EVALUATION OF IMPACT ASSESSMENT OF NON-LINEAR LIGHTING LOADS ON POWER QUALITY IN DISTRIBUTION NETWORK

by

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Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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List of Abbreviations

AC	Air Conditioner
ADB	Asian Development Bank
ANSI	American National Standard Institute
CFL	Compact Fluorescent Lamp
CO2	Carbon Di Oxide
DAQ	Data Acquisition
DFT	Discrete Fourier Transform
DSM	Demand Side Management
EB	Electronic Ballast
ELI	Efficient Lighting Initiative
FFT	Fast Fourier Transform
FL	Fluorescent Lamp
FTL	Fluorescent Tube Light
GEF	Global Environment Facility
IFFT	Inverse FFT
IEA	International Energy Agency
IFC	International Finance Corporation
IL	Incandescent Lamp
LED	Light Emitting Diode
MB	Magnetic Ballast
PCC	Point of Common Coupling
PELP	Poland Efficient Lighting Project
PF	Power Factor
PFI	Power Factor Improvement
RDSM	Residential Demand Side Management
RMS	Root Mean Square
THD	Total Harmonic Distortion
UV	Ultra Violet
VAR	Volt Amps Reactive
ZCF	Zero Crossing Flag

List of Symbols

a_n^v, b_n^v, c_n^v	Fourier Coefficients for Voltage
a_n^i, b_n^i, c_n^i	Fourier Coefficients for Current
v(t)	Instantaneous Voltage in Time Domain
v(k)	Sampled Voltage
ω	Phase
t	Time
θ_v	Phase Shift for Voltage
θ_i	Phase Shift for Current
N	Number of Samples
τ	Sampling Time
i(k)	Load Current Harmonics
P	Power
N_T	Samples in a Capture Period
i_{acq}	Acquired Current (Instantaneous)
v_{acq}	Acquired Voltage (Instantaneous)

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Abstract

Because of increased unit cost and lack of adequate power supply there is a trend worldwide to use lesser electricity without hampering comfort and production. But most of the energy saving electrical equipments used by residential and commercial users produce huge harmonics. High levels of harmonics in a power system can create voltage distortion resulting in power quality problems. Environmental concern on electrical power generation and electrical energy cost have diverted users to have more energy efficient systems rather than focussing on power quality. However, power quality indices are required by power utilities to ensure safe operation of the power supply network that essentially include generators, transmission lines and transformers. To address the adverse affects of harmonics generated by energy efficient gadgets, a comprehensive study is conducted in this research to assess the impacts of loads of different combination on the overall power quality of a distributed network. Different loads have been modeled using current waveform templates. A setup has been developed to acquire current waveforms of the different loads. These waveforms are processed and stored as templates for the specified load. These templates are later used in different combinations to determine the overall current waveform of a network. The overall waveform is analyzed for extracting the power quality parameters. A generalized approach is adopted in this work so that users can choose the load combinations and see the load impact on power quality. Few case studies have been conducted utilizing the proposed load models. It is observed that the impact of lighting loads where lamps and tube lights are completely replaced by CFL and Electronic Ballasts, do not significantly affect the power quality. This is because of the lesser share of the lighting loads of the total power in a network.

Chapter 1

Introduction

1.1 Background

Electrical power has become an essential item in everyday life for lighting, cooling, washing etc. and product developments. Electrical power crisis is a general issue in most countries. At present Bangladesh is facing an energy shortage in power sector. The ever increasing demand and the delays in capacity addition widen the gap between the energy demand and supply. As a solution of energy crisis, government is running energy conservation programmes in all sectors. Lighting is a big sector where a large amount of energy is consumed. One of the best method of energy saving in lighting sector is implementing energy efficient lamps.

Because of increased unit cost and lack of adequate power supply there is a trend worldwide to use lesser electricity without hampering comfort and production. In household and commercial applications, loads are mostly lighting, cooling, heating and small motors. Among them, lighting loads are mostly inefficient. Replacement of conventional incandescent lamps with fluorescent lamps are found to save huge amount of electricity. For this reason there is a worldwide trend of banning incandescent lamps. Compact fluorescent lamps (CFL) can easily replace incandescent lamps as the CFL can plug on the lamp holders without any modification.

Moreover, though CFL's are efficient but their initial cost compared to incandescent lamp is very high. But governments and Environmental NGOs encourage the use of energy efficient electronic lighting equipment as a way for consumers to reduce their energy consumption and prevent accelerated climate change. CFLs are being promoted as part of energy conservation programs for many electric utilities [1]. Also manufacturers have introduced simple electronics ballast for florescent lamps. These electronic ballasts having a good power factor and also a lower harmonic distortion compared to energy efficient CFLs become more popular now a days.

According to the International Energy Agency (IEA), lighting end uses consume 19 percent of global electricity consumption. In most developing countries, lighting is the most important use of electricity in the domestic sector, and the evening lighting loads contribute significantly to the local electric utilities peak load. Although the use of modern, energy-efficient lighting technologies has been increasing over the last several years, particularly in the commercial sector, most of the lighting in the domestic sector in developing countries continues to come in the form of incandescent lamps (ILs), which are very energy inefficient when compared to linear fluorescent tube lights (FTLs) and newer lighting technologies such as compact fluorescent lamps (CFL) and light-emitting-diode (LED) based systems. During the last decade, many programs have been sponsored by the World Bank, the International Finance Corporation (IFC), Asian Development Bank (ADB), the United Nations Development Programme (UNDP) and United Nations Environment Programme (UNEP) with support from the Global Environment Facility (GEF) to implement efficient lighting technologies and services in developing countries. Many of the programs are driven by the broader movement of the energy sector development toward climate change mitigation by reducing the energy usage and therefore GHG emissions associated with lighting. However the primary objective in most cases has been to address the peak power shortages and improve reliability of supply. Most of these programs involve the replacement of conventional, energy-intensive incandescent lamps (ILs) with more efficient high-quality CFLs (also referred to as "Energy Saver Lamps") that provide savings of more than 80 percent compared to ILs for the equivalent lighting output (measured in lumens); the CFLs last 5-10 times longer than ILs [2].

The European Commission also together with several national energy agencies and public and private organizations promotes end-use energy efficiency and conservation as a key component of the EU energy policy and the common goal of reducing climate change [2]. The Poland Efficient Lighting Project (PELP) was developed by the International Finance Corporation (IFC) and funded with 5 million USD from the Global Environment Facility (GEF). PELP was designed to greatly increase the sale of CFLs and was implemented in 1995-1998. One of its main components was a demand-side management (DSM) pilot, which was designed to use CFLs to help introduce the concept of DSM to Polish electric utilities [3].

The Republic of South Africa is one of the African countries that has a well developed industrial sector. South Africa covers about 1.22 million square kilometers and there are large areas in between the cities with a sparse population. The country is strengthening the environmental and economic benefits with the desire to ensure that the use of compact fluorescent lamps (CFLs) are in place of standard incandescent lamps. South Africa generates about 51.5 percent of all the electricity generated in Africa but occupies only 4.05 percent of the continent. Eskom is the electricity supply utility that supplies more than half of Africas electricity and about 90 percent of South African electricity. Eskoms Residential Demand Side Management (RDSM) programme is committed to the conservation and preservation of the environment through its Efficient Lighting Initiative (ELI). A central component of RDSM, ELI is a programme that benefited the whole of South Africa through the promotion of energy efficient lighting [4].

An energy crisis in 2008 forced Ethiopias government to review the countrys energy sector. The resulting IDA-funded electricity project helped save Ethiopia an estimated about 100 million US dollar. The government also distributed 5 million CFLs free to consumers in exchange for their incandescent bulbs, creating energy savings of 75 percent. The distribution coincided with a government-run awareness campaign called "Save Energy which highlighted the benefits of saving energy at home and work. Within three months of launching the initiative, with half the bulbs distributed, the Ethiopian Electric Power Corporation (EEPCo) succeeded in reducing peak demand by 80MW Generating this energy using emergency diesel generators.

Globally incandescent lamps are estimated to have accounted for 970 TWh of final electricity consumption in 2005 and given rise to about 560 million metric tonnes of CO2 emissions. About 61 percent of this consumption is in the residential sector with most of the rest in commercial and public buildings. The IEA estimates that incandescent lamps used in the USA and Canada jointly consumed about 350 TWh of delivered electricity in 2005 and gave rise to about 217 million metric tonnes of CO2 emissions. Cuba banned the sale of incandescent lamps and implemented a programme of direct substitution of ILs with CFLs in households. It is understood that this was completed sometime in 2007 making Cuba the first country in the world to have phased-out incandescent lighting. Another 10 Caribbean countries and Venezuela are reported to be implementing similar measures. The government of Australia also held a press conference announcing their intention to phase-out inefficient incandescent lighting by 2011. The Government of New Zealand has since confirmed that they support the policy and will harmonize their requirements with Australia [5].

1.2 Problem Statements

In recent years, concerns about the effects of non linear lighting products on power distribution systems have focussed attention on power quality issues. Due to technological limitations both electronic ballast and CFL's draw non-sinusoidal current with high harmonic contents. Historically, electricity distribution systems were not adequately designed to deal with a great quantity of non-linear loads. Up until now power quality issues associated with CFLs have largely been ignored as the number of these lamps on the system was small and the associated impact is difficult to quantify. However, the situation is likely to change in the near future as large numbers of CFLs penetrate the marketplace and as a result, harmonic emissions may have to be limited. Harmonics pose threat to transformers and transmission-feeder lines and hence the amount of harmonics in high voltage lines are always limited by power utilities as recommended in IEEE/IEC standards. Different utility organizations and individuals have focussed on the impacts of CFL on the overall power quality and other environmental issues.

Now a days power quality is becoming an important issue due to increase number of non linear devices being connected that draw a non sinusoidal current waveform. Many loads connecting to a power system rely on a stable sinusoidal supply voltage. If the power quality is allowed to deteriorate, some equipment that require sinusoidal supply voltage may malfunction or even subject to damage.

Though non-linear loads generate huge harmonics that are primarily responsible for corrupting the supply voltage waveforms, electricity industries allow use of non-linear loads because of their efficiencies and lesser power consumption. Also the deregulation of electricity industry having economic pressures that has caused Demand Side Management. One aspect of demand side management has been the promotion of energy efficient lighting. Most of the power utilities are now encouraging the replacement of incandescent lamp with compact fluorescent lamp changing the magnetic ballast to an electronic ballast to release some power consumption. This type of lighting system also expected the advantage of longer life and hence less maintenance cost. Although electronic ballasts and CFL result in power saving compared to incandescent lamps, they do pollute the power system with harmonics. In order to predict the effect of such technology will have on power quality an analysis must be performed to measure the effect of large number of energy efficient lamp on power quality.

1.3 Research Objective

The objectives of this research are to

i) Develop template based model of non-linear lighting loads like CFL, Electronic Ballasts and Magnetic Ballasts,

ii) Develop an integrated load model containing user defined numbers of different loads for quantifying power quality parameters like THD, PF etc,

iii) Propose load combinations for efficient use of household electric products without affecting utility side power quality.

Chapter 2

Literature Review: Non Linear Lighting Loads and Power Quality Issues

Power supply utilities generate electrical power using synchronous generators where the generated voltage is sinusoidal. After few step up and step down operations, the power is supplied to end users at low voltages except industries and bulk scale users. Use of non-linear loads generate current harmonics that ultimately affect the line and phase voltages. Excess current harmonics causes increased conductor surface heating and higher eddy current loss in transformers. Moreover, harmonic currents add non-linear drop in lines making the supply voltage non-sinusoidal that affect end users. Most electrical systems are designed for linear voltage and current waveforms, excessive nonlinear loads can cause serious problems such as overheating conductors, transformer and capacitor failures as well as malfunction of electronic equipment [6]-[7]. Power companies are therefore worried about deteriorating line/phase voltage waveforms caused by harmonics generated from consumer loads. Harmonics not only affect voltage waveforms but also generate reactive power affecting power factor.

Thus it is necessary to quantify the harmonics present in each type of load and evaluate the power factor. The harmonic contents are usually quantified by total harmonic distortion (THD) index and the power factor affected by harmonics are calculated considering non-sinusoidal waveforms.

2.1 Non-Linear Lighting and Accessories

The replacement of conventional incandescent lamps with energy efficient electronic lighting results in reduction of the overall power consumption of the electrical network and reduction in generated power at the power plants. Because of burning fuels in electrical power plants, there are huge CO2 emissions into the atmosphere. Lesser generation/usage of electricity mean lesser CO2 emission.But electronic lighting equipment is a nonlinear load that will inject harmonics into the supply mains. Different types of non linear lighting loads are used in an electrical network. Most of them are fluorescent type and use electronic ballasts. Compact fluorescent lamps and conventional fluorescent lamps are the most common non-linear lamps in use in our everyday life.

2.1.1 Fluorescent Lighting Technology

The fluorescent lighting may be categorized as a low pressure gas discharge lamp. Fluorescent lighting systems use a gas discharge tube similar to neon signs and mercury or sodium vapor street or yard lights. A pair of electrodes, one at each end are sealed along with a drop of mercury and some inert gases (usually argon) at very low pressure inside a glass tube. The inside of the tube is coated with a phosphor which produces visible light when excited with ultra-violet (UV) radiation [10].

During off condition, the mercury gas mixture is non-conductive. When powered on, a high voltage (several hundred volts) is needed to initiate the discharge. However, once this takes place, a much lower voltage usually under 100 V for tubes under 30 watts, 100 to 175 volts for 30 watts or more is needed to maintain it. When a potential is applied across the electrodes of the tube, free electrons are emitted from the electrodes and bombard the mercury atoms. The collision between the electrons and the mercury atoms result in heat generation, excitation of the mercury atoms and its molecules, and the ionization of the mercury atoms. Heat generation and the subsequent increase of the gas temperature is the result of elastic collisions that occur between the free electrons and the mercury atoms.

The excitation of the mercury atoms and molecules is the result of collisions between the free electrons and the mercury atoms which cause electrons belonging to the mercury atom to move to a higher energy level. The ionization of the mercury atoms is the result of collisions between the free electrons and mercury atoms which cause an electron of the mercury atom to be completely removed from its orbit and subsequently become a free electron. The main factors which determine the radiation of the two UV resonance lines are the mercury vapor pressure, the auxiliary gas, the current density, and the discharge tube dimensions. The fluorescent tube consist of a small amount of mercury necessary for the discharge in the lamp to occur. If the vapor pressure is too low, the probability that the mercury atom is excited by a free electron decreases and results in a lower luminous output of the lamp. If the vapor pressure is too high, the self-absorption of the UV resonance lines increases and also results in a lower luminous output [9]. When collisions between the free electrons and mercury atoms occur, the electrons travel a certain distance. If the auxiliary gas pressure is too low, the probability of the excitation of the mercury atoms decreases. If the auxiliary gas pressure is too high, the number of elastic collisions between the free electrons and the auxiliary gas increases and draws energy from the UV producing collisions between the free electrons and the mercury atoms [10].

