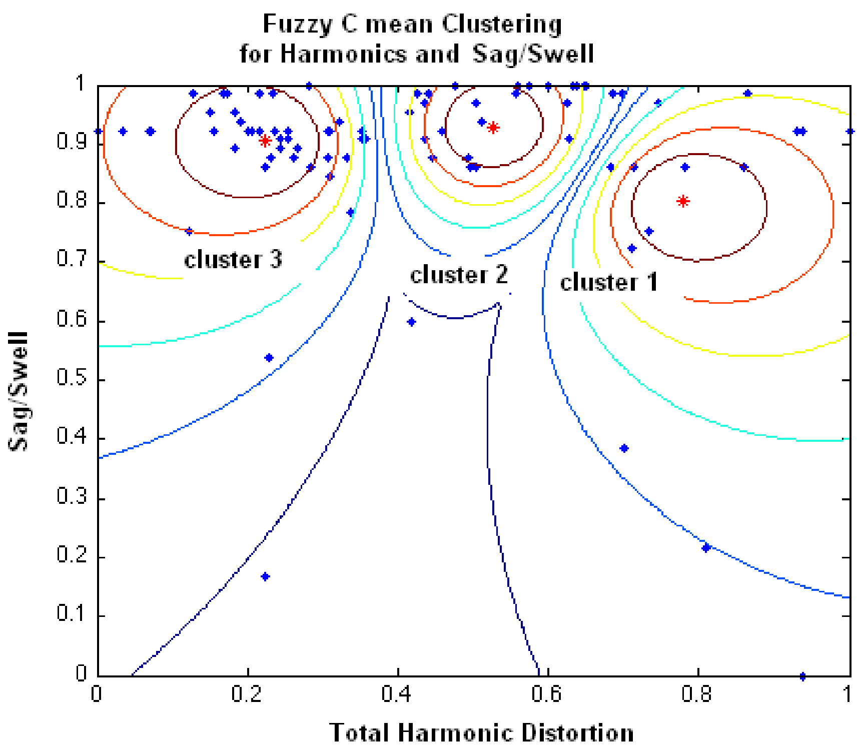

Figure 5-7 FCM clustering for harmonics and sag/swell

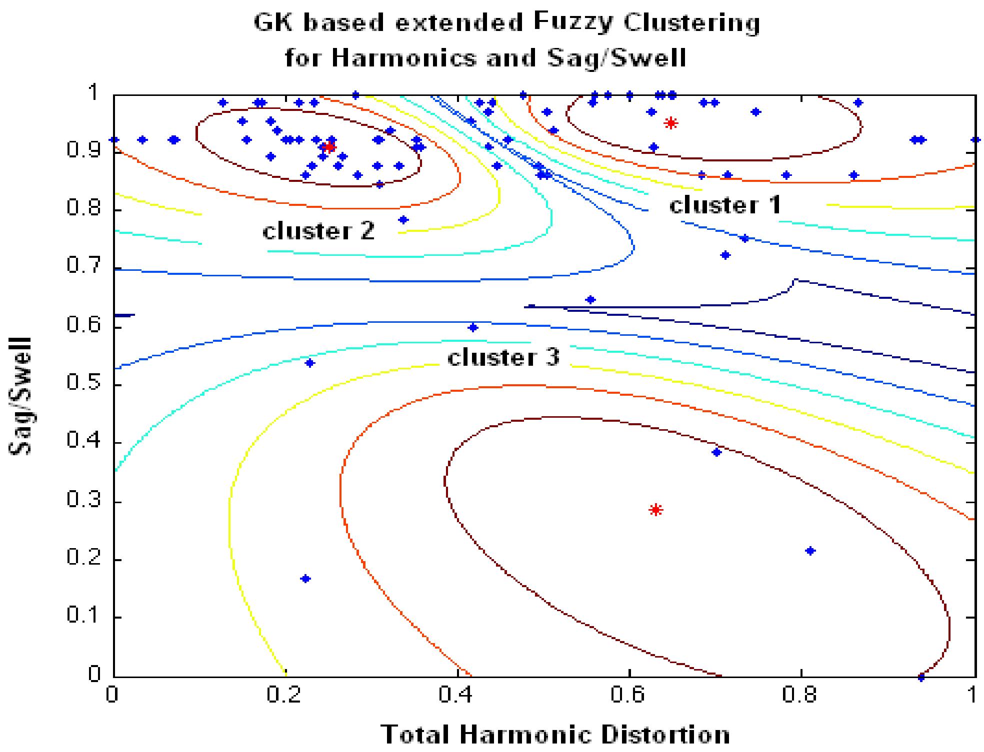

Figure 5-8 GK based extended FCM for harmonics and sag/swell

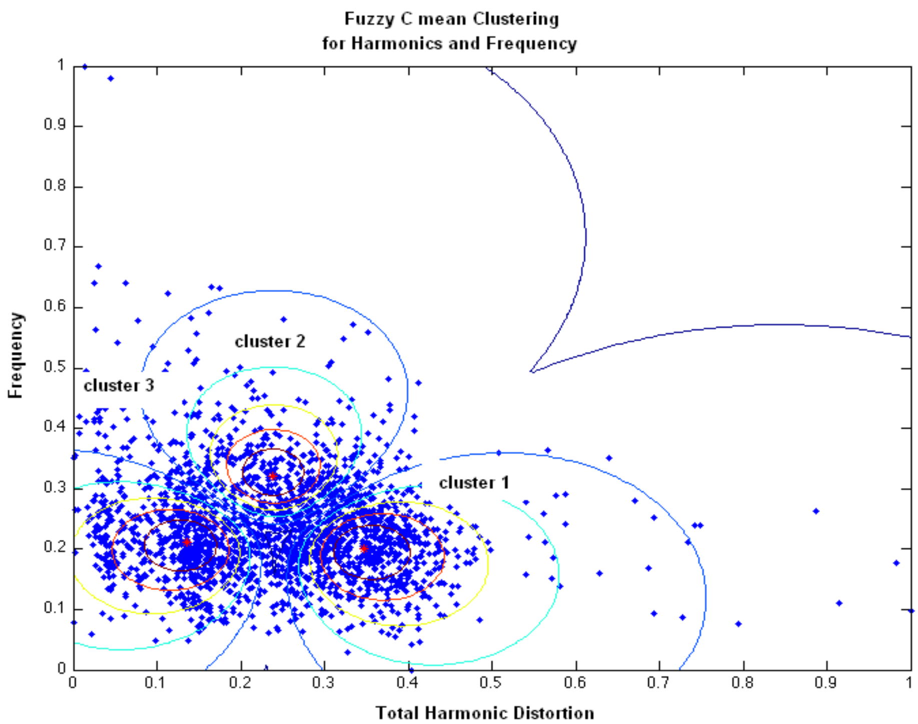

Figure 5-9 FCM clustering for harmonics and frequency

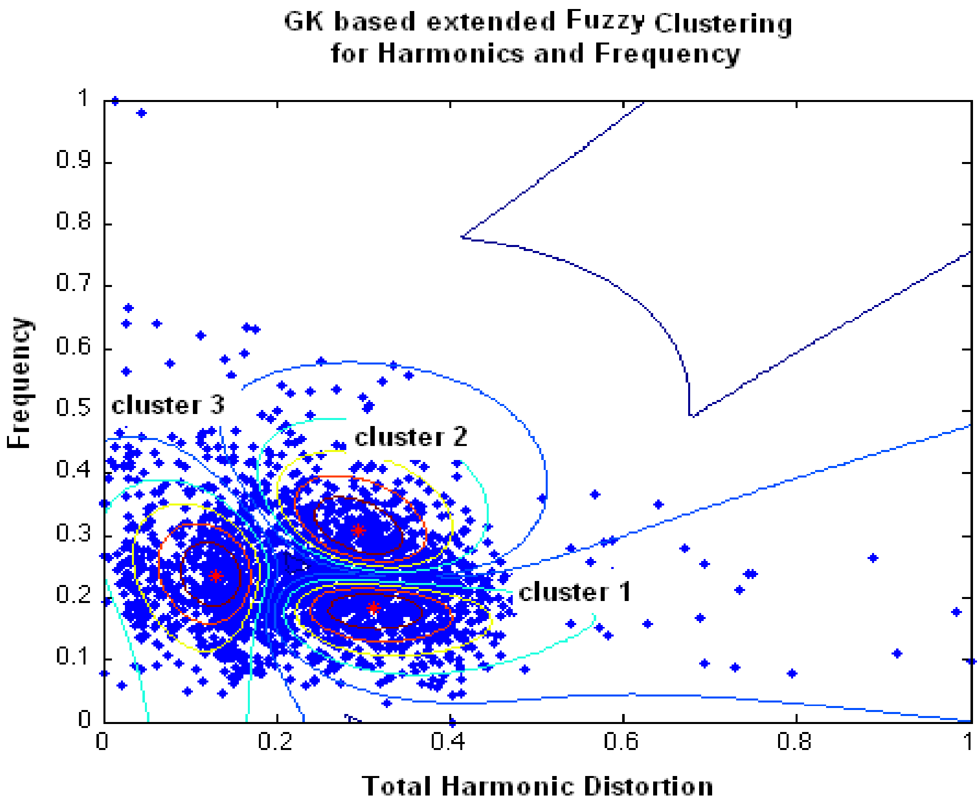

Figure 5-10 GK based extended FCM for harmonics and frequency

5.6 Conclusion

This Chapter reveals that the quality of supply power can only be maintained by applying diagnostic analysis to the core problems (which disturbs the operation of electrical power system). As discussed and analysed in previous Sections that generation of harmonics in power distribution networks is due to increased usage of non-linear loads leading to the all PQ problems thus making the power system incompatible and unreliable. In previous section of experimental results the comprehensive analysis of PQ data by the application of fuzzy clustering reveal that most harmful PQ data set in electrical power system are sag and swell. The data and validation with actual field results prove that if sag and swell are not properly managed in electrical power system, these harmful effects will lead to the ultimate shut down of the electrical power system.

The other major problem in electrical power system is the voltage unbalance and it is important that the electrical power system should be balanced at all times.

The frequency and power factor are also important factor and these need to be maintained within the prescribed limits to maintain the reliability of the electrical power system.

The comprehensive analysis of the PQ problems with the application of fuzzy clusters on PQ data in an electrical Power system is conducted in this research. The reference based AI techniques which gives maximum accuracy sets the criteria for the power company to adjust their power system data and its parameters with the aim of enhanced performance of their electrical distribution network. This research facilitates the power companies to control and manage PQ problems in an efficient way thus maintaining and retaining their customers and fulfilling their needs for availability of quality power supply at all times.

The most important aspects of this chapter is that management of the power utility can prioritize their planning in regards to the efficient management of the power distribution networks. The power utility can also save their capital cost by avoiding malfunctioning of the industrial equipment due to undesired PQ problems in the electrical power systems.

In Chapter 4 the computational analysis of PQ data was performed with the help of neural networks. In Chapter 5 it was established the fact that sag, swell, voltage unbalances, frequency changes are primarily responsible for increase in harmonics for the power distribution system. By applying fuzzy clustering algorithms it is established that undesired harmonics can be separated from raw PQ data with appreciable accuracy. It was shown that G.K based fuzzy clustering algorithm yielded better results than typical FCM algorithm. Finally the behaviour of the power distribution system was investigated and the need to address the core problem of non-linear load in the power distribution networks was stressed.

Chapter 6

Conclusion and Future Work

6.1 Summary

The focus of work in this thesis has been on refining of huge complex PQ data, classification of the major PQ problems and investigation of power distribution system behaviour considering the relationship of main PQ disturbance harmonics in conjunction with other major PQ parameters i.e. voltage unbalance, sag/swell and frequency.