2.1.2 Conventional Fluorescent Lamps

The basic construction of a fluorescent tube consist of the discharge tube, the fluorescent powder, the electrodes, the filling, and the end-caps. The discharge tube is cylindrical in form and serves to contain the filling gas and electrodes. The tube is constructed out of lime glass for straight-tube configurations (e.g. 24″, 48″, and 96″ lengths) and lead glass for bent-tube configurations (e.g. Circular and CFLs). Fluorescent lighting system consists of two or three main components:

i) The fluorescent lamp,

ii) The Ballast, and

iii) the Starter system.

Depending on the particular fluorescent lighting system, the starter may be a replaceable component, a starter may not be required, or the starter function may be integrated into the ballast. The starting function may also rely on the physical design of the fixture [10].

The basic concept behind a fluorescent lamp is that a flow of electrical current occurs between two metal conductors placed in a glass tube, a process also known as arcing. That current flow passes through the gases in the tube (argon and a small amount of mercury in a gaseous phase) and excites the atoms of gas. The excited atoms emit photons, some of which are vibrating at a frequency known as ultraviolet light. The ultraviolet light strikes a phosphor coating on the inside of the glass. The phosphor responds to the ultraviolet light by producing a bright visible light.The fluorescent powder which coats the inner surface of the discharge tube serves to convert UV produced by the discharge of the lamp into visible light. The visible light produced by the fluorescent powder, otherwise known as luminescence, can be subdivided into the fluorescence and phosphorescence properties of the powder. Fluorescence can be described as the light produced only when the fluorescent powder is being irradiated by the W radiation produced by the low pressure mercury discharge of the lamp. Phosphorescence can be described as the afterglow produced by the fluorescent powder after it has been irradiated. It is required that the fluorescent powder used have the latter property due to the “dark period” which occurs in fluorescent lamps supplied by an alternating voltage source (e.g., 50 or 60 Hz). When the instantaneous voltage supplying the lamp is below a point where an arc across the electrodes can no longer be produced, current no longer flows through the tube and no W radiation is emitted.

For a fluorescent lamp to start working, the potential of the electricity provided to the electrical conductors (called cathodes) inside the lamp must be greater than the initial electrical resistance of the gas in the lamp so that the electricity may begin arcing through the gas. There are two ways to overcome this initial electrical resistance:

i) Lower the electrical resistance of the gas in the lamp, or

ii) temporarily raise the electrical potential supplied to the lamp to a level greater than the resistance of the gas, so that arcing may begin. The Starter (or if absent, the Ballast) creates either or both of these conditions to start the lamp.

In fact, up to half of the wiring in some fluorescent fixtures is used only while starting the lamps.

Though discharge lamps (fluorescent, high intensity discharge etc.) are characterized by a high luminous efficiency and provide significant energy saving if compared to the incandescent lamps. These lamps inject harmonic currents into power systems as all non-linear loads. Their ballast and their arc tube can be an important source of higher-order harmonic components of current [22]. The harmonic currents pass through the impedance of the system and cause a voltage drop for each harmonic. This results in voltage harmonics appearing at the load bus and consequently it influences the quality of the supplied power as well as the electrical appliances.

The heart of every fluorescent lamp is its ballast. The ballast consists of a wire winding on an iron core, which reduces and regulates the voltage that flows through it. Electrical current enters the lamp through the ballast. From there, it flows through wiring to lamp holders, and ultimately, to cathodes within the tube. However, more power is required to start a fluorescent lamp than to maintain it. The starting circuit that sends increased current through the cathodes to heat their coated filaments. The heated cathodes send a high-voltage pulse along the tube that creates an arc through the mercury vapor. As the atmosphere inside the tube heats up, electron activity increases to its most efficient, ballast-sustained level and the mercury vapor carries the current on its own. The starting circuit is controlled by a starter switch that opens after a short preheat period.

2.1.3 Electromagnetic Ballasts

Electromagnetic ballasts consists of a wire wound coil connected in series with the lamp is available for use with conventional and compact fluorescent lamps. Magnetic (sometimes called Inductive) ballasts contain an electrical choke, which is a specially wound coil of wire. Since electrical current flowing through a wire generates a changing magnetic field around the wire, and a changing magnetic field generates electrical current in wires within that magnetic field, a ballast uses these opposing magnetic forces to limit the amount of electrical current that can pass through the coils inside. As the current flow through the ballast increases, the coils inside the ballast generate a stronger magnetic field that opposes the flow of current that is trying to pass through the ballast to the lamps. This interaction achieves a balance and limits the total current flow to the lamps to a specific amperage [11].

In addition the current limiting, an additional set of windings may exist inside the ballast that step-up or step-down the line input voltage to the levels needed to operate the lamps. This may be a discrete transformer, or be integrated into the current limiting section of the ballast.

Electromagnetic ballasts are also responsible for both the generation and limitation of harmonic current. Harmonic current is generated by the ballast due to its nonlinear magnetic characteristics but is also limited by the ballast due to its inductive nature.

2.1.4 Electronic Ballasts

Electronic ballasts consist of solid state devices used to create a high frequency ac voltage supplied to the lamp. The line voltage supplied to the ballast is converted into a dc voltage using a full-wave bridge rectifier and a filter capacitor. Unlike the electromagnetic ballast which supplies the lamp with a line frequency urgent of 50160 Hz, the electronic ballast provides the lamp with 25 to 50 Hz frequency current using an inverter [12]. There are a number of advantages of using an electronic ballast as opposed to an electromagnetic ballast. These devices are basically switching power supplies that eliminate the large, heavy, ‘iron’ ballast and replace it with an integrated high frequency inverter/switcher. Current limiting is then done by a very small inductor, which has sufficient impedance at the high frequency. Properly designed electronic ballasts should be very reliable. Whether they actual are reliable in practice depends on their location with respect to the heat produced by the lamps as well as many other factors. Since these ballasts include rectification, filtering, and operate the tubes at a high frequency, they also usually eliminate or greatly reduce the 100 or 120 Hz flicker associated with iron ballasted systems. However, this is not always the case and depending on design (mainly how much filtering there is on the rectified line voltage), varying amounts of 100 or 120 can still be present [13].

There are also disadvantages of using an electronic ballast as opposed to an electromagnetic ballast. Because the electronic ballast incorporates a bridge rectifier filter capacitor combination to convert the supply ac voltage into a dc voltage, a large amount of current distortion is injected into the voltage supply. The relatively small conduction time of rectifier filter capacitor combination creates a current waveform which is rich in odd harmonics and also has a relatively high crest factor.

2.1.5 Compact Fluorescent Lamps

Compact fluorescent lamps (CFLs) were introduced in the early 1980’s, promoting energy efficiency and long lamp life as compared to incandescent lighting. Available for the commercial, industrial, and residential markets, CFLs are available in a variety of shapes and sizes for both new and retrofit applications. Compact fluorescent lamps offer the energy-efficiency of the conventional fluorescent lamp, while having physical dimensions and luminance characteristics comparable to that of the incandescent lamp.

The compact fluorescent lamps are proved energy efficient lighting load as compared to incandescent light loads. It is clear that the use of CFL will cut down the energy demand for lighting approximately by one fifth. But widespread use of these lamps will introduce harmonics in the distribution network. Compact fluorescent light bulbs (CFLs) use at least 60 percent less electricity than the traditional incandescent lamps while lasting ten to twelve times as long and can therefore deliver substantial savings in terms of both electricity and money.CFLs represent only 5 percent of the lamp market in the residential sector [14].

CFLs are fed by power supply units which conduct the current only during a very small part of the 50 or 60 Hz period so that the current taken from the AC net has the shape of a short impulse. The remaining part of the sine wave is returned to the AC network producing distortion of the current wave of the supply system. The distorted current wave can be analyzed using the Fourier

Theorem and thus be represented by the fundamental sinusoidal component and a series of higher order harmonic components at frequencies that are integer multiples of the fundamental frequency, normally called "harmonics".

High harmonic distortion is the main reason that utilities hesitate to advocate increased use of CFLs. They focus mainly on the high relative current distortion. It is true that for CFLs, the relative current distortion expressed in percent of the fundamental may exceed 100 percent. However, since fundamental current is very low, the values of harmonic currents are very low too. It is a important factor that using CFLs reduces the total current in the distribution system.

So worldwide CFL lamp use increasing day bay day. But with their many benefits, CFLs having this unfortunate side effect on power quality. As a non linear load, CFLs draws current in non sinusoidal manner, rich in harmonic components. These harmonics flow through the power system where they can distort the supply voltage, overload electrical distribution equipments. In order to prevent harmonics negatively affecting the utility supply IEEE Std 519 was established [6].

CFLs are found in many types of physical configurations. One type is the single-ended twin-tube which is a U-shaped tube with filaments on both ends. Another type is the single-ended quad-tube which is similar to the twin-tube except that it consist of twice of the number of tubes. The twin- and quad-tube configurations are commonly found in $112''$ and $518''$ diameters (designated as "T4" and "T5" sizes, respectively) and have two-pin bases for connection to the ballast. Other types of CFL include square-shaped, globe-shaped, reflector, and Circline configurations. Due to the vast number of possible of combinations of lamp shapes, powers and base types, America's National Electrical Manufacturers Association (NEMA) has developed a generic designation system for non-integral CFLs [13]. The NEMA lamp product code for CFLs consists of the following elements:

$$CFL = [LS][LP]/[BD] \tag{2.1}$$

where, [LS] represents lamp shape that may be "T" (twin-tube), "Q" (quad-tube), "S" (square shape), or "M" (miscellaneous shape not covered by the other designators), [LP] represents power consumed by lamp, and [BD] represents manufacturer base designation code.

One of the reasons for the high efficacy of CFLs is the rare earth (RE) phosphors used in the fluorescent powder used to coat the tube. These RE phosphors are able to produce high lumen output from CFLs which have a high power density in the small diameter tube used. The use of conventional RE phosphors in CFLs would lead to a rapid and severe depreciation in luminance of the lamp. The RE phosphors used in CFLs also have excellent color rendering properties and various color temperatures which are obtainable by combining these phosphors. CFLs are available in several color temperatures for incandescent retrofit applications and special effect lighting applications [15].

But the main disadvantage of compact fluorescent lamps (CFL) is it exhibit the highest harmonic distortion among the discharge lamps. Their total harmonic distortion (THD) is usually higher than 100 percent. The international standard IEC 61000-3-2 requires that the 3rd and the 5th current harmonic shall not exceed 86 percent and 61 percent of the fundamental respectively [23]. ANSI defines a limit of 32 percent [24] as the maximum current THD of lamps with electronic ballast. This standard also specifies the limit of the magnitude of all high-order harmonics to 30 percent of the fundamental magnitude. The upper limit is defined as 7 percent of the fundamental for all higher than the 11th order harmonics. The limit of the current THD of electronic ballasts is 20 percent.

2.1.6 Electrode-less Fluorescent Lamps

One of the main causes of failure of fluorescent lamps is the degradation of lamp electrodes. Also, the glass-metal bonds required to introduce connections to lamp electrodes are costly and sometimes difficult to manufacture. For these reasons, an electrode-less design was developed for fluorescent lighting. Referred to as the H-discharge method, the electrode-less design incorporates a lamp tube surrounded by an air-core coil. This coil is supplied by a high-frequency (e.g., 1-100 MHz) power source which produces an electromagnetic field inside the lamp tube. This field causes the mercury vapor in the tube to ionize and subsequently phosphors produce luminous output. Similar to the electronic ballast CFL, the electrode-less fluorescent lamp is a compact electronic ballast mercury discharge light source. The electrode-less fluorescent consumes approximately the same power as a typical CFL (approximately 25 watts), while producing a comparable luminous output (approximately 1,000 lumens). The advantage of the electrode-less design is the relative long-life due its lack of electrodes. The power source for the electrode-less lamp comprises a rectifier inverter circuit, similar to that of the CFL, to generate the high-frequency RF current required by the lamp. In 1994, electrode-less designs are expected to be introduced commercially [16].

2.2 Power Quality Issues

The number of nonlinear lighting loads in homes, commercial complexes and offices have increased rapidly over the past 20 years. These types of lighting have raised the standard of living and are more efficient than conventional lamps. Electronic devices such as lighting ballasts, electronic light dimmers and many other devices that have electronic controls, cause distortion in output current. But quality regulated power supplies are intended for distributed networks. As the use of energy is increasing, the requirements for the quality of the supplied electrical energy are more tighten. Most power supplies are designed to meet regulated output, isolation and multiple outputs system. Regulation means that the output voltage must be held constant within a specified tolerance for changes within a specified range in the input voltage and the output loading. Isolation is needed when the output may be required to be electrically isolated from the input. There may be multiple outputs that may differ in their voltage and current ratings. Such outputs may be isolated from each other. Beside these requirements, common goals are to reduce power supply size and weight and improve their efficiency. Traditionally, linear power supplies have been used in the distributed networks. Linear power means unity power factor and no equipment injecting electrical noise into the power system. For purposes of assessing the impact of nonlinear lighting, it is convenient to examine power factor and the various IEEE standards relating to power quality.

2.2.1 Harmonics and Power Quality Standards

Harmonics are defined simply as unwanted frequency components on the source power generated by the loads. Harmonics cause equipment malfunction, equipment failure, unnecessary high operating costs and in some cases fires. Harmonics are created when electronic devices draw current in a non-linear fashion. This causes “Line Voltage Distortion”, which is an irregularity in the shape of the voltage waveform. Voltage Distortion produces such effects as motors prematurely burning out, clocks running fast, computers freezing up and system crashes. The percentage of harmonics in a waveform is called THD (total harmonic distortion). As the THD increases, the efficiency of the system is greatly reduced. The ever expanding application of power electronics load and increasing dependency upon energy saving electronics lighting equipments has produced serious concern about power quality. The term Power quality broadly refers to maintaining a waveform close to sinusoidal waveform of bus voltage magnitude and frequency. The standard organization IEEE guides references for power quality issues.

Although distortion problems happen particularly in the final customer, this problematic issue has other implications to be considered the production, propagation and resolution of this type of disturbances. The harmonics increasing disturbances brought a set of standards (resulting from previous guidelines), recommendations and limits, to assure the compatibility between equipment, devices and power distribution systems . When a equipment draws current from the utility in a nonlinear or choppy manner, this is called current distortion. It always produces harmonics in the load current waveform and can produce significant harmonics in the voltage waveform at the PCC and elsewhere. The harmonic distortion of voltage and/or current waveform corresponds to a specific case in the power quality problematic issues. In the proposed network that have current and voltage harmonic sources (CFL, FL run by EB) may exceed the permissible limits [19]-[6]. Typically, the standard limits are applied to individual loads. Nevertheless, monitoring all the loads is a strong challenge as IEEE Std 519 limits for current distortion. But we can assume for all lighting, motor drives, power supplies, and other equipment sharing a common electrical bus or panel with sensitive electronic loads THD value limits 15 percent.