Intelligent approaches have been developed and applied with the aim of PQ data analysis of UED network in Victoria Australia. This research developed the PCAT model for refining the PQ data and explored the use of intelligent algorithms FFBP, RNN, Fuzzy C-mean clustering and GK based extended Fuzzy C-mean for the classification of the PQ disturbances. The intelligent algorithms are applied here with precision for PQ data analysis for critical decision making for EPDS.

This work identifies the area of research for the next decade with the emphasis that power utilities around the world are focused on delivering a greater quality of supply power due to increased customer expectation in modern day challenging environment. EPDS need continuous improvement as well as cost minimisation for reliable and sustained operations. It establishes the fact the PQ is a complex and diversified problem which is encountered in all facets of power system operations.

This thesis provides a complete framework for analysis of PQ data and replaces the conventional PQ monitoring by intelligent computational techniques for timeliness, accuracy and cost savings in EPDS. It proposes clever collection, interpretation and intelligent application of power system data in present and future power distribution networks. It also gives the prevalent PQ standards and establishes the need for power utilities to think of way to separate the useful data from huge raw ones for intelligent analysis of PQ problems.

In this work experimental setup of the 66/22kV zone substation for Jemena UED network was used to record PQ data. This set up was part of PQ monitoring of a Victorian power distribution system. The experimental set up has the centralised PQ recording system which monitors the data through public switch telephone network and wide area network round the clock. The data consists of 15 attributes for the UED network. The different parameters being measured on the three phases of the EPDS are sag, swell, harmonics, power factor, frequency, voltage unbalance, real power, apparent power, reactive power and total harmonics distortion. Due to larger number of attributes being monitored for the power quality data containing multiple parameters it becomes very difficult to analyse the power system behavior by processing all the attributes. Moreover because of high correlation in the available power quality data, it becomes impossible to separate those parameters, which are significantly affecting the voltage and current disturbances in the power distribution system. It employs the technique of principal component analysis explains the pre-processing of the large PQ data with PCAT model. PCAT model shifts the zero axis of the PQ data to a new axis by taking the mean values of the total power quality data for the three months period. The covariances between all the 15 power quality data attributes are calculated to find the

Eigen vector. Each Eigen vector corresponds to new dimensions of the real power quality data. The pre-processing algorithm is applied at the Eigen Values and Eigen vectors to get the final two dimensional processed data. It was successfully proved that the nuisance of dimensionality for large PQ data can be evaded by using PCAT model.

The developed PCAT model in this thesis pre-processes the the large PQ data for reducing its dimesnsions. Each time PCAT model was implemented by eliminating the targeted PQ disturbances i.e power factor, voltage sag and swell and harmonics. After the data is processed for each main PQ disturbance neural networks are invoked for classification of main PQ disturbance. This chapter also explains the major PQ disturbances and their impact on EPDS.

The two techniques of neural networks used in this chapter are feed forward back propogation(FFBP) and recurrent neural networks(RNN). For predicting each main PQ disturbance the techniques of FFBP of neural network and RNN is applied on the processed data to perform the intelligent computational analysis for the classification of major PQ disturbances of the described experimental work. The technique of FFBP predicted power factor with accuracy of 93%, sag with accuracy of 93.5%, swell with accuracy of 91.5% and harmonics with an accuracy of 94.5%. The technique of RNN is also used to classify sag and swell and achieved the accuracy of 96%. It is being found that although the technique of recurrent neural network gave higher accuracy of 96% as compared to accuracy of sag (93.5%) and swell (91.5%) with FFBP, but RNN has more time complexity. Therefore, the technique of RNN was not used for classifying power factor and harmonics.

The final chapter of this thesis provides a comprehensive analysis of the EPDS while considering the interdependent relationship of PQ parameters. The goal was to classify the undesired PQ data considering the relationship of harmonics in conjunction with the corresponding PQ disturbances of voltage unbalance, sag, swell and frequency. An intelligent strategy was developed for feature selection and performed the analysis to establish the relationship of harmonics with voltage unbalance, sag /swell and frequency for experimental work. After the feature selection process the techniques of Fuzzy C-mean and GK based extended fuzzy was used to cluster the undesired harmonics.

The GK based extended fuzzy clustering gave accuracy of prediction of undesired harmonics of 96.2%, 96.4% and 96.8% when tested with voltage unbalance, sag/swell and power system frequency in an effort to monitor the overall behavior of the electric power distribution system. In comparison, Fuzzy C-mean clustering gave accuracy of prediction of undesired harmonics of 95.3%, 96.4% and 93.3% when tested with voltage unbalance, sag/sell and power system frequency in an effort to monitor the overall behavior of EPDS. From these results it is clear that GK based fuzzy clustering out performed fuzzy C-mean clustering.

The main conclusion of this chapter is that quality of supply power in EPDS can be maintained by applying holistic diagnostic analysis. It can be concluded that harmonics in EPDS are generated due to usage of non-linear loads and lead to major PQ problems thus making the power system incompatible and unreliable. Thus in a resource constraint environment harmonics in EPDS can be considered as a single basis for PQ data analysis.

Overall this thesis gives a framework for PQ data analysis in EPDS by developing PCAT model, application of neural network techniques and finally comprehensive analysis of

EPDS using fuzzy clustering. This framework is not only helpful for UED but generally applies to investigation all electric power distribution systems across the board.

6.2 Future Work

In this thesis a framework based on intelligent approaches was provided for power quality data analysis in EPDS. This research work can be extended by exploring other signal processing techniques with the aim of maintaining quality supply power, energy efficiency and cost management in electrical power distribution system. Some of the key areas which can be further investigated are:

- This framework used the off-line real data from UED network for PQ data analysis. This research can be extended by considering the on-line data analysis. This data analysis can be very help for corrective actions as this data will capture the PQ disturbances as they will occur. The analysis results will be available on plant for quick decision making.
- Further investigation of PQ disturbances in EPDS generated by specific industrial equipments using different intelligent approaches.
- Initiate development of a framework for power quality data analysis with the aim integrating PQ monitoring with monitoring for energy management in EPDS.
- Continue development of an expert system for automatic classification of PQ problems.
- Ultimately it is envisaged that comprehensive power quality data analysis in EPDS canz also be implemented for smart grid applications.

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Appendix 1

Freq mean	I 4 mean	I a mean	I avg mean	I b mean	I c mean	kVA tot mean	kVAR tot mean	kW tot mean	PF lag mean	Vll ab mean	Vll avg mean	Vll bc mean	Vll ca mean
50.00	0	652.48	654.48	658.65	652.33	25594.19	2164.05	25501.99	99.64	22568.77	22632.88	22610.74	22719.06
50.00	0	622.79	624.76	628.89	622.59	24223.98	1649.15	24167.62	99.77	22379.39	22445.04	22427.44	22528.34
50.00	0	615.97	617.03	620.28	614.83	23917.70	1539.07	23868.00	99.79	22361.57	22437.55	22428.47	22522.68
49.99	0	606.20	607.32	611.24	604.50	23577.88	1572.74	23525.15	99.78	22402.21	22474.59	22464.98	22556.57
49.99	0	601.15	601.56	604.87	598.68	23350.23	1556.67	23298.14	99.78	22399.71	22472.16	22465.53	22551.22
50.00	0	611.64	611.40	614.45	608.12	23753.38	1666.32	23693.93	99.75	22420.40	22492.63	22484.84	22572.71
49.99	0	660.47	661.66	665.58	658.94	25816.28	2484.15	25695.33	99.53	22509.07	22576.66	22556.60	22664.22
50.01	0	735.25	738.88	745.98	735.41	28884.09	3797.09	28632.68	99.13	22548.73	22610.84	22576.77	22707.14
50.00	0	768.43	771.55	778.75	767.46	30090.37	4403.88	29765.33	98.92	22510.44	22553.42	22517.83	22632.00
49.99	0	797.91	799.46	804.78	795.69	31364.94	4871.79	30982.60	98.78	22629.69	22682.29	22656.98	22760.21
50.01	0	819.15	819.03	824.95	812.99	32184.64	4933.27	31802.10	98.81	22669.50	22720.60	22691.72	22800.64
50.00	0	841.21	841.61	847.26	836.35	33177.61	5539.10	32710.77	98.59	22745.45	22794.94	22770.05	22869.39
50.00	0	861.07	861.65	867.00	856.89	33835.96	5301.83	33417.81	98.76	22654.33	22707.41	22684.29	22783.57
49.99	0	875.84	876.94	882.62	872.35	34388.10	5774.78	33898.36	98.58	22621.58	22675.91	22653.61	22752.35
49.97	0	883.80	885.47	891.96	880.64	34694.43	6154.55	34143.96	98.41	22603.97	22657.53	22633.05	22735.60
50.03	0	881.98	884.00	891.35	878.67	34758.25	6069.26	34224.19	98.46	22682.71	22736.58	22707.34	22819.66
50.01	0	880.43	882.93	889.42	878.94	34870.11	5899.05	34367.48	98.56	22783.92	22837.26	22800.18	22927.74
50.01	0	872.41	874.10	879.30	870.60	34499.38	5132.36	34113.94	98.88	22774.54	22823.44	22776.20	22919.49
49.97	0	837.28	838.87	844.11	835.21	32729.08	3471.22	32542.16	99.43	22523.81	22562.79	22502.61	22661.99
50.02	0	808.95	810.05	814.13	807.06	31778.15	2737.58	31659.79	99.63	22624.84	22686.95	22632.45	22803.45
50.01	0	794.07	794.04	797.02	791.02	31238.89	3136.49	31080.62	99.49	22681.71	22753.74	22700.87	22878.75
49.99	0	756.52	756.34	759.57	752.93	29813.14	2704.23	29689.30	99.59	22743.76	22808.34	22754.45	22926.78
50.00	0	706.13	706.87	711.12	703.37	27678.16	3276.64	27483.05	99.30	22597.51	22660.39	22613.28	22770.29
50.00	0	646.94	646.98	650.72	643.29	25565.76	2508.74	25441.71	99.52	22813.24	22879.41	22843.93	22981.03
50.00	0	649.04	648.71	651.32	645.75	25615.35	2313.96	25510.40	99.59	22783.30	22850.43	22818.78	22949.28
50.00	0	618.48	618.63	621.59	615.83	24423.83	2017.40	24340.24	99.66	22786.56	22851.93	22828.59	22940.72
50.00	0	598.99	598.26	600.13	595.66	23582.35	1546.32	23530.56	99.78	22744.00	22819.24	22804.22	22909.48
49.99	0	534.25	531.95	533.11	528.49	20943.26	-442.36	20932.38	99.95	22721.10	22794.50	22779.21	22883.16