According to the International Standards, the norms 1000 of the International Electrotechnical Commission (IEC) define the current and voltage harmonic levels that must not to be exceeded. The IEC 61000-3-2 Standard foresees limits for the current harmonics components emission in equipment (class grouped) for lesser than 16A RMS (per phase). For equipment with current superior to 16 A, this Standard recommends the application of the IEC 61000-3-4.Norms IEC-1000-

2-2 and IEC-1000-2-4 specify the voltage harmonic levels to be respected at the interconnection point of low voltage distribution network, for public and industrial customers, respectively.

The European Standard gives the main characteristics of the voltage, including harmonics voltage, in the customer delivery point for low and medium voltage under normal operating conditions [20].

However, the main reference for this subject is the American Standard that was presented by the IEEE in the recommendation 519-1992: IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, initially proposed in 1981 and revised in 1992 [6]. The standard recognizes the responsibility of an electricity user to not degrade the voltage of the utility by drawing heavy nonlinear or distorted current. It also recognizes the responsibility of utility to provide users with a near sine wave voltage. According to IEEE Std 519, harmonic voltage distortion of power systems 69KV or below is limited to five percent with each individual limits of three percent. The current harmonics limits very based on short circuit strength of the system their being inject to. Essentially, the more the system able to handle harmonic currents, the more the customers allowed to inject [6].

The widespread use of static rectification equipment in industrial loads on small and medium power transformers has resulted in a dramatic increase in the harmonic content of the load current for this equipment. It is quite common for the harmonic factor of the current to exceed 0.05 per unit, which is the limit specified for usual service conditions in IEEE Std C57.12.00-1993 and IEEE Std C57.12.01-1998. It is also well known that higher harmonic content in the current causes higher eddy current loss in winding conductors and structural parts linked by the transformer leakage flux field and, consequently, higher operating temperatures [21].

IEEE Std C57.110-1998 (Revision of IEEE Std C57.110-1986) describes transformer derating for harmonic loads. This recommended practice set forth by the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (IEEE) establishes two methods for the current derating of power transformers when connected to loads which consume non-sinusoidal currents. The standard applies to non-sinusoidal load currents which have a harmonic load factor (which is defined as the ratio of the effective value of all the harmonics to the effective value of the fundamental harmonic) greater than 0.05 per unit.

2.2.2 The Requirements of IEEE-519-1992

IEEE-519-1992 describes the recommended practices and requirements for Harmonic Control in Electrical Power Systems. The scope of IEEE-519-1992 is clearly stated as the intention of establishing goals for the design of electrical systems that include both linear and non-linear loads. The document describes the voltage and current waveforms that may exist throughout the system and establish waveform distortion goals. It defines the interface between sources and loads as the point of common coupling with observances of the design goals to minimize interference between electrical equipment.

It is the responsibility of any reputable equipment supplier to provide their customers with equipment, at the best possible cost per performance ratio, that will meet the known operating requirements of the Page 1 of 4 customer. Included with the purchase of that equipment are the less tangible but equally important application experience that the supplier can share with the customer. Lastly, the equipment supplier should be able to supply any necessary service and application support directly associated with the performance of that equipment and its impact on other electrical equipment utilizing the same point of common coupling.

The generation of harmonics in a power system can be attributed to the use of rectifiers, arc furnaces, static VAR compensators, inverters, electronic phase controllers, cyclo-converters, switched mode power converters, and pulse width modulated drives, as defined in IEEE Standard 519-1992. All of these devices may cause harmonics in the voltage and or current wave shape provided by the utility. In the case of devices containing solid state components to achieve switching, voltage harmonics can be attributed to voltage notching due to commutation periods while current harmonics can be attributed to discontinuous conduction due to the switching of the solid state components. The system response characteristics to harmonic loads on a distribution system determines the effect of these loads. The flow of harmonic currents in a distribution network is dependent on the system short-circuit capacity, the placement and size of capacitor banks, the characteristics of the loads on the system, anti finally, the balanced or unbalanced conditions of the system.

IEEE Standard 519-1992 provides recommended practices for harmonic control for both the utility and individual customer. Because of the wide range of harmonic- producing loads described above, three harmonic indices have been recommended for the individual customer to provide a meaningful insight of harmonic effects [6].

These indices include:

i) Depth of notches, total notch area, and distortion of bus voltage distorted by commutation notches (low-voltage systems),

ii) Individual and total voltage distortion, and

iii) Individual and total current distortion.

Voltage Notching Whenever ac voltage is rectified to dc with solid state switching devices, a phenomenon called commutation notching can occur. The duration of these notches in each ac voltage cycle is typically only a few microseconds, but they can last longer and cause equipment malfunction or resonance with attendant damage or loss to neighboring electrical equipment or the processes they control.

Current Distortion When a customers equipment draws current from the utility in a nonlinear or choppy manner, this is called current distortion. It always produces harmonics in the load current waveform and can produce significant harmonics in the voltage waveform at the PCC and elsewhere. The distribution side having responsibility to provide quality voltage to all its customers. If customers keep their voltage notching and current distortion within the limits, this will allow distribution to provide this service. Specifically, this service is defined as voltage having distortion levels within the limits.

Here are the tables for voltage (Table 2.1) and current (Table 2.2) harmonics distortion limits recommended by IEEE Std 519-1992.

Table 2.1: Voltage distortion limits in IEEE Std. 519-1992.

Voltage Distortion Limits for General Distribution Systems		
Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5
NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.		

Table 2.2: Current distortion limits in IEEE Std. 519-1992.

Current Distortion Limits for General Distribution Systems (120 V Through 69000 V)						
Maximum Harmonic Current Distortion in Percent of IL						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	< 11	$11 \geq h < 17$	$17 \geq h < 23$	$23 \geq h < 35$	$35 \leq h$	TDD
$< 20*$	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of the odd harmonic limits above. Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed. * All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L.						
Where I_{SC} = maximum short-circuit current at PCC. I_L = maximum demand load current (fundamental frequency component) at PCC. TDD = Total demand distortion, harmonic current distortion in % of maximum demand load current (15 or 30 min demand). PCC = Point of common coupling.						

2.3 Power Quality Parameters

The supply voltage for household and commercial applications deteriorate from sine wave because of load current harmonics. Considering a supply voltage of $v(t)$, the harmonic contents are evaluated using Fourier series. The Fourier components are

$$\begin{aligned} v(t) &= \frac{a_0^v}{2} + \sum_{n=0}^{\infty}\{a_n^v \cos(n\omega t) + b_n^v \sin(n\omega t)\} && (2.2)\\ &= \frac{a_0^v}{2} + \sum_{n=0}^{\infty} c_n^v \sin(\omega t + \theta_v) && (2.3)\end{aligned}$$

where,

$$\begin{aligned} a_0^v &= \frac{1}{2\pi}\int_0^{2\pi} v(t) d\omega t && (2.4)\\ a_n^v &= \frac{1}{\pi}\int_0^{2\pi} v(t)\cos(n\omega t) d\omega t && (2.5)\\ b_n^v &= \frac{1}{\pi}\int_0^{2\pi} v(t)\sin(n\omega t) d\omega t && (2.6)\\ c_n^v &= \sqrt{(a_n^v)^2 + (b_n^v)^2} && (2.7)\\ \theta_v &= \tan^{-1}\frac{a_n^v}{b_n^v} && (2.8)\end{aligned}$$

Similarly, the load current harmonics can be evaluated using Fourier series as follows:

$$\begin{aligned} i(t) &= \frac{a_0^i}{2} + \sum_{n=0}^{\infty}\{a_n^i \cos(n\omega t) + b_n^i \sin(n\omega t)\} && (2.9)\\ &= \frac{a_0^i}{2} + \sum_{n=0}^{\infty} c_n^i \sin(\omega t + \theta_i) && (2.10)\end{aligned}$$

where,

$$\begin{aligned} a_0^i &= \frac{1}{2\pi}\int_0^{2\pi} i(t) d\omega t && (2.11)\\ a_n^i &= \frac{1}{\pi}\int_0^{2\pi} i(t)\cos(n\omega t) d\omega t && (2.12)\\ b_n^i &= \frac{1}{\pi}\int_0^{2\pi} i(t)\sin(n\omega t) d\omega t && (2.13)\\ c_n^i &= \sqrt{(a_n^i)^2 + (b_n^i)^2} && (2.14)\\ \theta_i &= \tan^{-1}\frac{a_n^i}{b_n^i} && (2.15)\end{aligned}$$

2.4 Power Quality in Discrete Time Domain

Continuous time acquisition of voltage and current needs analog circuits to assess the power quality. Use of analog circuits are prune to drift because of bias and temperature problems. Moreover, storing information in analog domain is a tedious task and hence are discarded in present times. Use of discrete time voltage and current does not affect significantly the resolution of power quality parameters. Hence acquisition of voltage and current in discrete time using sampling analog-to-digital converter is a common practice in evaluating power quality parameters.

In discrete time domain considering N samples per cycle with a sampling time of τ , the Fourier components can be evaluated by replacing the continuous time equations in sampled form as follows:

$$\begin{aligned} v(k) &= \frac{a_0^v}{2} + \sum_{n=0}^{\infty}\{a_n^v \cos(n\omega k\tau) + b_n^v \sin(n\omega k\tau)\} && (2.16) \\ &= \frac{a_0^v}{2} + \sum_{n=0}^{\infty} c_n^v \sin(n\omega k\tau + \theta_v) && (2.17) \end{aligned}$$

where,

$$\begin{aligned} \tau &= \frac{2\pi}{\omega N} && (2.18) \\ a_0^v &= \frac{1}{N}\sum_{k=1}^{N} v(k) && (2.19) \\ a_n^v &= \frac{1}{N}\sum_{k=1}^{N} v(k)\cos(n\omega k\tau) && (2.20) \\ b_n^v &= \frac{1}{N}\sum_{k=1}^{N} v(k)\sin(n\omega k\tau) && (2.21) \\ c_n^v &= \sqrt{(a_n^v)^2 + (b_n^v)^2} && (2.22) \\ \theta_v &= \tan^{-1}\frac{a_n^v}{b_n^v} && (2.23) \end{aligned}$$

Similarly, the load current harmonics can be evaluated using discrete Fourier series as follows:

$$\begin{aligned} i(k) &= \frac{a_0^i}{2} + \sum_{n=0}^{\infty}\{a_n^i \cos(n\omega k\tau) + b_n^i \sin(n\omega k\tau)\} && (2.24) \\ &= \frac{a_0^i}{2} + \sum_{n=0}^{\infty} c_n^i \sin(n\omega k\tau + \theta_i) && (2.25) \end{aligned}$$

where,

$$\begin{aligned} a_0^i &= \frac{1}{N}\sum_{k=1}^{N} i(k) && (2.26) \\ a_n^i &= \frac{1}{N}\sum_{k=1}^{N} i(k)\cos(n\omega k\tau) && (2.27) \\ b_n^i &= \frac{1}{N}\sum_{k=1}^{N} i(k)\sin(n\omega k\tau) && (2.28) \\ c_n^i &= \sqrt{(a_n^i)^2 + (b_n^i)^2} && (2.29) \end{aligned}$$

$$\theta_i = \tan^{-1} \frac{a_n^i}{b_n^i} \tag{2.30}$$

Evaluation of Fourier components using the discrete Fourier series require huge computations. Discrete Fourier Transform (DFT) can be used to compute the Fourier components utilizing scaling factor of half the series length. Standard FFT algorithm are available for computing DFT.

Representing v and i arrays in discrete domain as

$$v = v(1), v(2), \cdots v(N) \tag{2.31}$$

$$i = i(1), i(2), \cdots i(N) \tag{2.32}$$

The Fourier components and the DFT samples are related by

$$c^v = \frac{2}{N}|FFT(v)| \tag{2.33}$$

$$c^i = \frac{2}{N}|FFT(i)| \tag{2.34}$$

$$\theta_v = \angle FFT(v) \tag{2.35}$$

$$\theta_i = \angle FFT(i) \tag{2.36}$$

So the total power consumption can be evaluated in discrete domain as

$$P = \frac{1}{N}\sum_{k=1}^{N} v(k)i(k) \tag{2.37}$$

Chapter 3

Template Based Modeling of Loads

For developing effective models of the different types of loads, it is necessary to acquire current waveforms of the different loads. Since, load current usually affects the supply voltage, distorted current waveforms would also affect the voltage waveform. To make the load model more practical, voltage waveforms are also captured along with current waveforms.

Once the voltage and current waveforms are captured for a particular load, it is possible to model the load either using a higher order polynomial or using waveform template. Load modeling using high order polynomial is computation intensive and also lossy in nature, whereas, model as a waveform template is exact in nature however requires high memory space. In this research we adopted template based model and stored the representative waveform of any load of fixed number of samples in a cycle.

Acquisition of voltage and current are performed using Advantech USB4711A Data Acquisition Module. High precision (0.1 accuracy class) mini-CT's and mini PT's are used to fed the current and voltage to the DAQ Module. Each time few cycles voltage/current are acquired and stored in memory. One cycle data is extracted from the acquired waveform, processed without affecting frequency components, and then stored in ASCII form to be used as the template.

3.1 Experimental Setup of Data Acquisition

A data acquisition setup shown as in Fig. 3.1 is developed using Advantech 4711A module, a Laptop PC, mini CT, PT and necessary lighting loads. Any combination of lighting loads can be connected to the single phase supply mains. The load current and supply voltage (stepped down by PT) are scaled and isolated, and then applied to two analog channels of the DAQ module. The Advantech 4711A DAQ module has easy interface with the PC through USB port and supports 150 kilo samples per second sampling rate (maximum).

A graphic user interface software is developed using Visual Basic .Net that captures the voltage and current waveforms utilizing Advantech's dynamic linking library (DLL) routines. The software program stores the raw data in a text file and voltage, current, power, THD, PF etc in an SQL-Server database. The raw data text file is processed from Matlab to generate the waveform templates.

3.2 Template Extraction

The supply voltage always contain less harmonics than load current. Hence, the templates for all types of loads are taken with positive zero crossing of the supply voltage as reference. The current waveform for any type of load is captured along with the supply voltage waveform. The template is chosen between consecutive positive zero crossing points.