49.99	0	522.09	519.78	521.44	515.80	20351.74	-928.05	20330.44	99.89	22614.66	22683.16	22667.43	22767.40
50.00	0	538.89	536.94	538.18	533.74	20942.98	-735.49	20929.70	99.94	22515.45	22583.37	22568.19	22666.44
49.99	0	580.82	579.51	582.02	575.68	22673.40	80.63	22672.02	100.00	22574.47	22642.58	22618.33	22734.91
49.98	0	651.58	653.11	659.19	648.56	25437.62	1223.45	25405.69	99.88	22468.13	22522.68	22482.91	22617.00
50.02	0	681.96	682.21	688.51	676.17	26759.34	1837.59	26695.28	99.76	22637.89	22679.48	22639.14	22761.45
50.01	0	718.81	718.42	723.70	712.75	28225.73	2355.26	28125.98	99.65	22662.05	22713.98	22684.13	22795.84
50.01	0	746.05	745.51	751.15	739.34	29288.68	2695.02	29163.03	99.57	22656.92	22715.71	22689.34	22800.84
50.00	0	772.96	772.93	779.06	766.78	30334.19	2691.25	30214.00	99.60	22637.58	22694.51	22668.15	22777.77
50.00	0	797.93	797.85	803.60	792.01	31140.14	3067.24	30988.38	99.51	22508.47	22567.97	22542.05	22653.30
50.00	0	810.81	811.60	817.92	806.07	31669.00	3450.78	31479.36	99.40	22500.87	22560.84	22534.08	22647.53
50.00	0	837.65	837.78	843.50	832.19	32688.83	3819.81	32464.72	99.31	22497.08	22557.26	22524.00	22650.77
50.00	0	840.71	840.14	844.79	834.94	32826.34	3849.97	32599.54	99.31	22528.06	22587.99	22551.64	22684.25
49.99	0	857.05	857.08	861.98	852.23	33459.46	3830.28	33239.48	99.34	22508.18	22568.52	22522.50	22674.77
49.98	0	847.93	847.43	851.47	842.87	33343.20	3427.01	33165.23	99.47	22691.55	22748.00	22688.99	22863.39
50.01	0	803.81	804.58	808.91	801.02	31807.71	2078.85	31738.34	99.78	22815.29	22861.89	22794.38	22975.88
50.02	0	782.76	785.48	792.20	781.49	30737.10	977.85	30720.92	99.95	22574.39	22630.02	22560.10	22755.58
50.00	0	764.70	766.17	771.28	762.52	30097.04	615.48	30090.31	99.98	22654.40	22718.32	22650.34	22850.26
50.00	0	734.16	734.68	739.59	730.30	28740.43	-45.76	28738.69	99.99	22565.02	22627.39	22563.85	22753.16
50.00	0	660.99	661.09	665.18	657.11	25998.82	482.73	25992.07	100.00	22687.34	22753.26	22702.10	22870.32
50.00	0	594.60	593.41	597.10	588.54	23410.65	285.52	23407.79	99.99	22767.01	22833.35	22791.06	22942.01
49.99	0	578.92	577.69	580.93	573.22	22797.73	-90.23	22797.20	100.00	22776.17	22843.56	22809.98	22944.54
50.00	0	547.25	545.96	549.15	541.47	21574.34	-439.14	21569.64	99.98	22829.42	22895.53	22868.69	22988.33
50.00	0	537.90	536.09	538.49	531.89	21189.56	-595.22	21180.88	99.96	22829.38	22903.05	22883.63	22996.10
49.99	0	523.50	520.71	522.65	515.97	20514.05	-789.08	20498.70	99.93	22765.38	22838.54	22822.04	22928.21
49.99	0	511.17	508.54	510.58	503.86	20027.51	-989.34	20002.75	99.88	22771.24	22839.37	22822.79	22923.98
49.99	0	522.37	520.66	522.86	516.75	20452.93	-766.80	20437.54	99.98	22712.01	22779.65	22764.63	22862.21
49.99	0	589.20	588.39	591.68	584.30	22939.64	538.66	22929.16	99.96	22500.17	22571.69	22551.19	22663.74
50.01	0	669.47	672.29	679.00	668.39	26374.50	2392.23	26262.42	99.58	22626.63	22688.67	22654.14	22785.20
50.01	0	732.80	733.96	739.77	729.30	28865.90	3811.42	28611.88	99.12	22697.89	22740.87	22701.72	22823.06
50.01	0	781.65	782.99	788.27	779.05	30568.97	4300.42	30263.20	99.00	22524.15	22571.20	22538.48	22651.02
50.00	0	797.41	797.20	801.96	792.22	31122.84	4175.55	30841.31	99.10	22518.76	22573.39	22545.73	22655.63
50.00	0	826.59	826.09	830.31	821.36	32241.10	4985.21	31851.85	98.80	22509.32	22566.04	22538.00	22650.83
50.00	0	843.93	843.95	848.23	839.69	33084.27	5565.73	32612.62	98.57	22606.32	22663.88	22630.57	22754.75
50.03	1E-05	764.23	762.33	765.10	757.66	29815.21	3747.98	29220.30	89.95	22705.82	22774.65	22741.95	22876.25
50.00	0	549.01	544.51	546.31	538.21	21043.44	-27.38	20943.16	99.86	22316.19	22383.42	22343.27	22490.82

50.00	0	745.73	745.07	749.81	739.68	28522.84	2453.27	28412.21	99.62	22083.11	22135.59	22090.13	22233.42
50.00	0	802.72	802.95	808.17	797.96	30513.72	3217.29	30343.43	99.44	21917.67	21967.69	21916.60	22068.93
50.00	0	799.16	799.54	803.14	796.33	30548.86	2993.39	30401.60	99.52	22041.73	22087.87	22031.09	22190.78
49.99	0	786.91	787.94	791.33	785.57	30133.92	2511.39	30028.65	99.65	22071.29	22112.34	22054.98	22210.58
50.00	0	790.64	791.78	794.43	790.27	30720.24	2759.95	30594.72	99.59	22365.77	22433.76	22385.34	22550.21
50.00	0	779.11	778.95	782.28	775.46	30471.92	2649.24	30356.25	99.62	22548.45	22619.67	22566.61	22744.10
50.00	0	734.73	734.87	738.71	731.18	28921.91	2140.50	28841.05	99.72	22697.40	22764.75	22712.08	22884.86
50.00	0	691.97	692.72	697.00	689.20	27278.58	2964.53	27116.44	99.41	22717.27	22782.12	22735.21	22893.94
49.99	0	644.05	644.72	648.85	641.28	25515.24	2334.53	25407.97	99.58	22841.00	22906.96	22868.90	23010.98
50.00	0	642.00	641.85	645.27	638.28	25343.79	1994.37	25264.83	99.69	22775.97	22841.91	22806.22	22943.50
50.00	0	612.42	612.85	616.26	609.87	24079.88	1609.73	24025.78	99.78	22665.68	22729.71	22698.25	22825.12
50.00	0	601.86	602.61	605.45	600.51	23735.53	1344.77	23697.14	99.84	22710.56	22780.53	22758.37	22872.70
49.99	0	587.39	587.37	589.62	585.11	23151.22	1273.43	23116.03	99.85	22735.34	22802.47	22783.52	22888.54
50.00	0	580.52	580.06	582.68	576.97	22807.25	1216.50	22774.49	99.86	22691.95	22753.63	22733.58	22835.29
49.99	0	586.00	585.73	588.57	582.63	22984.04	1354.63	22943.82	99.83	22649.18	22709.27	22689.02	22789.61
49.99	0	607.11	607.33	610.71	604.18	23741.14	1663.50	23682.20	99.75	22554.86	22614.57	22592.34	22696.50
50.00	0	644.77	645.85	649.88	642.91	25109.82	2020.70	25028.21	99.68	22431.55	22482.65	22448.30	22568.13
50.00	0	691.36	691.24	695.17	687.20	27076.90	2782.90	26933.07	99.47	22623.95	22648.83	22591.55	22730.89
50.01	0	723.40	723.86	727.83	720.35	28225.36	2830.66	28080.70	99.49	22514.87	22542.27	22483.99	22627.88
50.00	0	732.31	731.77	735.04	727.95	28530.03	2631.27	28408.24	99.57	22511.86	22541.58	22486.77	22626.07
50.00	0	739.12	737.88	740.94	733.58	28768.96	2823.33	28629.77	99.52	22512.48	22544.15	22492.03	22628.05
50.01	0	735.27	735.22	738.05	732.33	28702.97	2868.11	28559.22	99.50	22544.26	22575.15	22523.29	22657.79
50.00	0	732.28	730.93	734.08	726.43	28549.58	2873.09	28404.42	99.49	22558.00	22588.49	22533.51	22673.86
50.00	0	723.52	723.11	727.36	718.46	28281.48	2842.53	28137.95	99.49	22594.22	22621.92	22567.46	22704.01
50.00	0	721.38	721.17	726.02	716.10	28305.10	2956.75	28150.10	99.45	22681.56	22706.03	22648.59	22787.79
49.99	0	722.02	721.88	726.02	717.62	28294.95	2831.99	28152.52	99.50	22649.10	22673.69	22613.71	22758.29
49.99	0	716.90	717.60	722.18	713.72	28181.13	2347.75	28082.63	99.65	22705.14	22724.55	22658.57	22809.95
49.99	0	708.23	708.44	712.63	704.46	27871.65	1858.60	27809.27	99.78	22747.36	22767.33	22692.88	22861.60
50.01	0	734.66	735.70	738.92	733.50	28560.90	2100.49	28483.27	99.73	22403.53	22455.96	22390.70	22573.66
50.00	0	728.76	729.25	733.07	725.91	28321.38	2076.92	28244.95	99.73	22402.14	22463.38	22400.26	22587.73
50.00	0	709.53	710.35	714.15	707.36	27732.24	1842.86	27670.67	99.78	22528.77	22586.64	22527.56	22703.58
50.00	0	682.36	682.27	686.64	677.80	26557.36	2209.42	26464.78	99.65	22465.34	22521.71	22467.19	22632.67
50.00	0	648.70	648.29	651.95	644.21	25352.89	1858.93	25284.43	99.73	22570.47	22628.83	22585.34	22730.61
50.00	0	647.73	647.55	650.45	644.48	25405.12	1702.57	25347.74	99.77	22643.79	22702.23	22660.53	22802.43
50.00	0	618.93	620.04	623.86	617.34	24266.83	1397.21	24225.62	99.83	22597.83	22654.92	22619.88	22747.06

50.00	0	609.35	609.82	612.92	607.20	23969.42	1305.47	23933.48	99.85	22684.29	22753.21	22730.02	22845.21
50.00	0	597.36	597.72	600.23	595.56	23267.63	1088.53	23241.61	99.89	22473.75	22536.50	22515.78	22619.92
50.00	0	582.63	582.11	584.61	579.08	22595.18	844.96	22579.13	99.93	22427.18	22485.81	22466.03	22564.30
50.00	0	582.02	581.77	584.66	578.64	22575.65	894.11	22557.81	99.92	22422.58	22478.51	22459.12	22553.85
49.99	0	582.76	581.93	584.85	578.20	22555.04	962.50	22534.34	99.91	22394.95	22450.80	22428.38	22529.15
50.00	0	598.51	598.38	601.80	594.84	23242.76	1207.35	23210.70	99.86	22442.88	22489.13	22458.55	22565.94
49.99	0	629.15	628.93	632.29	625.34	24751.00	1666.15	24694.36	99.77	22759.09	22775.18	22717.37	22849.20
50.00	0	660.86	660.36	662.70	657.54	25928.07	1596.49	25876.34	99.80	22701.87	22718.92	22654.66	22800.15
50.01	0	686.58	686.51	690.13	682.82	26749.94	1540.76	26705.44	99.83	22521.44	22542.29	22476.78	22628.59
50.01	0	694.37	695.01	698.40	692.25	27206.37	1935.04	27136.91	99.74	22620.48	22646.96	22584.26	22736.10
50.00	0	700.60	699.79	702.34	696.44	27469.72	2090.50	27389.89	99.71	22679.45	22709.77	22649.32	22800.53
50.00	0	707.24	705.86	708.34	702.01	27667.17	2236.56	27576.48	99.67	22644.39	22676.41	22616.20	22768.51
50.01	0	709.33	708.32	711.03	704.58	27873.95	2328.05	27776.34	99.65	22736.72	22769.20	22710.10	22860.90
50.00	0	717.57	717.53	720.91	714.11	28228.96	2565.88	28112.08	99.59	22731.05	22761.51	22700.72	22852.84
50.00	0	722.77	722.40	726.66	717.76	28414.67	2612.16	28294.28	99.58	22727.21	22754.33	22686.66	22849.21
49.99	0	740.88	740.56	743.88	736.92	29039.30	2624.89	28920.40	99.59	22653.24	22681.19	22606.64	22783.63
49.96	0	770.20	770.70	774.72	767.16	30101.86	2565.75	29991.86	99.63	22555.96	22589.05	22497.23	22714.15
50.03	0	780.93	781.48	784.90	778.59	30751.55	2645.74	30637.31	99.63	22693.08	22759.14	22668.25	22916.11
50.02	0	761.59	761.33	765.05	757.35	30006.63	2385.63	29911.21	99.68	22732.86	22799.87	22714.63	22952.14
50.01	0	747.58	746.93	750.28	742.94	28981.84	1888.11	28919.98	99.79	22384.20	22447.94	22371.47	22588.16
50.01	0	720.61	720.51	723.92	717.01	28179.50	2611.11	28058.05	99.57	22571.92	22631.25	22564.69	22757.02
49.99	0	673.67	673.79	677.84	669.85	26552.33	2131.22	26465.81	99.68	22750.89	22810.47	22755.95	22924.50
50.00	0	661.52	661.67	665.32	658.16	25975.93	1655.83	25922.84	99.80	22668.05	22724.14	22675.83	22828.55
49.99	0	626.99	627.96	632.39	624.50	24353.94	1122.48	24327.81	99.89	22395.52	22449.62	22411.19	22542.05
50.00	0	609.95	611.01	615.77	607.29	23968.51	1131.63	23941.57	99.89	22651.78	22715.97	22688.12	22807.95
50.00	0	598.34	598.45	601.83	595.17	23360.59	1065.69	23335.80	99.89	22541.35	22603.63	22581.54	22687.99
49.99	0	591.01	590.53	593.46	587.13	22923.61	930.01	22904.58	99.92	22418.04	22477.69	22456.97	22558.12
49.99	0	590.88	591.01	595.14	587.03	22953.99	1065.67	22928.74	99.89	22425.65	22480.72	22457.90	22558.46
49.99	0	614.64	614.49	617.94	610.90	23971.05	1691.30	23909.86	99.75	22513.16	22570.13	22544.07	22653.13
49.99	0	678.41	679.18	683.40	675.72	26521.61	2904.53	26360.94	99.40	22524.06	22579.46	22543.60	22670.64
49.99	0	746.39	747.22	752.98	742.29	29194.33	3388.09	28995.33	99.32	22551.17	22587.71	22528.30	22683.66
50.03	0	790.38	792.51	798.30	788.85	31164.84	3871.62	30921.93	99.22	22693.58	22730.92	22673.37	22825.80
50.01	0	794.66	796.06	800.14	793.38	31413.63	3780.50	31185.14	99.27	22764.40	22811.96	22762.48	22909.12
50.00	0	790.01	791.39	795.58	788.58	31256.68	3756.35	31030.00	99.27	22785.91	22833.96	22788.13	22927.95
50.00	0	797.68	798.01	802.59	793.77	31443.92	3970.43	31192.03	99.20	22730.15	22780.47	22735.65	22875.60

50.00	0	810.52	810.92	814.67	807.55	31957.02	4065.63	31697.02	99.19	22729.50	22783.88	22740.40	22881.74
49.99	0	809.31	810.04	814.48	806.33	31678.29	4016.32	31422.52	99.19	22556.24	22609.70	22567.08	22705.77
50.00	0	798.33	799.78	804.71	796.30	31341.30	4029.04	31081.21	99.17	22603.80	22656.71	22612.78	22753.49
49.99	0	792.76	794.66	799.89	791.34	31113.80	3829.21	30876.72	99.24	22587.51	22636.80	22589.64	22733.32
49.99	0	794.27	795.73	800.05	792.87	31190.52	3513.32	30991.82	99.36	22617.74	22662.00	22603.70	22764.61
49.98	0	820.73	820.72	823.25	818.19	32098.51	3186.20	31938.89	99.50	22561.47	22608.89	22532.77	22732.32
50.02	0	839.10	840.20	842.98	838.52	33062.21	3049.21	32921.12	99.57	22678.49	22748.92	22665.54	22902.68
50.02	0	822.89	823.75	827.46	820.88	32109.46	2376.59	32020.42	99.72	22463.39	22535.01	22453.04	22688.66
49.99	0	795.70	794.99	797.39	791.88	31189.29	2191.42	31110.30	99.75	22620.35	22689.21	22610.54	22836.88
50.01	0	765.98	766.63	769.80	764.11	30197.07	3458.25	29998.33	99.34	22717.57	22779.27	22707.71	22912.50
50.00	0	711.23	712.48	716.61	709.59	28094.98	2794.71	27954.54	99.50	22749.45	22807.69	22749.69	22924.01
49.99	0	687.00	687.52	691.28	684.29	27181.44	2362.77	27078.48	99.62	22812.92	22872.41	22827.33	22977.00
50.00	0	647.19	647.84	651.28	645.05	25296.45	1676.36	25239.96	99.78	22535.27	22593.19	22557.82	22686.56
50.00	0	630.70	631.30	634.86	628.35	24763.85	1521.17	24716.89	99.81	22630.18	22697.13	22671.82	22789.44
49.99	0	616.61	616.79	620.36	613.40	24046.17	1401.03	24004.81	99.83	22493.71	22557.96	22534.88	22645.23
49.99	0	604.74	603.95	607.30	599.82	23454.43	1201.97	23423.39	99.87	22412.38	22476.88	22459.14	22559.11
49.99	0	604.29	604.02	607.77	600.02	23451.75	1327.49	23413.49	99.84	22409.73	22472.30	22457.74	22549.29
50.00	0	631.37	630.39	633.76	626.05	24636.03	2082.15	24546.66	99.64	22544.24	22609.44	22591.67	22692.37
50.00	0	692.60	693.45	697.90	689.85	26997.19	2989.56	26830.05	99.38	22445.99	22509.34	22482.48	22599.46
50.01	0	755.41	757.26	763.98	752.39	29569.38	3516.07	29358.04	99.28	22536.79	22579.45	22534.93	22666.58
50.00	0	787.02	790.31	797.62	786.30	30919.58	3726.61	30693.62	99.27	22582.30	22617.46	22570.53	22699.46
50.00	0	801.63	804.26	810.22	800.93	31570.45	3988.14	31317.37	99.20	22644.72	22691.31	22650.72	22778.49
49.99	0	780.24	781.90	788.57	776.88	30550.87	3585.81	30339.31	99.31	22542.04	22588.85	22550.58	22673.91
49.99	0	805.70	807.10	813.07	802.52	31448.08	3874.08	31208.32	99.24	22478.22	22525.88	22490.65	22608.85
50.00	0	818.09	819.13	823.93	815.37	31906.97	3960.22	31660.12	99.23	22468.17	22518.77	22486.61	22601.54
50.00	0	807.41	808.38	813.83	803.90	31800.55	4198.39	31520.98	99.12	22692.36	22745.02	22714.80	22827.89
50.00	0	806.24	807.14	812.60	802.58	31836.93	4579.78	31505.66	98.96	22754.75	22806.65	22776.59	22888.46
49.99	0	803.72	805.72	811.15	802.29	31471.08	4111.63	31201.03	99.14	22534.12	22583.36	22550.69	22665.29
50.00	0	803.98	805.79	810.61	802.78	31375.41	3718.50	31154.10	99.29	22461.32	22511.36	22470.71	22601.98
50.00	0	812.32	815.03	819.43	813.34	31772.80	3325.66	31597.01	99.45	22494.06	22536.65	22475.79	22640.06
50.00	0	824.05	828.12	831.78	828.54	32569.97	3073.01	32424.20	99.55	22672.04	22737.63	22668.03	22872.72
50.00	0	818.24	819.45	822.82	817.29	32109.73	2602.60	32001.92	99.67	22582.41	22654.81	22586.71	22795.10
50.01	0	792.51	794.00	797.48	792.03	31117.48	2197.26	31038.32	99.75	22596.24	22663.27	22601.91	22791.73
50.00	0	757.76	759.01	762.89	756.39	29899.01	3284.61	29717.45	99.39	22716.68	22782.37	22724.39	22906.00
50.00	0	715.05	715.81	720.25	712.13	28028.99	2615.10	27904.69	99.56	22589.82	22651.81	22603.21	22762.47

50.00	0	695.37	695.82	700.40	691.71	27100.57	2022.00	27024.86	99.72	22477.20	22537.29	22496.47	22638.13
49.99	0	650.94	651.92	655.36	649.46	25493.85	1780.82	25431.17	99.75	22570.98	22632.96	22606.04	22721.86
50.01	0	627.03	627.63	630.52	625.35	24562.85	1386.10	24523.58	99.84	22586.21	22656.27	22639.88	22742.79
50.00	0	604.96	605.17	608.53	602.02	23718.60	1207.08	23687.69	99.87	22634.37	22703.74	22691.21	22785.67
49.99	0	593.35	593.10	596.67	589.28	23263.06	1162.64	23233.84	99.87	22662.82	22730.10	22718.58	22808.86
50.00	0	598.85	598.92	602.28	595.62	23474.30	1419.95	23430.56	99.81	22646.62	22710.62	22699.92	22785.19
50.00	0	618.37	619.14	623.66	615.39	24217.78	1850.55	24146.67	99.71	22597.11	22656.47	22640.08	22732.25
50.00	0	666.56	668.29	673.50	664.81	25913.94	2335.04	25808.33	99.59	22387.53	22446.35	22422.26	22529.24
50.00	0	722.60	724.25	731.68	718.48	28310.13	2824.13	28167.18	99.50	22582.13	22617.42	22575.18	22694.98
50.01	0	753.31	755.08	760.72	751.20	29510.27	3027.83	29352.82	99.47	22573.04	22610.52	22566.96	22691.61
50.00	0	774.28	775.22	780.82	770.55	30200.97	3136.10	30037.50	99.46	22482.50	22527.01	22488.03	22610.45
50.00	0	769.42	768.38	774.11	761.60	29992.54	3131.37	29828.26	99.45	22521.85	22571.03	22534.51	22656.73
50.00	0	773.75	773.73	779.51	767.94	30153.75	3316.04	29970.29	99.39	22482.91	22535.41	22507.82	22615.34
50.00	0	768.97	770.90	776.65	767.09	30222.97	3569.94	30010.26	99.30	22595.56	22666.24	22652.78	22750.47
50.00	0	778.29	780.96	788.16	776.43	30662.59	4008.98	30398.73	99.14	22631.94	22700.21	22685.86	22782.80
50.01	0	775.26	775.72	781.39	770.52	30652.06	4303.28	30348.05	99.01	22795.19	22851.96	22829.87	22930.80
50.00	0	784.02	784.59	790.54	779.21	30764.34	4138.76	30484.27	99.09	22629.12	22677.44	22648.51	22754.57
49.99	0	784.90	785.16	790.25	780.32	30674.37	3746.25	30444.59	99.25	22543.75	22592.32	22558.01	22675.30
49.99	0	800.89	800.92	805.61	796.26	31310.27	3424.71	31121.04	99.40	22559.46	22605.78	22554.15	22703.75
50.00	0	824.41	826.17	829.86	824.24	32304.88	3191.26	32146.41	99.51	22543.76	22610.31	22543.56	22743.56
50.00	0	814.14	812.86	815.95	808.48	32026.51	2954.99	31889.20	99.57	22712.82	22784.84	22712.06	22929.74
50.00	0	798.43	797.91	801.54	793.77	30987.26	2324.85	30898.49	99.71	22394.87	22458.71	22387.14	22594.16
50.00	0	770.80	771.92	776.30	768.67	29974.29	3375.55	29783.38	99.36	22392.66	22456.38	22394.73	22581.76
50.00	0	716.94	718.14	721.90	715.59	28034.17	2622.30	27910.31	99.56	22522.21	22583.48	22533.95	22694.32
50.00	0	694.69	695.77	698.91	693.71	27080.11	2029.97	27003.72	99.72	22462.44	22521.13	22477.55	22623.33
49.99	0	653.57	655.38	659.35	653.23	25654.77	1767.71	25593.64	99.76	22606.74	22660.17	22625.47	22748.41
50.00	0	633.51	634.22	637.17	631.99	24889.68	1489.99	24844.85	99.82	22655.54	22721.05	22698.51	22809.10
49.99	0	613.68	614.07	616.99	611.54	24144.32	1439.52	24101.16	99.82	22709.50	22772.58	22754.51	22853.66
49.99	0	600.82	600.77	603.59	597.90	23662.55	1353.29	23623.60	99.84	22762.54	22822.93	22805.53	22900.78
50.00	0	609.28	609.59	612.57	606.92	23963.56	1618.86	23908.39	99.77	22713.50	22772.26	22754.66	22848.71
50.00	0	636.10	636.74	640.09	634.05	24767.87	2001.63	24686.49	99.67	22456.80	22516.38	22496.18	22596.22
50.00	0	685.35	686.77	690.27	684.69	26987.67	3071.22	26811.80	99.35	22671.13	22731.30	22704.18	22818.64
50.00	0	748.07	749.54	754.87	745.67	29351.84	3440.04	29148.29	99.31	22611.38	22648.05	22599.98	22732.76
50.01	0	785.02	786.10	789.98	783.29	30790.65	3695.47	30566.66	99.27	22608.13	22649.15	22599.82	22739.56
50.00	0	790.52	791.49	794.46	789.49	31210.10	4084.06	30941.62	99.14	22741.68	22794.61	22749.93	22892.13