Considering N_T samples in a capture period, the acquired samples are sequences of length N_T as shown in (3.1) and (3.2).

$$v_{acq} = \{v_{acq}(n)\}_{n=1}^{N_T} \tag{3.1}$$

$$i_{acq} = \{i_{acq}(n)\}_{n=1}^{N_T} \tag{3.2}$$

The positive zero crossings and samples in one cycle are obtained from the v_{acq} and i_{acq} sequences. At first step, the value of ZCF is zero. This value of ZCF will increases by one if the value of $v_acq(n-1)$ is smaller than zero and $v_acq(n)$ is greater than zero, that is

$$ZCF = ZCF + 1 \quad (\text{if}, v_{acq}(n-1) < 0 \text{ and } v_{acq}(n) > 0) \tag{3.3}$$

When the value of ZCF is increased to one, the sample number is stored in a variable C1. Again, for the next increment of the value of ZCF sample number is stored in variable C2. Finally, the sample length for one cycle can be found from following equation,

$$N = C2 - C1 + 1 \tag{3.4}$$

$$v_{template} = v_{acq}(C1 : C2) \tag{3.5}$$

$$i_{tmp} = i_{acq}(C1 : C2) \tag{3.6}$$

The flag ZCF keeps track of the number of zero crossings. At the first zero crossing ($ZCF = 1$), the sample number is stored in a counter C1 and at the 2nd zero crossing $ZCF = 2$, the sample number is stored in counter C2. The difference between C2 and C1 gives the total number of samples in a cycle.

$$N = C2 - C1 + 1 \tag{3.7}$$

The voltage and current templates are obtained from

$$v_{tmp} = \{v_{tmp}\}_{n=1}^{N} \tag{3.8}$$

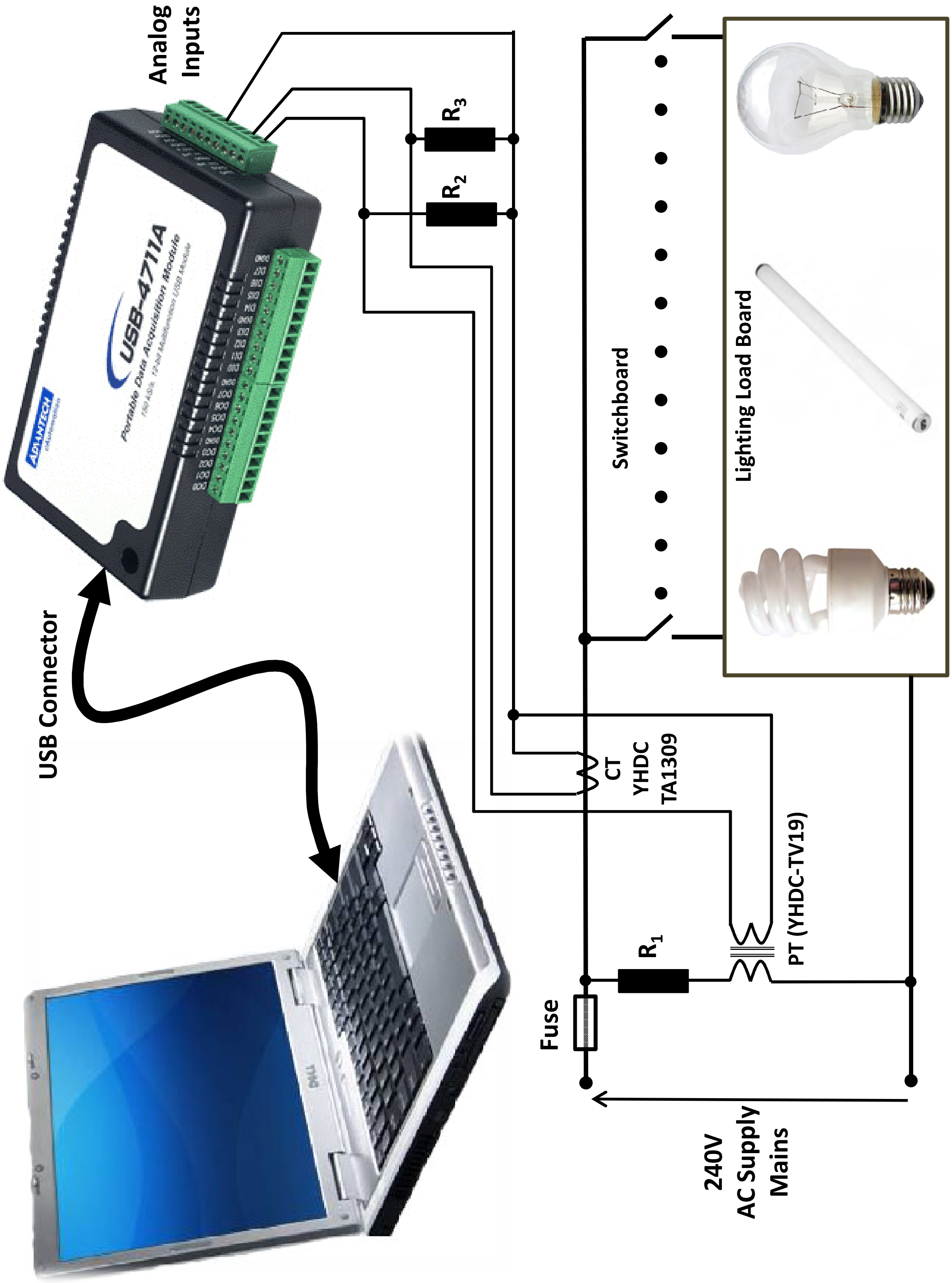

Figure 3.1: Experimental setup for data acquisition of current and voltages from a single phase network.

$$\begin{aligned} &= \{v_{acq}\}_{C1}^{C2} \qquad (3.9) \\ i_{tmp} &= \{i_{tmp}\}_{n=1}^{N} \qquad (3.10) \\ &= \{i_{acq}\}_{C1}^{C2} \qquad (3.11) \end{aligned}$$

Data acquisition is done at high sampling rate (25kHz per channel) and templates for different loads cannot be taken simultaneously. Since supply frequency does not remain constant over time, with fixed sampling rate, the data samples in a cycle will vary with frequency change.

Template based model need equal number of samples in each cycle. But achieving equal number of samples with conventional data acquisition systems is not feasible. However, data sample lengths are made equal from unequal sequences using a new method. The method rearranges the sequence without affecting the harmonic distribution and THD of the original acquired waveform.

3.2.1 Power from Templates

The power for any number of particular load (like CFL, FL with Electronic Ballast, FL with Magnetic Ballast) can be obtained from

$$P_{load} = \frac{1}{N}\sum_{n=1}^{N} v_{tmp}(n) i_{tmp}(n) \qquad (3.12)$$

For any mixed combination, the power can be calculated as

$$\begin{aligned} P_{mixedload} &= \frac{1}{N}\sum_{n=1}^{N} v_{tmp}(n)\left[n_{CFL} \times i_{CFL}(n) + n_{EBFL} \times i_{EBFL}(n)\right. \\ &\quad \left. + n_{MBFL} \times i_{MBFL}(n) + \ldots\right] \qquad (3.13) \end{aligned}$$

3.2.2 Total Harmonic Distortion and Power Factor

The power for any number of particular load (like CFL, FL with Electronic Ballast, FL with Magnetic Ballast) can be obtained from

$$\begin{aligned} THD &= \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \cdots}}{I_1} \qquad (3.14) \\ &= \frac{\sqrt{I_{rms}^2 - I_1^2}}{I_1} \qquad (3.15) \\ I_{rms} &= \sqrt{\frac{\sum_{n=0}^{\infty} I_n^2}{N}} \qquad (3.16) \\ I_1 &= \frac{1_{spectrum}(2)}{\sqrt{2}} \qquad (3.17) \\ I_{spectrum} &= \frac{2}{N}|FFT(i)| \qquad (3.18) \end{aligned}$$

The power factor is computed using

$$pf = \frac{P}{V_{rms}I_{rms}} \tag{3.19}$$

$$= \frac{\frac{1}{N}\sum_{n=1}^{N} v_{tmp}(n)i_{tmp}(n)}{V_{rms}I_{rms}} \tag{3.20}$$

3.3 Equalizing Per-Cycle Sample Sequences

Equalizing the number of samples in each cycle is done by a Matlab program. We know, the flag ZCF that keeps track of the number of zero crossing. The total number of the samples in a cycle is the difference between the first zero crossing number to the second zero crossing number. The sample lengths are not equal for different data sequences as the supply frequency do not remain steady all time. To equalize the length of sample data, voltage and load current of the sample sequences are converted in frequency domain.

The highest value of the data sample length is taken as an ideal value. To equalize the length of sample data, a number of zero valued samples are inserted in frequency domain in between the analogous cycles. Inverse FFT is done to return the sample in time domain. If the total sample number is odd then the value of the sample in the middle remains unchanged. Otherwise imaginary value may contains in further calculation. The total method is explained in the next subsection.

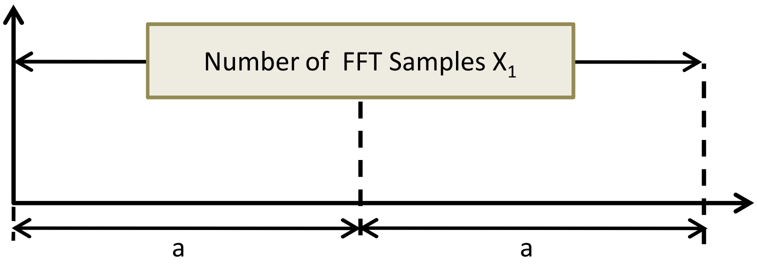

Figure 3.2: Frequency domain sample sequences.

Considering a sample sequence having $X1$ number of samples and the ideal value of the sample is $X2$ where

$$X_1 = 2a \tag{3.21}$$

Also $2b$ is the number of inserted zero valued samples,

$$2b = X_2 - X_1 \tag{3.22}$$

These zero valued samples are inserted after a number of samples.

For odd number of samples,

$$X_1 = (2a + 1) \tag{3.23}$$

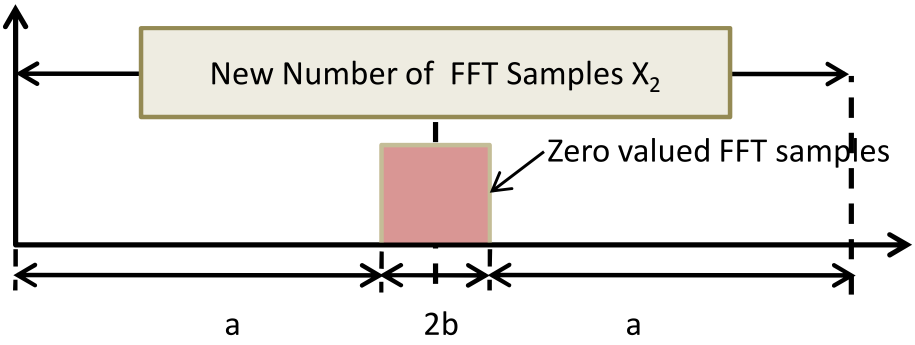

Figure 3.3: New value of frequency domain samples for even number of samples in a cycle.

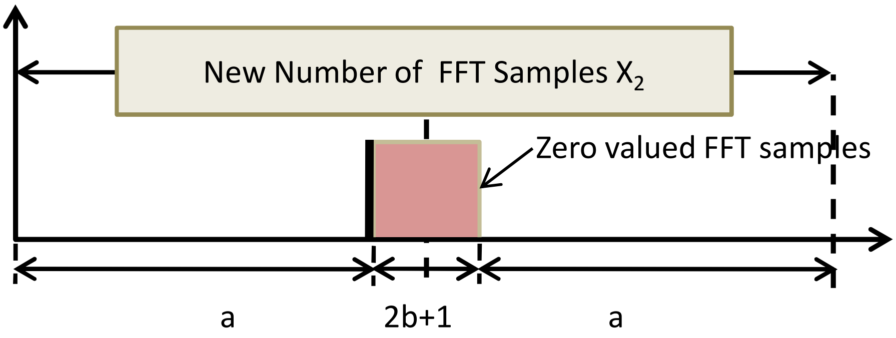

Figure 3.4: New value of frequency domain samples for odd number of samples in a cycle.

The zero valued samples are inserted after $(a + 1)$ number of sample. So, one sample remain unchanged,

$$N_{a+1} = N_{a+1} \tag{3.24}$$

The remaining b number of zero valued samples inserted after this sample. As all zero valued samples inserted in frequency domain there is no effect in overall frequency and sample sequence.

3.4 Examples of Equalizing Per-Cycle Sample Sequences

Here is a example for a sample sequence having $X1$ data samples in each cycle. In this case, the ideal value of sample sequences is $X2$ number of samples. Following equations are used to equalize the per cycle sequences. At first, sample values are converted into frequency domain,

$$v_{x:Spectrum} = FFT(v_x) \tag{3.25}$$

$$i_{x:Spectrum} = FFT(i_x) \tag{3.26}$$

3.4.1 Case 1: For Even Number of Samples

For even number of samples, half of the sample sequence remains unchanged. So the equation for first half of sample sequences,

$$\{v_{x:spectrum}(X2)\}_{x2=0}^{a} = \{v_{x:spectrum}(X1)\}_{x1=0}^{a} \tag{3.27}$$

$$\{i_{x:spectrum}(X2)\}_{x2=0}^{a} = \{i_{x:spectrum}(X1)\}_{x1=0}^{a} \tag{3.28}$$

$2b$ number of zero valued samples are inserted after half of the sample sequence. So the equation for inserted zero valued samples,

$$\{v_{x:spectrum}(X2)\}_{x2=(a+1)}^{a+2b} = 0 \tag{3.29}$$

$$\{i_{x:spectrum}(X2)\}_{x2=(a+1)}^{a+2b} = 0 \tag{3.30}$$

The remaining last half of the sequence number is rearranged. So the equation for arranged samples,

$$\{v_{x:spectrum}(X2)\}_{x2=(a+2b+1)}^{2a+2b} = \{v_{x:spectrum}(X1)\}_{x1=(a+1)}^{2a} \tag{3.31}$$

$$\{i_{x:spectrum}(X2)\}_{x2=(a+2b+1)}^{2a+2b} = \{i_{x:spectrum}(X1)\}_{x1=(a+1)}^{2a} \tag{3.32}$$

3.4.2 Case 2: For Odd Number of Samples

For odd number of samples, half of the sample sequence remains unchanged. So the equation for first half of sample sequences,

$$\{v_{x:spectrum}(X2)\}_{x2=0}^{a} = \{v_{x:spectrum}(X1)\}_{x1=0}^{a} \tag{3.33}$$

$$\{i_{x:spectrum}(X2)\}_{x2=0}^{a} = \{i_{x:spectrum}(X1)\}_{x1=0}^{a} \tag{3.34}$$

As the total sample number is odd one sample remains unchanged after half of the sample sequence

$$\{v_{x:spectrum}(X2)\}_{x2=(a+1)} = \{v_{x:spectrum}(X1)\}_{x1=(a+1)} \tag{3.35}$$

$$\{i_{x:spectrum}(X2)\}_{x2=(a+1)} = \{i_{x:spectrum}(X1)\}_{x1=(a+1)} \tag{3.36}$$

$2b$ number of zero valued samples are inserted after this sample. So the equation for inserted zero valued samples,

$$\{v_{x:spectrum}(X2)\}_{x2=(a+2)}^{a+2b+1} = 0 \tag{3.37}$$

$$\{i_{x:spectrum}(X2)\}_{x2=(a+2)}^{a+2b+1} = 0 \tag{3.38}$$

The remaining last half of the sequence number is rearranged. So the equation for rearranged samples,

$$\{v_{x:spectrum}(X2)\}_{x2=(a+2b+2)}^{2a+2b+1} = \{v_{x:spectrum}(X1)\}_{x1=(a+2)}^{2a+1} \tag{3.39}$$

$$\{i_{x:spectrum}(X2)\}_{x2=(a+2b+2)}^{2a+2b+1} = \{i_{x:spectrum}(X1)\}_{x1=(a+2)}^{2a+1} \tag{3.40}$$

Finally, all the sample values are returned into time domain,

$$v_x = IFFT(v_{x:Spectrum}) \tag{3.41}$$

$$i_x = IFFT(i_{x:Spectrum}) \tag{3.42}$$

Chapter 4

Load Templates

AC generators in power system always generate sinusoidal voltages. Resistive loads such as incandescent lights and heaters are linear loads since the current is always proportional to the voltage applied. Some types of generators and non-linear loads can alter this perfect sine wave. A non-linear electrical load does not have a linear relationship between the voltage applied and the current that flows into the load. Certain types of electronics, lighting ballasts, arc welders and other devices produce a non-linear distorted AC wave.