50.00	0	793.24	793.63	796.32	791.34	31214.80	4274.28	30920.49	99.06	22681.59	22737.53	22699.88	22831.06
50.00	0	797.89	797.94	801.50	794.41	31224.52	4422.08	30909.49	98.99	22567.46	22623.64	22588.10	22715.44
50.00	50.00	802.74	803.12	806.31	800.33	31369.95	4723.17	31012.18	98.86	22526.10	22583.18	22549.57	22673.95
50.00	50.00	821.03	821.43	825.68	817.59	32218.64	5351.61	31769.55	98.61	22622.30	22678.59	22644.95	22768.51
50.00	0	827.58	828.36	832.84	824.66	32425.28	5528.43	31949.97	98.53	22582.54	22635.23	22600.68	22722.49
50.00	0	819.76	821.07	825.83	817.63	32083.11	5226.35	31654.44	98.66	22543.90	22595.38	22558.90	22683.30
50.00	0	809.48	810.26	814.29	807.02	31693.12	4779.31	31329.94	98.85	22567.84	22617.31	22579.02	22705.10
49.99	0	791.23	790.97	794.53	787.15	31191.39	3988.28	30934.10	99.18	22761.05	22805.19	22752.95	22901.53
50.00	0	804.28	804.83	808.33	801.88	31579.42	3265.37	31409.40	99.46	22622.69	22691.30	22634.34	22816.89
50.00	0	782.83	782.89	785.75	780.09	30866.88	2823.20	30736.91	99.58	22736.41	22806.45	22748.60	22934.14
50.00	0	756.43	756.01	759.55	752.06	29633.88	2191.58	29550.63	99.72	22611.41	22677.82	22622.22	22799.76
50.00	0	724.31	725.21	730.24	721.07	28335.29	3249.24	28147.77	99.34	22547.55	22611.46	22560.19	22726.67
50.00	0	634.67	633.40	636.86	628.66	24862.63	1964.41	24784.10	99.68	22668.74	22735.51	22690.66	22847.25
50.00	0	634.79	634.77	637.57	631.94	24772.56	1212.81	24742.13	99.88	22534.75	22597.21	22556.34	22700.55
50.00	0	616.03	616.60	619.56	614.20	24222.10	1158.82	24193.29	99.88	22692.22	22752.74	22721.67	22844.39
50.00	0	608.82	608.90	611.88	606.02	23865.41	1102.05	23839.72	99.89	22636.16	22705.46	22684.87	22795.37
50.00	0	594.77	594.88	597.66	592.22	23160.05	939.73	23140.82	99.92	22492.80	22559.17	22542.20	22642.50
50.00	0	587.94	586.98	589.86	583.15	22792.64	926.13	22773.58	99.92	22438.22	22502.79	22486.86	22583.25
49.99	0	582.06	581.95	585.01	578.77	22764.64	1095.18	22737.42	99.88	22614.30	22676.67	22664.15	22751.66
49.99	0	586.37	585.95	589.00	582.47	23005.12	1330.14	22966.29	99.83	22693.44	22757.08	22741.75	22836.02
50.00	0	606.21	606.00	608.51	603.28	23735.71	1690.55	23675.12	99.74	22629.44	22686.90	22667.00	22764.29
50.00	0	630.37	629.65	632.71	625.86	24713.10	1336.53	24674.46	99.84	22701.74	22726.42	22685.66	22791.80
50.00	0	657.07	656.29	659.02	652.78	25734.69	904.15	25715.43	99.92	22681.19	22706.42	22657.65	22780.39
49.99	0	669.15	668.67	671.96	664.91	26246.46	652.72	26238.07	99.97	22710.48	22734.33	22682.18	22810.32
50.01	0	681.13	681.57	684.96	678.62	26732.09	916.16	26716.17	99.94	22690.72	22715.07	22664.03	22790.49
50.00	0	687.26	686.34	689.44	682.30	26836.98	1128.39	26813.02	99.91	22620.29	22648.10	22596.50	22727.46
50.01	0	693.80	692.56	695.32	688.55	27052.12	1191.95	27025.68	99.90	22593.91	22623.44	22571.02	22705.43
50.00	0	691.20	689.63	691.89	685.80	26980.36	1062.07	26959.25	99.92	22634.06	22661.23	22606.36	22743.29
50.00	0	680.89	678.47	680.48	674.04	26565.04	881.81	26550.21	99.94	22655.06	22681.96	22628.83	22761.90
49.99	0	675.42	673.49	675.88	669.17	26360.17	914.14	26344.13	99.94	22648.69	22673.26	22619.49	22751.61
50.00	0	681.18	679.61	682.14	675.50	26562.02	873.43	26547.45	99.94	22617.88	22641.42	22584.61	22721.88
49.99	0	710.57	710.00	713.08	706.35	27798.45	1145.90	27774.33	99.91	22640.17	22668.53	22604.51	22760.94
50.02	0	740.93	742.12	743.49	741.93	28960.65	1416.13	28925.86	99.88	22515.19	22580.13	22523.03	22702.20
50.00	0	727.92	727.63	728.61	726.34	28380.08	1172.91	28355.57	99.91	22504.72	22573.15	22517.79	22697.03
50.00	0	709.41	708.66	709.65	706.91	27496.05	794.58	27482.56	99.95	22398.80	22464.15	22412.99	22580.69

49.99	0	691.10	690.54	692.93	687.57	26797.57	2106.78	26714.42	99.69	22401.72	22466.67	22418.80	22579.58
50.00	0	663.17	662.62	664.66	660.03	25907.35	1818.21	25843.29	99.75	22575.36	22642.59	22598.81	22753.58
50.00	0	660.67	660.19	662.56	657.34	25886.46	1546.91	25839.94	99.82	22635.15	22699.65	22656.71	22807.12
50.00	0	629.70	629.64	631.86	627.36	24643.11	1262.84	24609.74	99.87	22594.94	22658.06	22625.31	22754.08
50.00	0	616.54	616.48	619.15	613.74	24094.95	1050.74	24071.82	99.90	22561.96	22631.72	22611.31	22721.90
50.00	0	597.27	596.78	599.16	593.91	23458.22	1063.99	23433.90	99.90	22701.55	22773.60	22761.04	22858.38
50.00	0	588.33	587.66	590.31	584.34	23048.26	922.25	23029.64	99.92	22662.71	22732.34	22719.94	22814.37
49.99	0	588.38	587.78	590.24	584.72	23054.21	1113.40	23026.88	99.88	22668.94	22735.10	22725.36	22811.05
50.00	0	590.71	590.62	593.93	587.22	23143.42	1224.25	23110.56	99.86	22646.95	22712.93	22701.56	22790.28
49.99	0	612.04	612.35	615.64	609.38	24029.36	1742.82	23965.77	99.74	22667.24	22730.11	22713.96	22809.03
49.99	0	639.51	639.59	642.89	636.36	24931.90	1773.22	24868.10	99.74	22534.40	22566.67	22533.53	22632.12
50.00	0	673.75	673.56	676.44	670.50	26609.30	2098.48	26523.76	99.68	22832.22	22860.46	22818.72	22930.42
50.01	0	694.19	694.65	698.08	691.67	27377.06	2051.15	27299.91	99.72	22766.88	22799.71	22758.07	22874.03
50.01	0	706.51	707.31	710.60	704.81	27854.52	2367.65	27753.47	99.64	22748.76	22782.49	22744.70	22854.06
49.99	0	707.65	708.07	711.03	705.52	27815.66	2461.76	27706.29	99.61	22693.69	22729.38	22692.38	22802.10
50.00	0	710.36	709.86	713.80	705.43	27845.59	2477.07	27735.05	99.60	22663.13	22700.02	22660.54	22776.44
50.00	0	701.38	700.46	704.25	695.76	27471.37	2470.84	27359.66	99.59	22663.77	22699.52	22657.97	22776.71
50.00	0	703.62	704.03	707.65	700.83	27574.13	2657.27	27445.68	99.53	22633.74	22669.32	22632.27	22742.01
50.00	0	704.08	704.63	708.51	701.30	27583.59	2693.26	27451.67	99.52	22625.24	22659.62	22620.62	22732.83
49.99	0	701.40	700.82	704.30	696.76	27478.94	2385.24	27375.09	99.62	22658.35	22694.68	22652.72	22773.00
49.99	0	713.35	713.78	717.78	710.20	28008.82	2285.38	27915.21	99.67	22680.15	22714.80	22662.91	22801.35
50.02	0	730.18	732.63	736.19	731.52	28709.36	2391.74	28609.13	99.65	22608.31	22676.95	22627.76	22794.81
50.00	0	719.53	719.71	722.19	717.41	28338.65	2256.88	28248.21	99.68	22714.22	22788.45	22739.38	22911.68
50.00	0	705.07	705.34	707.67	703.29	27789.33	2001.87	27716.89	99.74	22734.84	22806.05	22758.26	22925.12
50.00	0	688.30	689.21	692.53	686.81	27238.54	2709.34	27103.35	99.50	22810.75	22878.97	22832.15	22993.96
49.99	0	662.57	663.56	666.96	661.15	26173.56	2165.28	26082.77	99.65	22772.60	22841.35	22798.62	22952.90
50.00	0	666.23	667.72	671.31	665.61	26155.48	1791.26	26093.92	99.76	22608.38	22673.75	22632.21	22780.59
50.00	0	633.43	634.18	637.68	631.44	24764.82	1429.86	24722.92	99.83	22540.56	22607.40	22576.78	22704.97
50.01	0	620.25	620.97	624.11	618.54	24263.68	1281.16	24229.62	99.86	22555.54	22630.17	22611.01	22723.91
49.99	0	600.74	600.41	603.37	597.12	23612.42	1273.72	23577.87	99.85	22714.52	22788.86	22775.91	22876.06
50.00	0	585.54	585.73	588.67	582.99	23040.91	1111.47	23013.88	99.88	22736.63	22807.03	22797.01	22887.47
50.00	0	578.54	578.91	581.68	576.51	22765.54	965.40	22744.69	99.91	22735.06	22804.34	22794.56	22883.38
49.99	0	584.01	584.71	588.22	581.91	22915.76	1156.38	22886.17	99.87	22657.19	22725.21	22714.06	22804.39
50.00	0	591.90	592.02	595.30	588.86	23176.92	1132.09	23148.94	99.88	22633.58	22694.16	22678.00	22770.93
50.00	0	614.93	614.64	618.18	610.80	24111.89	1339.42	24074.33	99.84	22697.45	22723.91	22686.03	22788.33