Continuous time acquisition of voltage and current needs analog circuits and causes complexity. Acquisition of voltage and current in discrete time using sampling analog-to-digital converter is a common practice in evaluating power quality parameters. The current waveform for any type of load is captured along with the supply voltage waveform in discrete time domain. A template can be chosen between consecutive positive zero crossing points. As our future load modeling and calculation accuracy depends on the accuracy of the load templates the current waveform for any type of load is captured along with the supply voltage waveform.

For obtaining an accurate template it is important to take in consideration the excellence of input voltage, the number of sample taken for each type of load. As we know the output of any type of load is fully dependent of input voltage characteristics and it's very due to different harmonics rise. So THD of input voltage needs to be as fewer as possible to avoid any abnormal characteristics in output curve. Also the number of sample data is taken for each type of load must be equal otherwise the addition of templates for different type load is not possible in time domain.

The dynamic behavior of different type of load can very. So we have taken the sample data for each type of load more than once. Also we have used more than one sample for each type of load to avoid any type of abnormality in saved templates. The most common one is chosen from several sample data and also the number of sample for each type of load is reserved equal. The data file is created for each type of load using the ASCII value and saved according to the name of the load.

4.1 23W CFL Template

A wide variety of CFL lamps are available in the market. We have tested six number of CFL lamps manufactured locally by Energypac. The current waveforms drawn by the CFL lamps are not very too much between the different samples. Figure 4.1 shows the wave form of input voltage and output current drawn by a CFL. CFLs are fed by power supply units which conduct the current only during a very small part of the 50 or 60 Hz period so that the current taken from the AC net has the shape of a short impulse. The remaining part of the sine wave is returned to the AC network producing distortion of the current wave of the supply system. The background harmonic distortion on voltage wave form is also noted. At first a template for 23W CFL is saved in ASCII text file for future use.

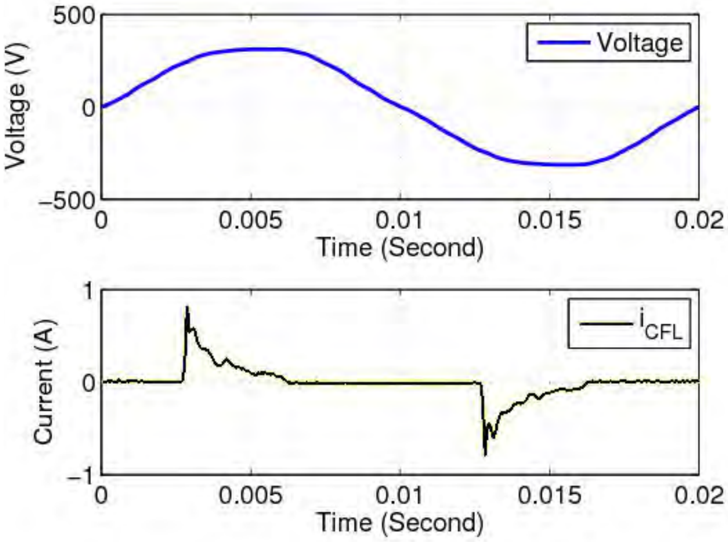

Figure 4.1: Voltage and current waveforms of CFL each 23W

4.2 40W Fluorescent Lamp with Magnetic Ballast

We have tested four feet 40 W standard fluorescent tube of five different samples available in the lab. The current waveforms drawn by the FTL s with magnetic ballast are not very too much between the different samples. Figure 4.2 shows the wave form of input voltage and output current drawn by a FTL operating with magnetic ballast. A 40 W FTL when operating with magnetic ballast having poor PF but THD is minimum. The background harmonic distortion on voltage wave form is also noted.

Load templates are taken for 40W fluorescent lamp with magnetic ballast is saved in ASCII text file. This template can be used to find out the current waveform for any no of fluorescent lamp with magnetic ballast.

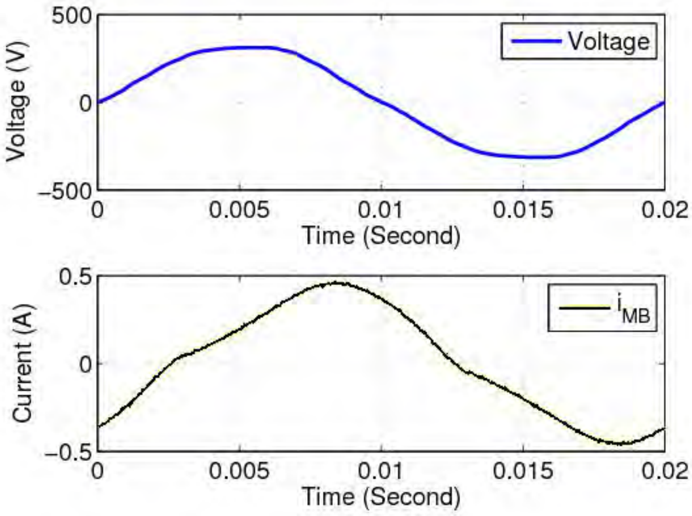

Figure 4.2: Voltage and current waveforms of fluorescent with lamp 1 MBs each 40W

4.3 40W Fluorescent Lamp with Electronic Ballast

A large range of electronics ballasts are available for FTL in the market. We have tested six numbers of FTL from Energy Pac. The current waveforms drawn by the FTL s with electronic ballast are not very too much between the different samples. Figure 4.3 shows the wave form of input voltage and output current drawn by a FTL. A 40 W FTL operating with electronic ballast having better PF than that of FTL operating with magnetic ballast. But THD is pretty more than that of a FTL operating with magnetic ballast.

Another template for 40W fluorescent lamp with electronic ballast is saved in ASCII text file. Using the program it can be possible to find out the current waveform for any no of fluorescent lamp with electronic ballast.

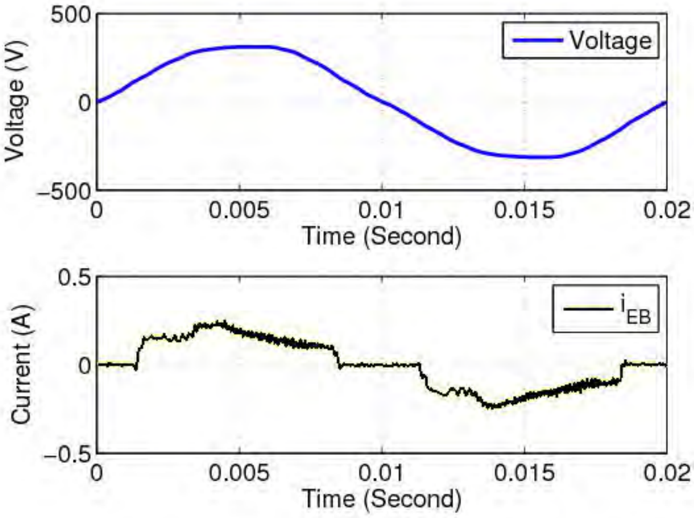

Figure 4.3: Voltage and current waveforms of fluorescent lamp with 1 EBs each 40W

4.4 60W Incandescent Lamp

As 60W incandescent lamp is a resistive load no harmonic distortion and THD for this type of load. Load templates are taken for 60W incandescent lamp is saved in ASCII text file for future use. This template can be used to find out the current waveform for any no of incandescent lamp.

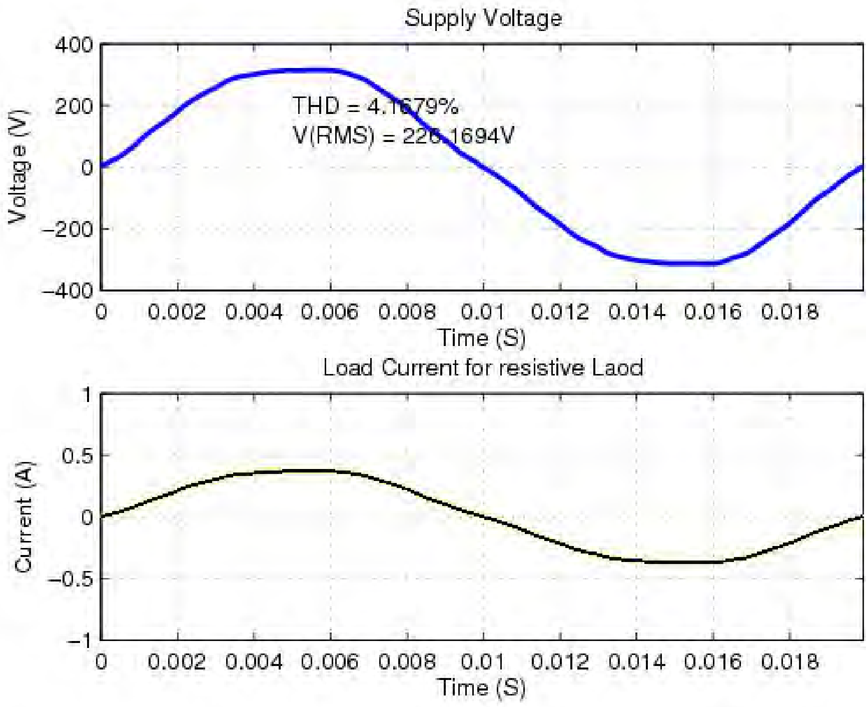

Figure 4.4: Voltage and current waveforms of incandescent lamp each 60W

Chapter 5

Case Studies for Different Types of Residential Loads

People use different kinds of electrical load in everyday life to make their life easy and comfortable. Load type and power consumption vary from locality to locality. Domestic energy consumption is increasing day by day. But capability of using varieties of electrical items depend on income. Luxury items like air coolers, washing machines, dish washers, hot water heater, deep frizzers are mostly used by higher income group peoples. In a country like Bangladesh, majority of residential electrical power are consumed for lighting and cooling fans. Most residential loads are single phase in nature and are supplied from single phase mains. Using the load templates it is possible to determine the impact of different types of residential loads on a distributed system. We know, for any specified number of loads in any feeder, it would be possible to determine the system parameters like power, THD, PF and energy requirement using the load templates. We are considering a distribution system having a 200KVA transformer serving a residential area. Most of the residential loads are lighting loads and inductive loads such as Fan, AC and Washing machine. For a residential area, the types of installed load in different houses are not same. We can categorize them based on income ability and house types. A close scenario of overall power consumption of a particular area is calculated combining these few load types.

For residential area we have considered five types of loads except lighting loads. The total loading is constrained not to exceed the 200KVA rating of the transformer. For simplicity of analysis, the following assumptions are made:

i) A balanced three phase system was assumed that means all three phases were equally loaded with single phase loads.

ii) Calculation was conducted using single phase representation, thus results were obtained from the representation of one phase, assuming the same results for the other two phases.

iii) Although cooling loads like air coolers consume lagging VARs, in our analysis we considered 100% VAR compensation (using capacitor banks) inclusive in the AC load.

5.1 Case Study 1: Loads in Posh Area

Posh area means the part(s) of a city where the standard of living is higher than any other part. Normally businessman, high professionals, foreign delegators etc live in this type of area. A posh area is well organized and well established part of a city. All facilities of a classic municipality is available in a posh area. Street lighting, pure water supply with adequate pumps, distribution networks and communication facilities are available in this part of the city. In the posh area, most of the people use luxurious equipments like air cooler, washing machines and refrigerators in their daily life. To avoid complexity we considered three types of houses which have a common load type. We can consider the following loads (shown in Table 5.1) are used in the houses in a posh area,

Table 5.1: Residential load in posh area

Residence Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Large Residence	Fan	60	2	120
	Refrigerator	150	2	300
	AC	1500	3	4500
	Washing Machine	500	1	500
	Heater	1000	2	2000
	Lamp	60	4	240
	CFL	23	5	115
	TL with MB	40	3	120
	TL with EB	40	3	120
Medium Residence	Fan	60	3	180
	Refrigerator	150	2	300
	AC	1500	2	3000
	Washing Machine	500	1	500
	Heater	1000	1	1000
	Lamp	60	3	180
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	2	80
Small Residence	Fan	60	3	180
	Refrigerator	150	1	150
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	2	120
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	1	40

5.1.1 Residential Area from a 200KVA Transformer

In Table 5.1 we presented various types of electrical loads used in the different residences in a posh area. In this section we consider 8 large residences, 20 medium residences and 40 small residences are available in a particular posh area supplied from a 200KVA distribution transformer. The over all consumption scenario in this typical posh area is shown in Table 5.2.

Table 5.2: Typical residential load in posh area

Load Type	Unit Power Watt	Quantity Pcs	Total Power Watt
Fan	60	196	11760
Refrigerator	150	96	14400
AC	1500	64	96000
Washing Machine	500	28	14000
Heater	1000	36	36000
Lamp	60	172	10320
CFL	23	220	5060
TL with MB	40	144	5760
TL with EB	40	104	4160

5.1.2 Waveforms for Large Residential Loads in a Posh Area

Here is a presentation of input voltage and output load current waveforms for different types residences in a posh area. The output waveforms are computed from the stored templates. Parameters like total Power, RMS current, Percent THD, PF etc are evaluated from the instantaneous waveforms. The first three figures (Figs. 5.1, 5.2, 5.3) represents the output for the load combination of three types of residences and the last one (Fig. 5.4) represents the overall load combination under a 200KVA transformer.