50.00	0	639.47	638.66	641.28	635.23	25019.21	1126.66	24991.42	99.89	22658.16	22686.12	22642.18	22758.09
50.00	0	653.11	652.75	656.25	648.89	25454.69	960.66	25436.41	99.93	22558.25	22585.19	22541.19	22656.08
50.00	0	664.52	663.33	666.09	659.38	25827.37	1222.23	25798.03	99.89	22518.04	22549.78	22508.38	22622.98
50.00	0	672.09	671.57	675.17	667.46	26156.26	1489.35	26113.62	99.84	22524.91	22556.67	22515.67	22629.47
50.01	0	675.49	673.81	676.82	669.14	26192.92	1553.88	26146.68	99.82	22477.30	22512.29	22472.22	22587.23
50.00	0	666.92	665.51	668.89	660.71	25862.78	1556.58	25815.70	99.82	22479.26	22513.99	22476.37	22586.33
50.00	0	664.67	663.40	667.11	658.41	25795.55	1573.14	25747.32	99.81	22495.42	22530.08	22493.15	22601.60
49.99	0	661.58	660.65	664.42	655.95	25700.37	1502.99	25656.14	99.83	22509.20	22541.33	22502.16	22612.73
50.00	0	661.60	660.71	664.36	656.16	25725.99	1341.00	25690.86	99.86	22531.85	22562.68	22519.76	22636.39
49.99	0	675.95	675.11	678.33	671.03	26273.33	1232.74	26244.07	99.89	22517.38	22547.44	22496.19	22628.62
50.01	0	716.37	717.03	719.31	715.41	28044.98	1853.66	27982.41	99.78	22574.96	22643.63	22599.60	22756.27
50.01	0	708.10	707.56	710.35	704.22	27855.12	1811.62	27795.90	99.79	22723.11	22796.98	22752.41	22915.26
49.99	0	695.04	694.73	697.06	692.08	27393.17	1669.47	27341.96	99.81	22762.37	22835.25	22791.45	22951.91
50.00	0	679.43	680.70	684.39	678.28	26858.53	2349.96	26755.21	99.62	22785.71	22851.21	22806.76	22961.20
50.00	0	657.87	658.83	662.91	655.70	25764.42	1710.96	25707.31	99.78	22586.87	22652.32	22613.43	22756.71
50.02	0	657.31	658.23	661.94	655.43	25763.01	1465.08	25721.09	99.84	22603.73	22666.07	22629.05	22765.45
49.99	0	624.05	624.62	627.39	622.41	24560.77	1285.79	24526.74	99.86	22710.66	22778.94	22754.94	22871.22
50.00	0	605.47	606.14	608.66	604.29	23873.98	986.27	23853.34	99.91	22744.42	22820.52	22806.43	22910.65
49.99	0	590.81	591.18	593.77	588.95	23254.25	888.03	23237.14	99.93	22727.16	22801.41	22789.23	22887.79
49.99	0	583.04	583.05	585.97	580.13	22985.29	937.93	22965.96	99.92	22790.21	22860.10	22848.43	22941.63
50.00	0	585.85	586.11	589.23	583.24	23087.79	1096.39	23061.35	99.89	22770.79	22839.33	22828.76	22918.49
50.00	0	594.31	595.04	599.20	591.61	23371.29	1345.01	23332.12	99.83	22696.20	22761.34	22747.52	22840.13
50.00	0	616.69	616.84	620.60	613.24	24137.55	1733.75	24074.96	99.74	22607.03	22664.29	22646.63	22739.21
50.00	0	643.97	644.38	649.03	640.13	24984.33	1179.78	24953.84	99.88	22423.45	22446.13	22408.57	22506.42
50.00	0	664.37	664.05	667.80	659.99	25767.57	650.33	25755.14	100.00	22441.71	22464.93	22421.05	22532.03
50.00	0	677.98	677.65	681.68	673.28	26553.83	648.63	26545.06	99.97	22657.83	22686.91	22643.23	22759.59
50.00	0	692.93	692.68	695.83	689.28	27012.41	1204.92	26985.14	99.90	22536.37	22571.77	22536.58	22642.31
50.00	0	699.19	698.33	700.51	695.28	27142.88	1495.97	27101.42	99.85	22462.28	22500.91	22469.43	22570.93
50.00	0	713.21	712.53	715.91	708.47	27610.97	1681.19	27559.63	99.81	22392.45	22431.05	22396.21	22504.53
50.00	0	712.54	711.57	715.31	706.85	27594.12	1873.40	27529.97	99.77	22411.86	22450.43	22415.45	22523.90
49.99	0	712.20	711.54	715.47	706.93	27873.71	2253.99	27782.30	99.67	22644.38	22682.92	22648.84	22755.58
49.99	0	710.60	711.19	715.94	707.03	27825.29	2251.98	27733.93	99.67	22619.91	22656.55	22619.42	22730.33
50.00	0	706.87	706.97	710.83	703.20	27696.31	1943.83	27627.73	99.75	22650.11	22686.19	22644.84	22763.68
50.00	0	715.61	715.50	720.06	710.82	28147.70	1644.20	28099.32	99.83	22750.02	22784.94	22728.62	22876.10
50.01	0	751.27	752.38	756.02	749.85	29484.00	1828.65	29426.58	99.81	22608.83	22681.18	22623.91	22810.77

50.00	0	740.58	740.68	744.39	737.05	28813.87	1391.19	28779.94	99.88	22446.28	22518.91	22462.05	22648.38
50.00	0	717.69	717.58	721.04	714.03	28035.21	1164.18	28009.40	99.91	22557.01	22623.85	22569.21	22745.21
50.00	0	696.35	697.49	701.22	694.88	27149.44	2374.22	27045.25	99.62	22473.27	22536.47	22490.15	22645.89
50.00	0	666.17	668.13	672.62	665.62	26116.73	1996.03	26040.04	99.71	22575.89	22637.26	22596.43	22739.56
49.99	0	656.08	657.82	662.11	655.26	25719.30	1618.46	25667.94	99.80	22578.16	22637.21	22600.53	22732.92
50.00	0	618.21	619.18	622.87	616.45	24333.58	1299.32	24298.66	99.86	22701.24	22763.11	22737.16	22850.90
50.01	0	601.77	603.23	606.33	601.58	23739.24	1100.58	23713.46	99.89	22725.49	22797.30	22783.72	22882.77
49.99	0	590.41	591.25	594.24	589.10	23253.08	1086.36	23227.50	99.89	22714.42	22786.45	22778.42	22866.59
50.00	0	579.51	579.75	582.44	577.29	22838.02	1004.31	22815.83	99.90	22762.11	22832.54	22824.58	22910.84
49.99	0	578.19	579.01	582.23	576.61	22794.73	1091.73	22768.25	99.88	22747.83	22816.13	22809.20	22891.41
50.00	0	595.75	596.72	600.21	594.21	23408.11	1475.24	23360.18	99.80	22653.60	22720.65	22709.99	22798.26
50.00	0	654.15	655.31	659.15	652.64	25601.14	2517.19	25476.75	99.51	22539.48	22602.89	22583.17	22685.94
50.00	0	706.20	707.75	713.24	703.81	27468.05	2584.75	27344.39	99.55	22411.63	22448.79	22410.08	22524.61
50.00	0	746.22	748.91	754.86	745.66	29151.74	3011.13	28994.53	99.46	22477.52	22517.02	22478.78	22594.77
50.00	0	774.39	777.19	782.82	774.37	30574.35	3831.97	30332.50	99.21	22707.60	22756.87	22726.34	22836.79
50.00	0	794.17	796.55	802.14	793.36	31231.91	4313.05	30931.96	99.04	22620.87	22676.49	22648.81	22759.76
50.00	0	804.22	806.79	812.62	803.54	31557.15	4649.01	31212.70	98.91	22563.13	22619.05	22595.06	22699.13
50.01	0	815.15	817.79	823.40	814.82	31995.51	4859.46	31624.23	98.84	22568.90	22625.51	22601.45	22706.23
50.00	0	825.88	828.23	834.45	824.35	32306.94	5228.57	31880.72	98.68	22500.33	22558.26	22533.77	22640.61
49.99	0	824.57	826.98	833.69	822.69	32252.01	5190.90	31831.35	98.70	22498.63	22554.40	22527.88	22636.64
50.00	0	819.50	822.77	829.62	819.18	32125.15	5058.40	31724.18	98.75	22528.38	22581.89	22552.41	22664.91
50.00	0	811.79	814.25	820.12	810.83	31969.37	4855.83	31598.40	98.84	22653.82	22706.73	22674.42	22791.98
49.99	0	802.92	804.63	809.19	801.78	31464.27	3900.07	31218.42	99.22	22563.40	22614.42	22570.03	22709.74
50.01	0	799.36	802.03	805.86	800.86	31518.30	3015.21	31373.19	99.54	22655.02	22729.22	22676.85	22855.79
50.00	0	780.99	780.85	784.20	777.35	30337.64	2184.92	30258.13	99.74	22399.52	22472.63	22414.73	22603.69
50.00	0	757.75	758.24	762.71	754.25	29406.10	1849.95	29346.34	99.80	22374.39	22441.16	22386.71	22562.48
50.00	0	727.78	730.35	736.14	727.12	28345.18	2957.38	28190.23	99.45	22397.52	22459.12	22410.32	22569.50
50.00	0	685.96	688.14	693.58	684.88	26810.73	2277.62	26713.31	99.64	22490.00	22553.45	22513.48	22656.91
50.01	0	669.76	671.01	676.02	667.26	26276.26	1980.92	26201.36	99.71	22601.63	22665.68	22630.40	22764.98
49.98	0	629.31	630.91	634.89	628.53	24805.34	1767.74	24742.08	99.75	22697.59	22763.76	22742.37	22851.24
50.01	0	612.11	613.51	617.61	610.81	24122.02	1544.14	24072.23	99.79	22697.20	22768.60	22754.86	22853.80
49.99	0	597.58	598.05	601.64	594.93	23462.38	1386.16	23421.10	99.82	22657.02	22730.87	22726.14	22809.41
50.00	0	586.20	586.50	589.56	583.76	23082.79	1353.86	23042.92	99.83	22736.30	22811.17	22807.69	22889.36
49.99	0	590.02	590.86	594.08	588.48	23217.24	1483.36	23169.59	99.80	22700.65	22773.43	22772.14	22847.48
50.00	0	609.52	610.69	614.75	607.79	23841.71	1812.47	23771.75	99.71	22539.49	22609.94	22605.21	22685.03