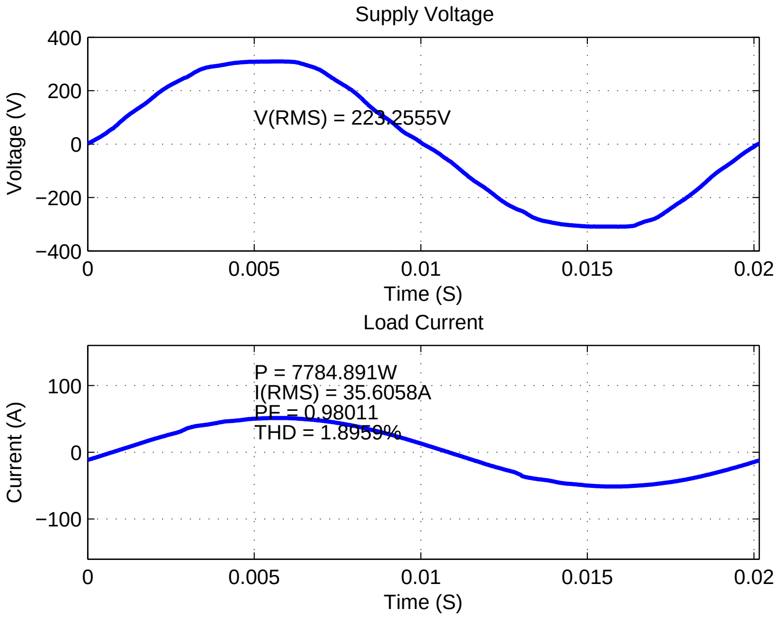

Figure 5.1: Current voltage waveforms for large residential loads in posh area

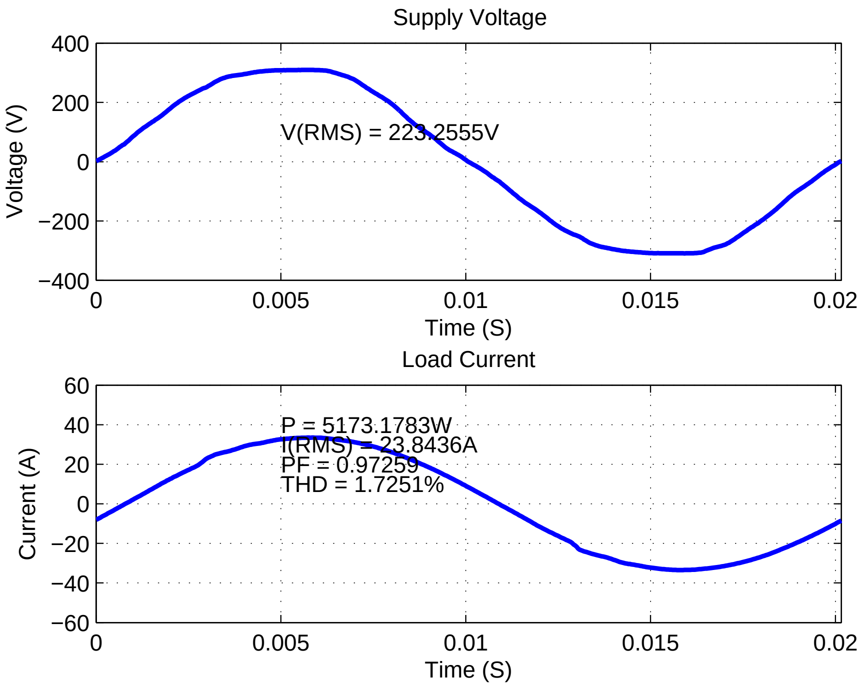

Figure 5.2: Current voltage waveforms for medium residential loads in posh area

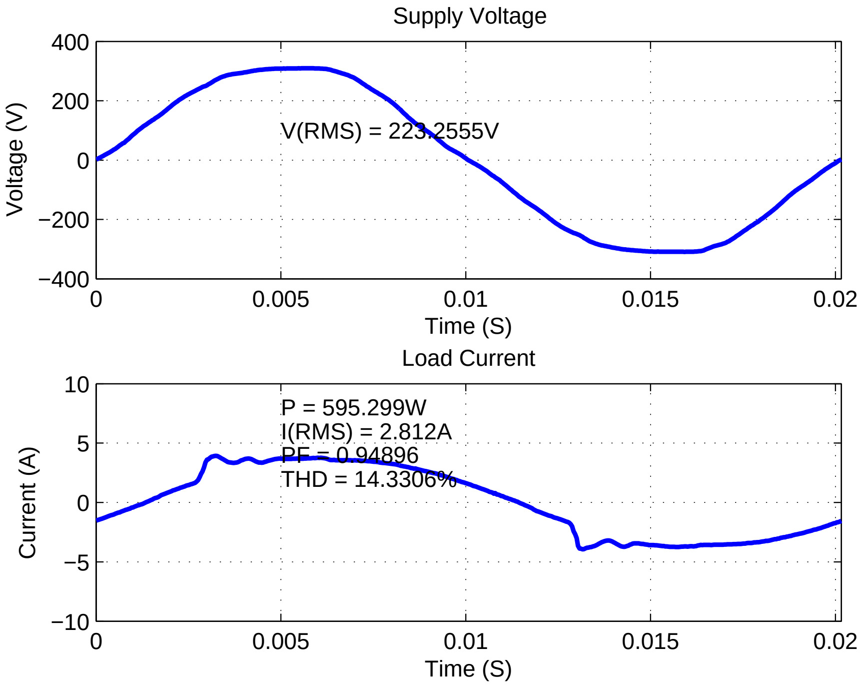

Figure 5.3: Current voltage waveforms for small residential loads in posh area

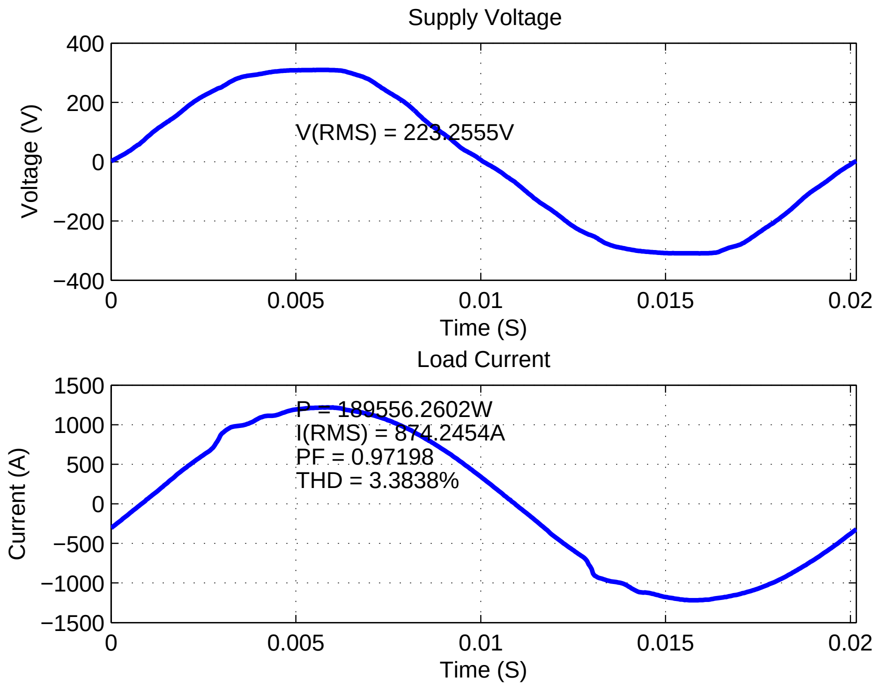

Figure 5.4: Current voltage waveforms for all residential loads in posh area

5.1.3 Summary of Power Quality in a Posh Area

For a posh area driven from a 200kVA distribution transformer, the power quality parameters are summarized in Table 5.3. Small residences contribute the largest THD of 14.33%. The overall THD which is 3.38% is much lesser than the IEEE-519 standard limit.

Table 5.3: Summary of power quality parameters in a posh area.

Para.	Large Res.	Medium Res.	Small Res.	Over all
Total Power	7784.89	5173.22	595.29	7784.89
RMS current	35.61	23.84	2.81	874.25
PF	0.98	0.97	0.95	0.97
Percent THD	1.89	1.72	14.33	3.38

5.2 Case Study 2: Loads in Rural Area

Rural area is the area which is situated at a remote place and far from a city area. Most of the rural areas in Bangladesh are under the coverage of electrification mainly supplied by BPDB or Rural Electrification Board (REB). Although the REB has been successful in electrifying almost half of all villages, less than half of residents in these villages have taken up the service. We can consider the following loads (as shown in Table5.4) are used in residential houses of a rural area:

Table 5.4: Residential load in rural area

Residence Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Large Residence	Fan	60	4	240
	Refrigerator	150	1	150
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	1	1000
	Lamp	60	4	240
	CFL	23	2	46
	TL with MB	40	1	40
	TL with EB	40	1	40
Medium Residence	Fan	60	3	180
	Refrigerator	150	0	0
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	3	180
	CFL	23	2	46
	TL with MB	40	1	40
	TL with EB	40	1	40
Small Residence	Fan	60	1	60
	Refrigerator	150	0	0
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	2	120
	CFL	23	2	46
	TL with MB	40	0	0
	TL with EB	40	0	0

In any rural area, over all power consumption is less than urban areas. Living standard of the overall population in this area is more or less lower than the urban areas of the country. Main electrical power consumption in any rural area is due to lighting loads. To avoid complexity we considered three types of houses which have a common load type. Finally, it is possible to find out the over all consumption of this area combining this three types of houses.

5.2.1 Residential Area from a 200KVA Transformer

Here we consider 50 big residences, 100 medium residences and 200 small residences are available in a particular area. A 200KVA transformer is serving the area. The over all consumption in this area is given in the following table (Table 5.5):

Table 5.5: Typical residential load in rural area

Load Type	Unit Power Watt	Quantity Pcs	Total Power Watt
Fan	60	700	42000
Refrigerator	150	50	7500
AC	1500	0	0
Washing Machine	500	0	0
Heater	1000	50	50000
Lamp	60	900	54000
CFL	23	700	16100
TL with MB	40	150	6000
TL with EB	40	150	6000

5.2.2 Current and Voltage Waveforms for Residential Loads in a Rural Area

Figures 5.5, 5.6 and 5.7 represents the output for the load combination of three type of residences. Fig. 5.8 represents the overall load combination under a 200KVA transformer.

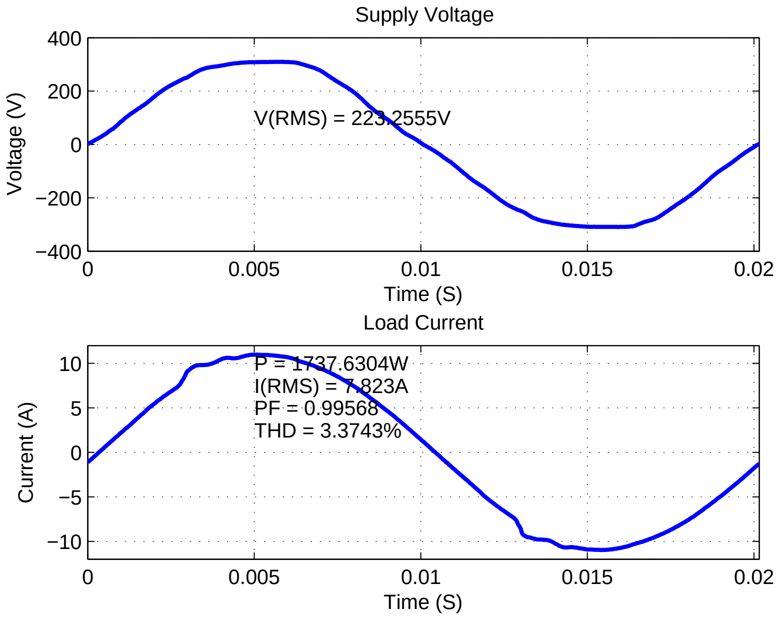

Figure 5.5: Current voltage waveforms for large residential loads in a rural area

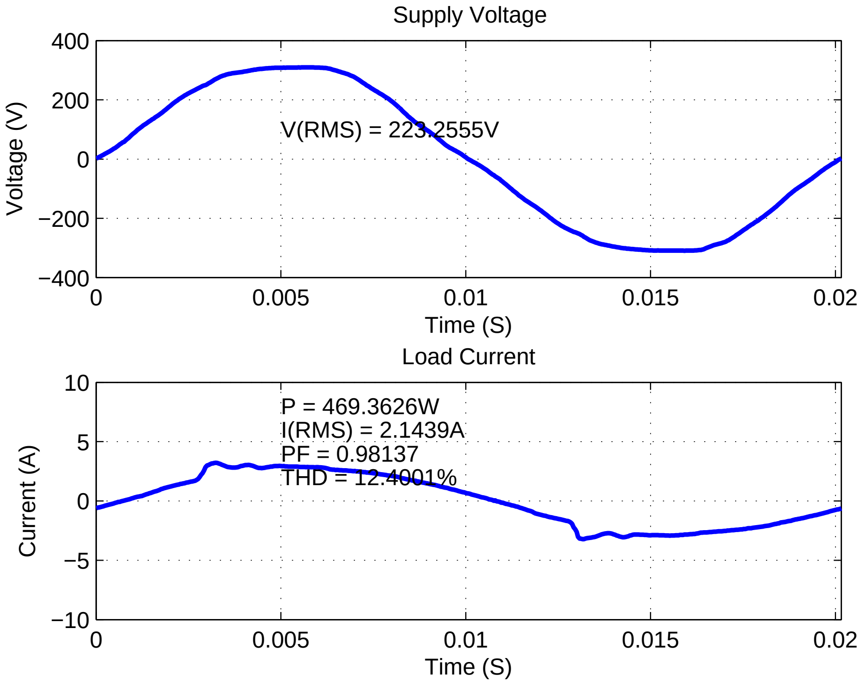

Figure 5.6: Current voltage waveforms for medium residential loads in a rural area

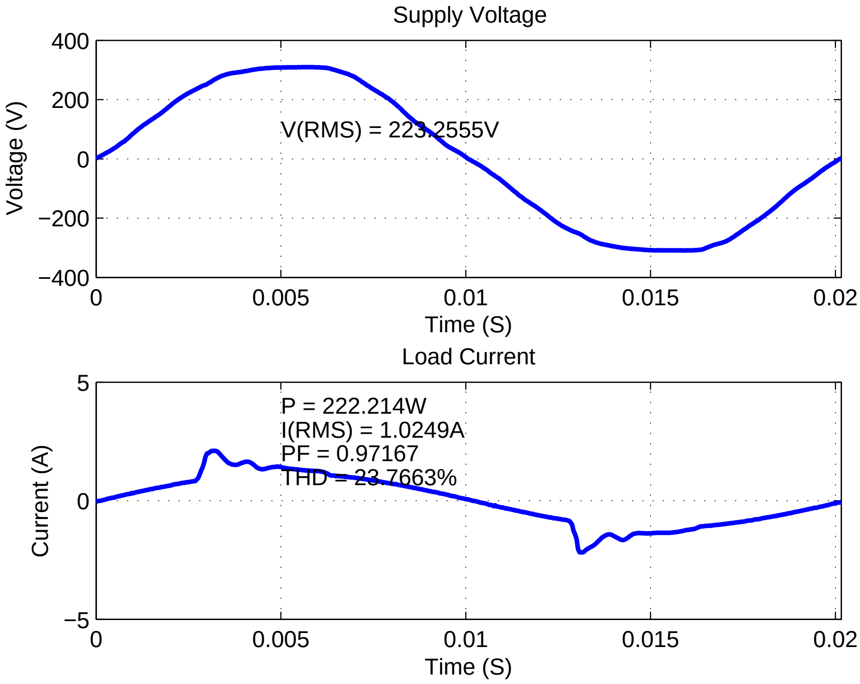

Figure 5.7: Current voltage waveforms for small residential loads in a rural area