50.00	0	659.57	661.69	666.51	658.98	25784.15	2648.93	25647.59	99.47	22481.79	22551.68	22539.88	22633.29
49.99	0	725.38	728.14	734.92	724.11	28449.27	3267.57	28259.72	99.33	22547.86	22601.43	22575.30	22681.22
50.01	0	755.90	760.28	767.46	757.47	29719.27	3376.03	29525.25	99.35	22560.97	22610.86	22581.46	22690.13
50.01	0	771.85	775.44	781.78	772.69	30558.60	3676.73	30336.52	99.27	22738.68	22794.40	22767.30	22877.35
50.00	0	782.40	784.64	791.16	780.36	30825.58	3777.18	30593.10	99.25	22663.96	22724.57	22698.57	22811.27
49.99	0	784.36	786.77	794.40	781.55	30904.68	3941.52	30652.08	99.18	22662.21	22723.58	22696.40	22812.01
50.01	0	789.88	791.94	799.59	786.34	31104.71	3880.61	30861.63	99.22	22660.45	22722.07	22693.70	22812.05
50.01	0	789.59	791.91	798.98	787.17	31067.69	4114.65	30793.89	99.12	22635.66	22695.34	22668.89	22781.58
50.00	0	789.32	791.27	798.37	786.12	31053.96	4127.52	30778.29	99.11	22644.67	22703.84	22674.11	22792.67
50.00	0	786.05	788.41	796.00	783.18	31021.50	4123.02	30746.08	99.11	22711.10	22764.47	22728.52	22853.70
49.99	0	783.53	785.74	792.31	781.37	31006.42	3816.53	30770.01	99.24	22777.77	22830.59	22790.05	22923.95
50.00	0	798.86	800.84	806.74	796.93	31446.17	3281.74	31273.61	99.45	22661.18	22713.29	22658.17	22820.74
50.00	0	819.98	823.82	828.95	822.53	32239.58	2750.07	32121.54	99.63	22554.74	22634.75	22573.57	22776.03
50.00	0	800.65	804.05	809.25	802.23	31708.02	2473.17	31611.22	99.70	22732.28	22811.31	22747.77	22953.96
50.00	0	778.54	782.02	788.05	779.46	30767.91	2061.72	30697.24	99.77	22690.27	22761.82	22699.77	22895.39
50.00	0	754.06	756.94	763.33	753.43	29575.10	3094.63	29412.57	99.45	22539.55	22607.19	22553.49	22728.34
50.00	0	702.82	706.09	712.83	702.61	27354.16	2172.15	27267.40	99.68	22353.69	22420.38	22378.16	22529.16
50.00	0	687.30	689.12	694.83	685.23	26761.30	1895.51	26693.83	99.75	22403.37	22471.31	22437.46	22573.10
50.00	0	639.22	641.13	646.68	637.48	25128.34	1497.73	25083.26	99.82	22624.50	22692.55	22668.53	22784.70
50.00	0	614.16	616.23	621.13	613.41	24220.36	1200.47	24190.41	99.88	22685.27	22759.02	22745.16	22846.56
49.99	0	481.06	480.35	483.97	476.04	18875.31	-1414.76	18710.01	98.73	22748.80	22822.58	22809.12	22909.86
49.99	0	393.72	390.62	393.28	384.85	15315.06	-3427.26	14925.90	97.46	22804.29	22876.19	22861.60	22962.65
49.99	0	391.60	387.88	390.27	381.78	15191.38	-3396.00	14806.44	97.47	22780.66	22851.63	22835.52	22938.73
49.99	0	405.45	402.44	405.27	396.59	15678.04	-3084.07	15369.85	98.03	22616.12	22687.89	22671.89	22775.66
50.00	0	458.67	455.94	460.12	449.03	17690.50	-2078.82	17564.22	99.28	22446.95	22516.46	22488.86	22613.53
49.99	0	508.61	507.85	514.72	500.22	19868.93	-1558.59	19804.33	99.67	22632.55	22675.07	22622.97	22769.69
50.01	0	543.65	545.64	553.55	539.72	21453.49	-1122.03	21421.95	99.85	22732.79	22778.60	22729.97	22873.12
50.01	0	559.88	561.37	568.32	555.89	22093.88	-1030.86	22068.80	99.89	22721.39	22778.78	22738.45	22876.43
50.00	0	560.56	558.60	565.72	549.54	21808.31	-1183.60	21775.94	99.85	22535.68	22594.37	22549.60	22697.78
50.00	0	555.55	554.05	560.66	545.94	21636.84	-1044.34	21611.33	99.93	22546.80	22607.47	22567.81	22707.81
49.99	0	559.95	558.45	564.11	551.28	21817.30	-982.45	21794.89	99.91	22553.63	22616.91	22581.89	22715.27
50.00	0	558.79	557.85	563.66	551.08	21760.98	-768.00	21747.10	99.94	22522.69	22583.87	22551.04	22677.84
49.99	0	559.18	558.33	563.51	552.31	21763.70	-602.76	21754.94	99.97	22504.14	22565.55	22534.43	22658.00
50.00	0	568.66	567.61	572.17	562.00	22134.08	-375.70	22130.41	99.99	22506.12	22567.52	22533.04	22663.48
50.00	0	669.94	669.73	673.49	665.76	26232.69	1542.88	26153.18	99.57	22596.21	22654.98	22616.74	22751.97

49.96	0	783.07	783.39	786.64	780.45	30684.44	3133.97	30523.03	99.48	22595.57	22653.20	22601.38	22762.59
50.03	0	829.94	833.21	837.59	832.10	32654.04	3194.61	32497.11	99.52	22590.89	22665.19	22604.39	22800.17
50.02	0	807.00	808.18	812.80	804.75	31872.99	2900.72	31739.95	99.58	22736.07	22811.89	22748.75	22950.76
50.01	0	773.67	775.48	780.74	772.04	30289.47	2084.87	30214.89	99.75	22531.52	22597.95	22536.87	22725.32
50.00	0	738.86	740.58	746.00	736.90	29242.43	3374.18	29046.85	99.33	22788.09	22853.76	22801.99	22971.27
50.00	0	701.95	703.96	709.68	700.25	27342.27	2409.07	27233.58	99.61	22418.44	22481.34	22439.23	22586.41
50.00	0	686.64	687.47	693.16	682.61	26725.63	1864.37	26660.40	99.76	22439.79	22504.27	22467.55	22605.50
49.99	0	639.19	640.40	645.70	636.31	25077.71	1630.08	25024.38	99.79	22611.35	22674.89	22648.76	22764.43
50.00	0	622.97	624.20	628.99	620.63	24358.11	1302.32	24323.15	99.86	22523.74	22596.17	22581.68	22683.04
50.00	0	602.43	603.16	606.79	600.25	23622.42	1197.28	23591.95	99.87	22619.66	22691.79	22685.41	22770.34
49.99	0	595.85	596.24	599.74	593.11	23400.26	1347.43	23361.09	99.83	22673.57	22741.38	22735.46	22815.04
49.99	0	598.47	599.14	603.18	595.78	23517.46	1483.86	23470.25	99.80	22677.47	22743.03	22735.16	22816.43
50.00	0	618.73	619.66	624.00	616.24	24147.44	1773.90	24081.75	99.73	22498.60	22566.92	22558.26	22643.92
50.00	0	662.35	663.45	668.41	659.58	25750.31	2369.30	25640.69	99.58	22392.54	22459.82	22443.27	22543.76
50.00	0	721.05	722.81	728.48	718.89	28332.82	3150.48	28156.22	99.38	22630.03	22672.74	22634.37	22753.82
50.00	0	759.04	761.33	766.97	757.97	29693.82	3328.41	29505.08	99.36	22518.42	22559.05	22513.39	22645.21
50.00	0	781.92	784.11	788.10	782.31	30476.28	3502.69	30274.23	99.34	22431.02	22477.67	22442.16	22559.78
49.99	0	789.21	790.36	795.13	786.73	30884.51	3854.68	30641.90	99.22	22551.47	22600.87	22562.96	22688.13
50.00	0	801.13	802.12	806.81	798.41	31606.85	4607.41	31268.99	98.93	22727.19	22783.53	22750.18	22873.22
50.00	0	803.90	804.45	809.12	800.34	31659.08	4756.67	31299.59	98.86	22695.81	22756.29	22726.24	22846.76
50.00	0	803.12	803.98	809.66	799.15	31671.82	4778.32	31309.19	98.86	22720.39	22779.80	22748.02	22871.06
50.00	0	803.42	805.69	810.96	802.68	31782.50	4867.25	31407.44	98.82	22756.11	22811.68	22781.54	22897.50
50.00	0	794.55	797.39	802.95	794.66	31600.27	4856.55	31224.72	98.81	22864.62	22917.75	22884.31	23004.22
50.00	0	789.03	791.38	796.12	788.98	31180.16	4406.53	30866.19	98.99	22730.92	22784.47	22748.39	22874.17
49.99	0	799.32	799.86	804.15	796.12	31468.76	3886.46	31227.08	99.23	22693.35	22748.81	22698.15	22854.82
50.01	0	826.66	828.70	833.04	826.39	32476.43	3495.54	32287.42	99.42	22583.04	22657.92	22600.20	22790.60
50.00	0	803.76	805.29	809.65	802.45	31529.01	2906.38	31392.73	99.57	22563.41	22638.27	22582.67	22768.65
50.00	0	777.44	779.03	783.98	775.66	30481.43	2423.83	30383.21	99.68	22557.91	22629.16	22576.27	22753.28
50.00	0	744.15	746.35	751.26	743.66	29376.13	3494.08	29167.17	99.29	22699.10	22769.53	22723.46	22886.13
50.00	0	697.60	699.87	704.98	697.03	27569.53	2654.89	27439.10	99.53	22727.32	22794.60	22753.00	22903.42
50.01	0	688.97	690.35	695.05	687.02	27002.42	1982.56	26929.26	99.73	22573.11	22637.74	22598.78	22741.30
50.01	0	644.20	646.60	651.57	644.02	25307.78	1569.09	25258.89	99.81	22603.25	22665.17	22639.41	22752.92
49.98	0	617.65	619.53	622.98	617.98	24246.34	987.74	24100.34	97.76	22631.38	22705.62	22692.51	22792.96
49.98	0	350.33	344.33	343.62	339.03	13315.54	-6040.37	11830.79	88.77	22527.93	22605.17	22588.05	22699.49
50.00	0	346.97	341.21	340.23	336.44	13223.72	-5802.23	11880.76	89.84	22550.61	22625.10	22611.73	22712.78

50.00	0	350.87	346.78	347.01	342.46	13414.90	-4976.47	12411.24	93.98	22493.60	22563.03	22552.22	22643.18
49.99	0	493.90	492.59	495.99	487.88	19140.86	-829.12	19099.98	99.91	22506.41	22571.80	22560.26	22648.73
49.99	0	569.95	570.10	574.41	565.96	22086.55	182.70	22085.46	99.96	22389.91	22454.96	22441.87	22533.11
50.00	0	617.64	617.15	621.16	612.64	24149.27	945.20	24127.86	99.91	22609.84	22642.69	22604.43	22713.73
50.00	0	676.35	676.74	680.20	673.69	26484.02	1542.38	26437.79	99.83	22615.32	22638.37	22586.22	22713.68
50.00	0	705.09	706.39	711.87	702.22	27410.29	1676.05	27358.79	99.81	22410.93	22440.50	22388.36	22522.21
50.00	0	722.53	722.41	727.08	717.62	28317.28	2301.26	28223.30	99.67	22635.53	22670.15	22617.94	22756.96
50.01	0	727.40	726.48	730.22	721.82	28549.70	2419.00	28446.98	99.64	22694.34	22731.24	22682.04	22817.34
50.00	0	731.61	730.71	734.76	725.77	28748.80	2503.97	28639.37	99.62	22724.63	22758.53	22707.81	22843.09
50.00	0	728.25	727.77	731.58	723.48	28653.45	2562.20	28538.39	99.60	22739.12	22776.10	22731.44	22857.75
50.00	0	723.44	722.58	726.32	717.98	28474.92	2490.87	28365.63	99.62	22763.24	22801.88	22757.73	22884.65
50.00	0	718.69	717.59	722.00	712.06	28242.76	2331.10	28146.23	99.66	22741.66	22776.18	22728.04	22858.89
50.00	0	718.36	717.51	721.43	712.75	28243.82	2177.43	28159.59	99.70	22745.47	22778.10	22726.12	22862.56
49.96	0	738.32	738.36	742.90	733.86	29030.72	2040.32	28958.72	99.75	22716.76	22752.94	22687.10	22854.92
50.03	0	771.73	774.54	779.76	772.12	30570.30	2438.10	30472.54	99.68	22764.00	22831.28	22760.08	22969.78
50.00	0	754.01	755.00	759.71	751.29	29318.13	1747.30	29265.81	99.82	22396.90	22464.35	22398.85	22597.32
49.99	0	732.21	733.43	738.10	729.97	28530.18	1508.96	28489.61	99.86	22443.49	22508.14	22450.54	22630.44
50.00	0	705.82	707.51	712.77	703.94	27551.60	2133.19	27468.70	99.70	22467.54	22533.15	22482.09	22649.91
50.00	0	673.99	675.12	680.60	670.77	26476.13	1797.03	26414.78	99.77	22634.77	22699.94	22654.44	22810.67
50.00	0	670.27	671.91	676.48	668.99	26387.08	1539.13	26342.04	99.83	22665.62	22725.69	22683.72	22827.65
49.99	0	631.37	633.71	637.88	631.87	24812.61	1172.31	24784.49	99.89	22601.45	22662.42	22632.62	22753.12
50.01	0	616.30	618.46	622.25	616.83	24103.34	887.64	24086.72	99.93	22492.66	22561.98	22543.93	22649.39
49.99	0	596.33	597.56	600.99	595.35	23464.59	929.99	23445.93	99.92	22672.06	22740.40	22726.14	22823.00
50.00	0	578.72	579.00	581.97	576.31	22765.18	773.64	22751.76	99.94	22718.47	22785.46	22773.04	22864.87
49.99	0	574.80	574.90	578.29	571.61	22635.20	796.48	22620.96	99.94	22754.22	22818.90	22807.59	22894.95
50.00	0	578.12	578.48	582.22	575.11	22763.21	947.44	22743.32	99.91	22735.74	22800.81	22788.46	22878.19
50.00	0	593.12	593.29	597.07	589.67	23282.50	1187.84	23251.92	99.87	22668.22	22733.14	22719.15	22812.04
49.99	0	613.04	613.21	618.30	608.28	24099.96	1297.60	24064.81	99.85	22725.94	22754.94	22718.99	22819.99
50.00	0	650.32	650.83	656.34	645.82	25419.40	1110.53	25392.81	99.89	22582.04	22602.23	22551.78	22672.85
50.00	0	683.46	684.01	688.47	680.10	26702.00	1322.32	26668.70	99.88	22560.56	22584.75	22531.78	22661.84
50.01	0	701.57	701.09	704.45	697.24	27251.08	1567.40	27205.76	99.83	22454.36	22483.10	22431.36	22563.63
49.99	0	710.58	710.03	713.26	706.24	27507.10	1746.72	27451.47	99.80	22378.89	22409.76	22360.49	22489.95
49.99	0	711.07	709.93	713.26	705.48	27684.09	1945.95	27615.17	99.75	22529.51	22562.08	22511.84	22644.82
50.01	0	702.40	700.99	704.30	696.29	27483.48	2087.76	27403.88	99.71	22653.02	22687.76	22642.13	22768.06
50.00	0	698.79	698.37	701.89	694.42	27401.48	2251.21	27308.78	99.66	22674.08	22706.94	22665.04	22781.65

49.99	0	693.47	693.18	696.92	689.15	27209.26	2230.95	27117.47	99.66	22687.70	22717.22	22669.47	22794.53
50.00	0	704.15	703.00	706.24	698.61	27596.75	2087.61	27517.50	99.71	22685.60	22716.56	22663.05	22801.07
49.97	0	732.86	734.53	738.56	732.18	28796.63	2019.03	28725.35	99.75	22648.56	22681.62	22614.51	22781.96
50.03	0	770.15	773.28	777.79	771.91	30535.21	2372.46	30442.64	99.70	22771.45	22842.28	22770.15	22985.31
50.00	0	756.88	758.98	763.00	757.07	29559.74	1781.43	29504.91	99.82	22458.23	22529.23	22462.40	22667.08
50.00	0	737.48	739.05	743.25	736.43	28635.00	1354.30	28602.68	99.89	22350.60	22418.13	22355.88	22547.80
50.00	0	713.91	715.95	721.89	712.05	27805.01	2012.45	27731.95	99.74	22409.82	22473.44	22414.37	22596.13
50.00	0	671.07	671.50	675.88	667.53	26286.27	1554.27	26240.03	99.82	22595.71	22662.53	22618.73	22773.28
49.99	0	662.40	662.70	666.33	659.38	26054.73	1347.56	26019.50	99.87	22693.33	22757.76	22721.18	22858.78
49.99	0	621.02	621.42	624.81	618.44	24291.89	789.40	24278.28	99.94	22564.46	22630.53	22603.39	22723.71
50.00	0	606.68	608.61	611.74	607.43	23674.80	525.87	23668.80	99.97	22449.77	22521.13	22507.38	22606.20
49.99	0	591.75	592.81	595.99	590.68	23089.56	515.60	23083.70	99.97	22485.88	22557.19	22545.95	22639.80
50.01	0	580.36	580.96	583.95	578.58	22609.94	328.67	22607.34	99.99	22470.03	22539.46	22530.94	22617.39
49.99	0	577.32	578.28	581.74	575.77	22538.35	422.14	22533.60	99.98	22510.21	22580.47	22576.08	22655.18
49.99	0	597.25	598.36	602.56	595.28	23477.38	1047.71	23452.87	99.90	22654.06	22723.89	22714.08	22803.48
50.00	0	667.43	670.18	675.95	667.17	26043.73	2126.25	25955.44	99.66	22413.10	22479.87	22459.40	22567.10
50.00	0	733.64	736.47	743.60	732.18	28863.69	2920.43	28713.34	99.48	22617.92	22660.34	22617.29	22745.73
50.00	0	774.47	778.76	786.72	775.09	30588.64	3476.40	30389.37	99.35	22665.58	22709.00	22670.94	22790.43
50.01	0	787.56	791.34	797.40	789.06	31137.88	3604.71	30928.35	99.33	22696.44	22746.13	22716.64	22825.29
50.00	0	785.89	787.25	793.19	782.67	31008.85	3709.00	30785.98	99.28	22713.04	22770.68	22744.40	22854.47
50.00	0	790.33	790.38	795.90	784.90	31045.93	3843.71	30806.98	99.23	22646.34	22706.57	22681.48	22791.81
50.00	0	793.45	793.21	798.49	787.70	31200.09	3921.98	30952.45	99.21	22675.50	22738.19	22714.79	22824.31
50.00	0	802.36	802.52	808.21	796.98	31399.80	4243.35	31111.61	99.08	22558.66	22618.11	22594.50	22701.04
50.00	0	801.29	802.40	808.40	797.52	31379.64	4360.84	31075.06	99.03	22548.62	22606.96	22582.27	22689.92
50.00	0	791.91	793.63	799.84	789.14	31213.46	4378.72	30904.66	99.01	22679.36	22736.66	22709.75	22820.98
50.00	0	796.66	798.54	804.36	794.61	31432.16	4118.60	31159.87	99.13	22701.93	22756.32	22721.20	22845.80
49.98	0	812.22	812.63	816.79	808.87	31845.13	3374.70	31663.91	99.43	22603.16	22656.22	22597.73	22767.69
50.02	0	827.76	829.65	833.74	827.45	32424.11	2624.10	32317.55	99.67	22522.76	22595.56	22521.59	22742.39
49.99	0	805.06	807.73	813.19	804.92	31627.32	2289.63	31543.76	99.74	22576.18	22644.74	22571.75	22786.36
50.00	0	781.49	783.12	788.45	779.43	30815.44	2062.38	30745.02	99.77	22697.26	22761.25	22690.89	22895.59
50.00	0	753.23	755.48	760.84	752.36	29840.87	3401.81	29646.26	99.35	22784.66	22843.34	22780.98	22964.46
50.00	0	711.65	713.40	718.84	709.70	27770.25	2320.45	27670.12	99.64	22452.34	22509.90	22458.31	22619.08
50.01	0	686.96	688.16	693.49	684.04	26791.04	1733.26	26734.55	99.79	22458.08	22515.97	22476.52	22613.35
49.99	0	638.15	640.23	644.31	638.22	25070.70	1367.80	25033.23	99.85	22590.17	22650.90	22627.73	22734.82
49.99	0	621.06	623.15	626.75	621.65	24440.85	1198.66	24411.31	99.88	22615.22	22685.75	22672.76	22769.20

50.00	0	606.19	607.98	611.27	606.46	23817.93	1084.28	23792.91	99.89	22610.83	22679.94	22671.28	22757.72
49.99	0	597.38	598.11	601.06	595.89	23411.45	999.06	23389.95	99.91	22612.48	22679.42	22671.30	22754.47
49.99	0	594.60	596.11	599.75	593.99	23298.18	1019.08	23275.68	99.90	22581.19	22645.81	22637.35	22718.90
50.00	0	620.65	621.17	625.00	617.85	24199.73	1449.56	24155.66	99.82	22492.35	22556.82	22541.01	22637.13
49.98	0	685.26	686.87	691.93	683.43	26781.84	2512.61	26662.29	99.56	22487.41	22548.83	22518.95	22640.10
50.01	0	762.19	765.57	773.19	761.34	29876.79	3279.42	29694.83	99.39	22527.51	22562.16	22503.78	22655.12
50.02	0	788.72	790.80	797.30	786.39	31050.32	3731.29	30823.95	99.27	22655.48	22699.40	22652.14	22790.52
50.00	0	792.10	794.06	798.97	791.09	31298.29	3904.70	31053.29	99.22	22731.14	22784.25	22747.82	22873.68
50.00	0	796.29	797.21	802.55	792.79	31405.68	4290.38	31111.10	99.06	22718.32	22772.38	22737.34	22861.46
49.99	0	758.29	758.35	763.48	753.28	29848.95	3861.14	29597.12	99.16	22702.31	22755.96	22724.15	22841.46
49.98	0	763.55	763.35	767.88	758.61	30027.88	4032.16	29755.78	99.09	22683.72	22740.33	22710.16	22827.11
50.01	0	803.63	804.73	809.62	800.93	31476.81	4607.68	31137.34	98.92	22555.82	22610.99	22585.20	22691.87
50.01	0	812.38	813.69	819.44	809.27	31842.34	4893.26	31463.91	98.81	22567.82	22620.92	22595.57	22699.38
50.01	0	807.11	808.87	814.52	804.99	31740.53	4916.11	31356.81	98.79	22631.47	22683.66	22656.27	22763.15
49.99	0	805.68	806.47	811.18	802.55	31549.58	4337.09	31249.82	99.05	22568.24	22618.66	22581.07	22706.58
49.98	0	815.42	817.36	821.88	814.78	32050.90	3858.92	31815.94	99.27	22621.93	22674.23	22626.00	22774.81
50.02	0	820.09	822.78	826.58	821.66	32353.62	3151.61	32199.55	99.52	22664.39	22738.78	22678.00	22874.04
50.01	0	802.55	804.90	810.63	801.50	31497.79	2443.04	31401.13	99.69	22570.83	22637.20	22573.51	22767.25
50.00	0	780.88	781.84	786.99	777.64	30347.82	1791.27	30292.93	99.82	22396.81	22458.86	22399.49	22580.24
50.00	0	751.21	754.29	759.72	751.93	29473.15	3127.32	29306.60	99.44	22551.96	22610.15	22557.71	22720.76
50.00	0	701.25	703.15	708.75	699.44	27728.49	2593.45	27606.58	99.56	22769.36	22827.27	22783.56	22928.94
50.00	0	681.78	682.45	686.93	678.62	26940.09	2194.89	26850.00	99.67	22783.47	22844.98	22809.19	22942.24
49.99	0	645.96	646.51	650.49	643.07	25325.00	1734.25	25265.30	99.76	22612.54	22674.21	22650.43	22759.65