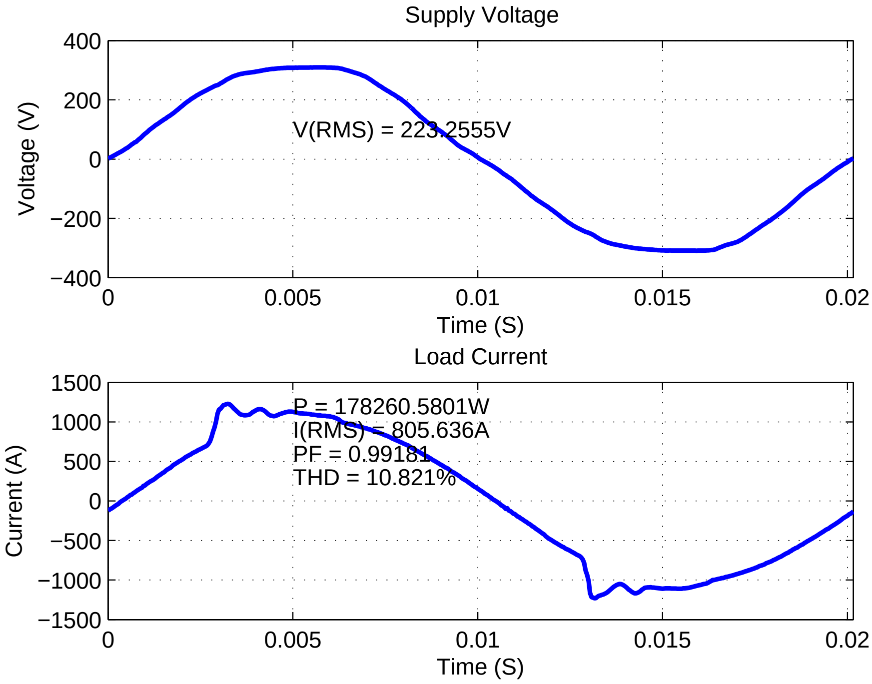

Figure 5.8: Current voltage waveforms for combined residential loads in a rural area

5.2.3 Summary of Power Quality in a Rural Area

The power quality accessed from the combination of loads in a rural area driven from a 200KVA transformer is summarized in Table 5.6. The overall current THD is 10.82 that is much higher than a city area. This is because of the extensive use of CFL's. The overall THD is within the recommended limit of IEEE-519 standard.

Table 5.6: Power quality parameters summary for a rural area.

Para.	Large Res.	Medium Res.	Small Res.	Over all
Total Power	1737.63	469	222.21	178260.58
RMS current	7.82	2.14	1.024	805.63
PF	.99	.98	.97	.99
Percent THD	3.37	12.4	23.76	10.82

5.3 Case Study 3: Loads in Common City Area

The term city might be simply the historical core municipality (local authority area). In a city area, most of the people have medium income ability and use common electrical equipments in their daily life. Living standard of the overall population in this area is not more than average. Our country having moderately warm temperature but in the summer season the temperature is high enough. So, commonly, ceiling fans are used for cooling purpose. Very few people use air conditioners for cooling purpose. Also refrigerators are common electrical equipments that are used in almost every houses. Over all load consideration for a common city area is presented in Table 5.7. To avoid complexity we considered three types of houses which have a common load type. Finally, it is possible to find out the over all consumption of this area combining these three types of houses.

Table 5.7: Residential load in common city area

Residence Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Large Residence	Fan	60	4	240
	Refrigerator	150	2	300
	AC	1500	2	3000
	Washing Machine	500	1	500
	Heater	1000	1	1000
	Lamp	60	4	240
	CFL	23	5	115
	TL with MB	40	3	120
	TL with EB	40	3	120
Medium Residence	Fan	60	4	240
	Refrigerator	150	1	150
	AC	1500	0	0
	Washing Machine	500	1	500
	Heater	1000	1	1000
	Lamp	60	3	180
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	2	80
Small Residence	Fan	60	3	180
	Refrigerator	150	1	150
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	2	120
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	1	40

5.3.1 Common City Area from a 200KVA Transformer

In the previous table (Table 5.7) there is a presentation of various type of electrical loads used in different residences in a common city area. In this section we consider 15 big residences, 30 medium residences and 60 small residences are available in a particular area. A 200KVA transformer is serving the area. A consideration is taken for a particular time when all the loads are on. So the over all consumption in this area at that moment is given in the following table (Table 5.8):

Table 5.8: Total residential load in common city area

Load Type	Unit Power Watt	Quantity Pcs	Total Power Watt
Fan	60	360	21600
Refrigerator	150	120	18000
AC	1500	30	45000
Washing Machine	500	45	22500
Heater	1000	45	45000
Lamp	60	270	16200
CFL	23	345	7935
TL with MB	40	225	9000
TL with EB	40	165	6600

5.3.2 Current and Voltage Waveforms for Residential Loads in a Common City Area

The overall computed instantaneous waveforms for three types of residences in a residential area in a city are shown in Figs. 5.9, 5.10 and 5.11. The overall load combination under a 200KVA transformer are shown in Fig. 5.12.

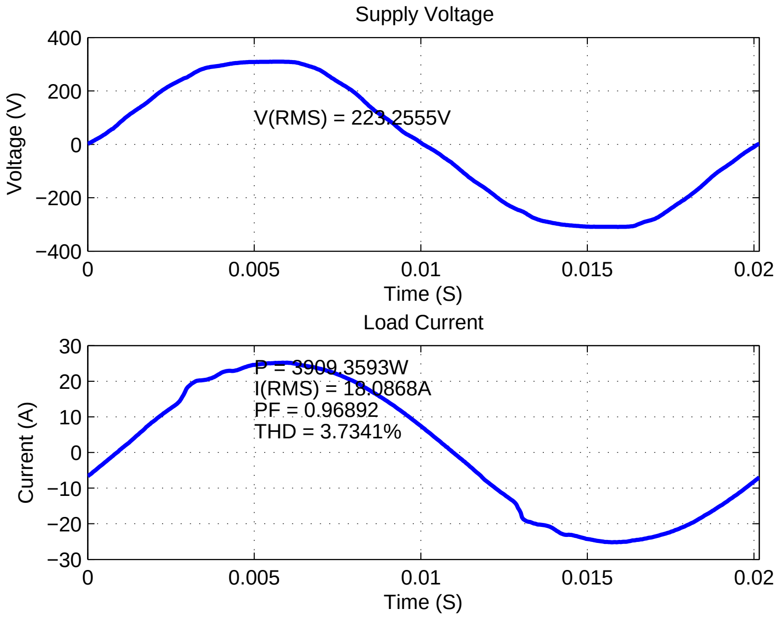

Figure 5.9: Current voltage waveforms for large residential loads in a suburb area

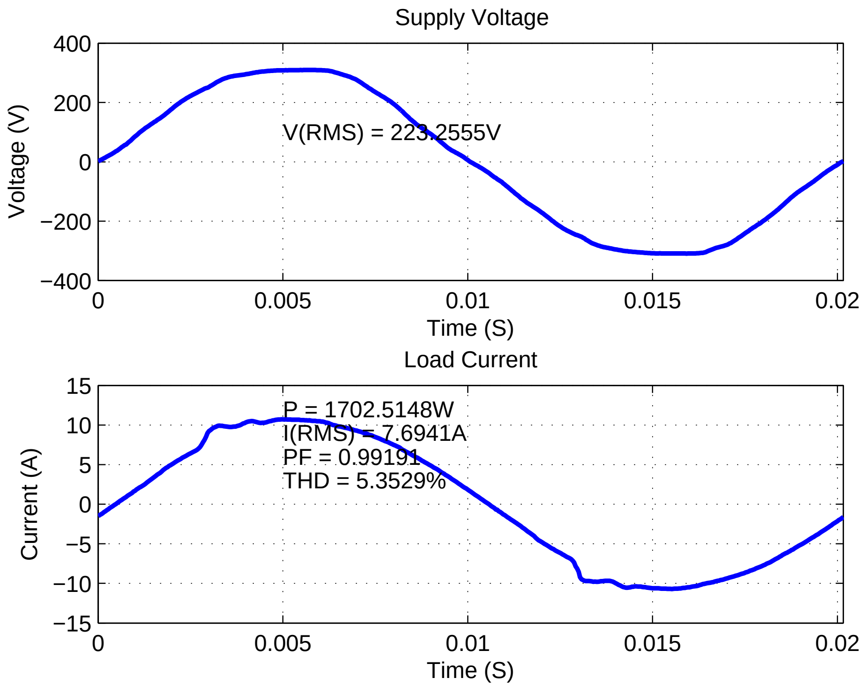

Figure 5.10: Current voltage waveforms for medium residential loads in a suburb area

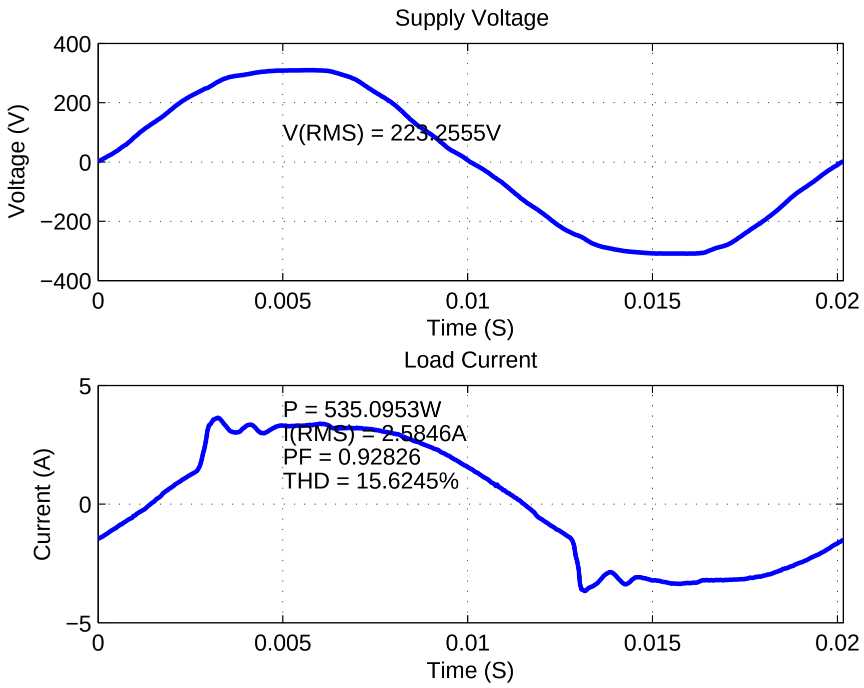

Figure 5.11: Current voltage waveforms for small residential loads in a suburb area

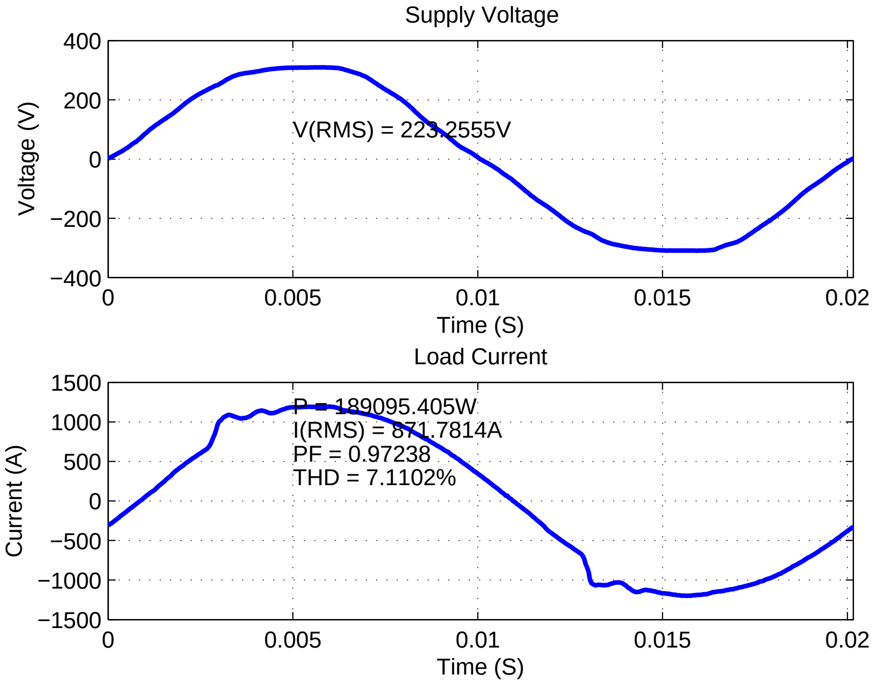

Figure 5.12: Current voltage waveforms for combined residential loads in a suburb area

5.3.3 Summary of Power Quality Parameters in a City Residential Area

A summary of the power quality parameters computed from the template based models for a residential area of a city are shown in Table 5.9. It is seen that the overall current THD is 7.11%.

Table 5.9: Power quality summary for a suburb area supplied from a 200KVA transformer.

Para.	Large Res.	Medium Res.	Small Res.	Over all
Total Power	3909.36	1702.51	535.09	189095.40
RMS current	18.09	7.69	2.58	871.71
PF	0.97	0.99	0.93	0.97
Percent THD	3.73	5.35	15.62	7.11

5.4 Case Study 4: Loads in Suburb Area

Suburb mostly refers to a residential area. They may be the residential areas of a city or separate residential communities within commuting distance of a city. Modern suburbs grew in the 20th century as a result of improved road and rail transport and an increase in commuting. Suburbs tend to proliferate around cities that have an abundance of adjacent flat land. Collectively, the suburbs are all of the continuous urbanization that extends beyond the core city. A specific suburb can be an individual municipality or community in the suburbs. The type of residential loads in a suburb area is shown in Table 5.10. In a suburb, most of the people have medium income ability and use common electrical equipments in their daily life. In the summer season people mostly use ceiling fans for cooling purpose. Also refrigerators are common electrical equipments that are used in almost every houses. Three types of houses are considered which have a common load type.

Table 5.10: Residential loads in suburb area

Residence Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Large Residence	Fan	60	4	240
	Refrigerator	150	2	300
	AC	1500	1	1500
	Washing Machine	500	1	500
	Heater	1000	1	1000
	Lamp	60	4	240
	CFL	23	5	115
	TL with MB	40	3	120
	TL with EB	40	3	120
Medium Residence	Fan	60	3	180
	Refrigerator	150	1	150
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	1	1000
	Lamp	60	3	180
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	2	80
Small Residence	Fan	60	2	120
	Refrigerator	150	1	150
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	2	120
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	1	40

5.4.1 Suburb Area from a 200KVA Transformer

In Table 5.10 various types of electrical loads are shown used in different residences in a suburb area. In this section we consider 20 large residences, 40 medium residences and 80 small residences to be available in a particular area where the total consumption is 200KVA. The over all consumption in this suburb area is given in the Table 5.11.

Table 5.11: Total residential load in suburb area

Load Type	Unit Power Watt	Quantity Pcs	Total Power Watt
Fan	60	360	21600
Refrigerator	150	160	24000
AC	1500	20	30000
Washing Machine	500	20	10000
Heater	1000	60	60000
Lamp	60	360	21600
CFL	23	460	10580
TL with MB	40	300	12000
TL with EB	40	220	8800

5.4.2 Current and Voltage Waveforms for Residential Loads in a Suburb Area

This section presents the input voltage and output load current waveforms for different types residences in a suburb area. The first three figures (Figs. 5.13, 5.14 and 5.15) represents the output for the load combination of three types of residences and the last one (Fig. 5.16) represents the overall load combination under a 200KVA transformer.

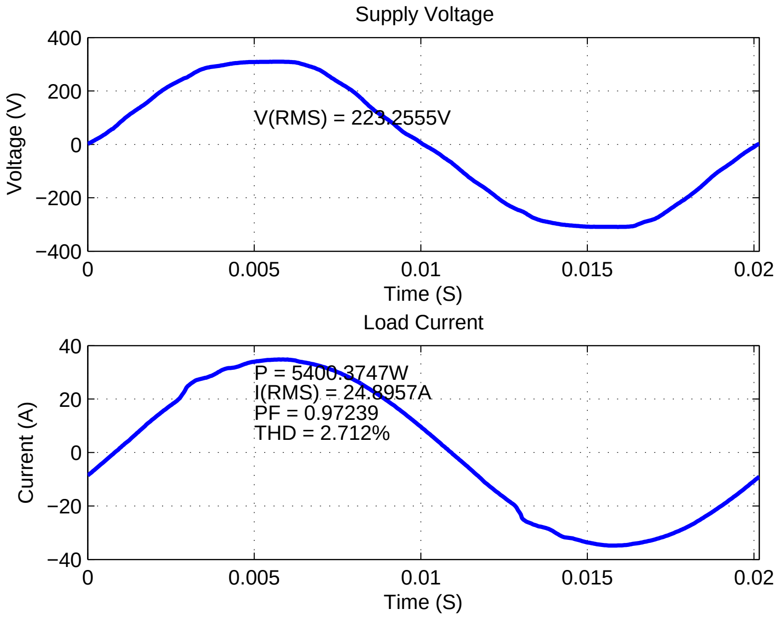

Figure 5.13: Current voltage waveforms for large residential loads in a common city area

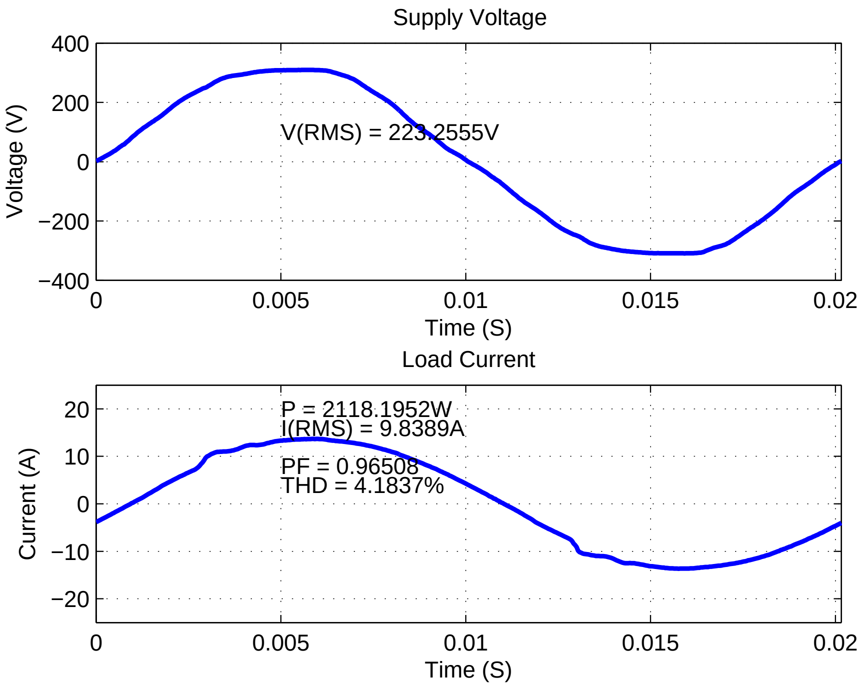

Figure 5.14: Current voltage waveforms for medium residential loads in a common city area

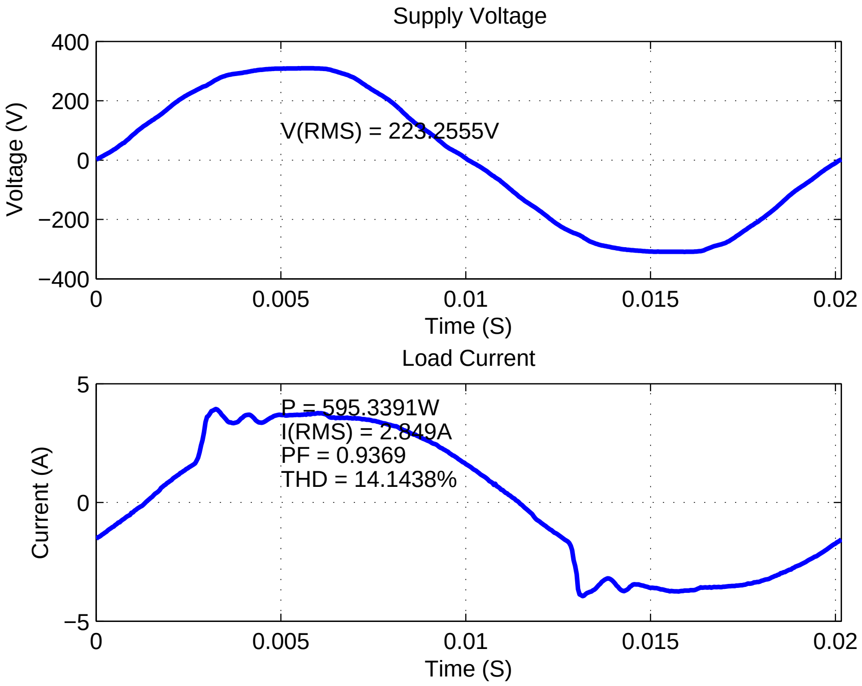

Figure 5.15: Current voltage waveforms for small residential loads in a common city area

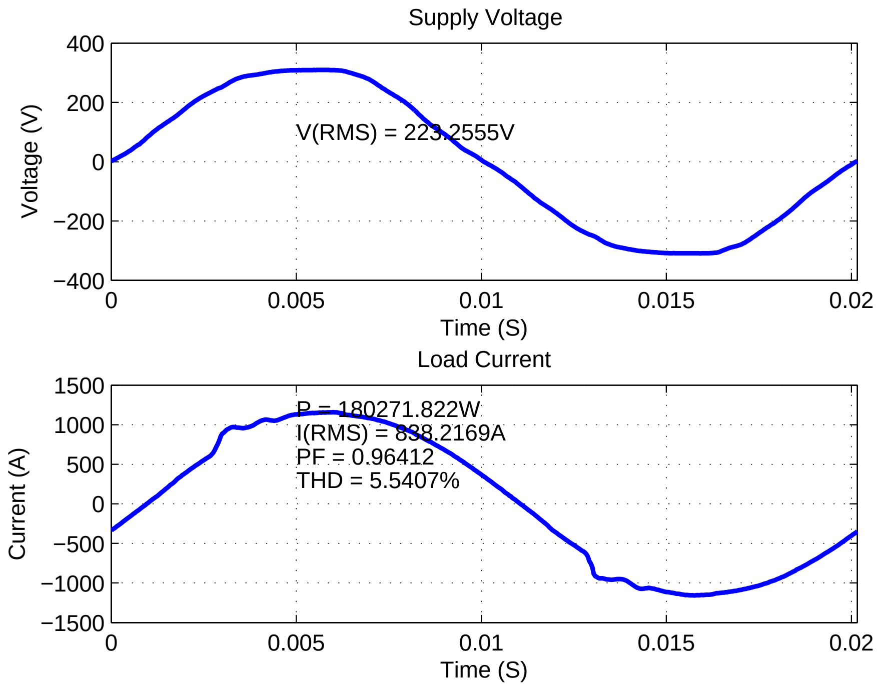

Figure 5.16: Current voltage waveforms for combined residential loads in a common city area

5.4.3 Power Quality Parameters Summary for a Typical Suburb Area

The different parameters for a typical suburb area driven from a 200KVA distribution transformer is summarized in Table 5.12. The overall THD for current is 5.54%.

Table 5.12: Power quality parameters summary for a suburb area.

Para.	Large Res.	Medium Res.	Small Res.	Over all
Total Power	5400.37	2118.19	595.33	180271.82
RMS current	24.90	9.83	2.85	838.22
PF	0.97	0.97	0.94	0.96
Percent THD	2.71	4.18	14.14	5.54

Chapter 6

Case Studies for Different Type of Industrial and Commercial Loads

This chapter describes and assesses a template based load model of different commercial and industrial area. Using the load templates it is possible to determine the impact of different types of industrial and commercial loads on a distributed system. A distribution system is considered having a 200KVA transformer serving an industrial or commercial area. An industrial area consists of different type of industries where big and heavy duty machines run regularly. In a commercial area the type of load in different shopping centers vary. A close scenario of overall power consumption of a particular area is calculated combining the different types of loads.

We consider some common load in every offices or industries to reduce complexity of calculation. The total loading is constrained not to exceed the 200KVA rating of the transformer. For simplicity of analysis, the following assumptions are made:

i) A balanced three phase system was assumed that means all three phases were equally loaded with single phase loads.

ii) Calculation is conducted using single phase representation, assuming the same results for the other two phases.

6.1 Case Study 1: Industrial Loads

Industrial zones mean the areas where industries are located and heavy duty machines run regularly. Normally, industrial zones have separate feeders having no connection with residential areas, provide good communication infrastructures and empty sites for future expansions. Most of the large industries uses their own substation and own back-up power generation. As heavy industrial equipments have low power factor, each industry have their own power factor improvement (PFI) plant for PF improvement. We consider the loads shown in Table 6.1 are used in industries in an industrial area.

Table 6.1: Typical Industrial Load

Industry Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Big Garments	Fan	60	50	3000
	Exhust Fan	750	15	11250
	Sewing Machine	100	100	10000
	AC	1500	10	15000
	Washing Machine	750	30	22500
	Iron	1000	10	10000
	Vacuum Cleaner	600	20	12000
	Water Pump	375	6	2250
	Lamp	60	30	1800
	CFL	23	30	690
	TL with MB	40	100	4000
	TL with EB	40	100	4000
Big Paint Industry	Fan	60	10	600
	Exhaust Fan	750	30	2250
	Mix Machine(L)	400	15	6000
	AC	1500	15	22500
	Mix Machine(S)	250	30	7500
	Iron	1000	10	10000
	Vacuum Cleaner	600	10	6000
	Water Pump	375	10	3750
	Lamp	60	30	1800
	CFL	23	50	690
	TL with MB	40	50	2000
	TL with EB	40	50	2000

In Table 6.1 we have considered two big industries (i.e., a garments industry and a paint industry). In the garments industry a lot of lighting loads are used due to a large number of workers working inside a building. Also a large number of sewing machines are used for production purposes. Also a small number of washing machines are used for washing purposes. Some vacuum cleaner and iron machines are also used in the garment industry. In the paint industry most electrical power consumption is occurred due to large and small mixture machines. Also there are exhaust fans as well as vacuum cleaners used in a paint industry.

6.1.1 Industrial Area from a 200KVA Transformer

In this section we have considered one big garments factory and one paint industry are sharing the same transformer. They have their own PFI plant and overall power factor is always maintained over 0.95. A 200 KVA transformer is serving the area. A consideration is taken for a particular time when all the loads are on. The over all consumption in this area are considered to be as presented in Table 6.2.

Table 6.2: Total Industrial Load

Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Fan	60	60	3600
Exhaust Fan : Industrial	750	45	33750
Sewing M/C Cloth	100	100	10000
AC	1500	25	37500
Washing Machine Fully Auto	750	30	22500
Iron	1000	20	20000
Vacuum Cleaner	600	30	18000
Water Pump 0.5 Hp	375	16	6000
Lamp	60	60	3600
CFL	23	60	1380
TL with MB	40	150	6000
TL with EB	40	150	6000
Mixer machine big	400	15	6000
Mixer machine small	250	30	7500

6.1.2 Waveforms for Different Loads in an Industrial Area

Here is a presentation of input voltage and output load current waveforms for different types of industries in a particular area. The output waveforms are generated by Matlab program using the stored templates. First two figures (Figs. 6.1, 6.2) represent the output for the load combination of two industries and the last one (Fig. 6.3) represents the overall load combination under a 200KVA transformer.

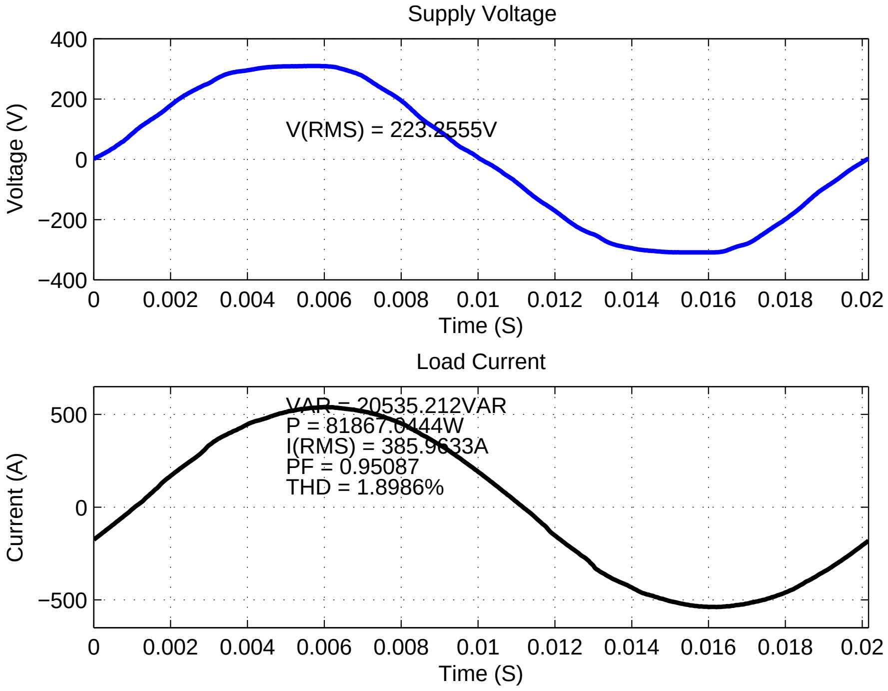

Figure 6.1: Current voltage waveforms for large garments industry

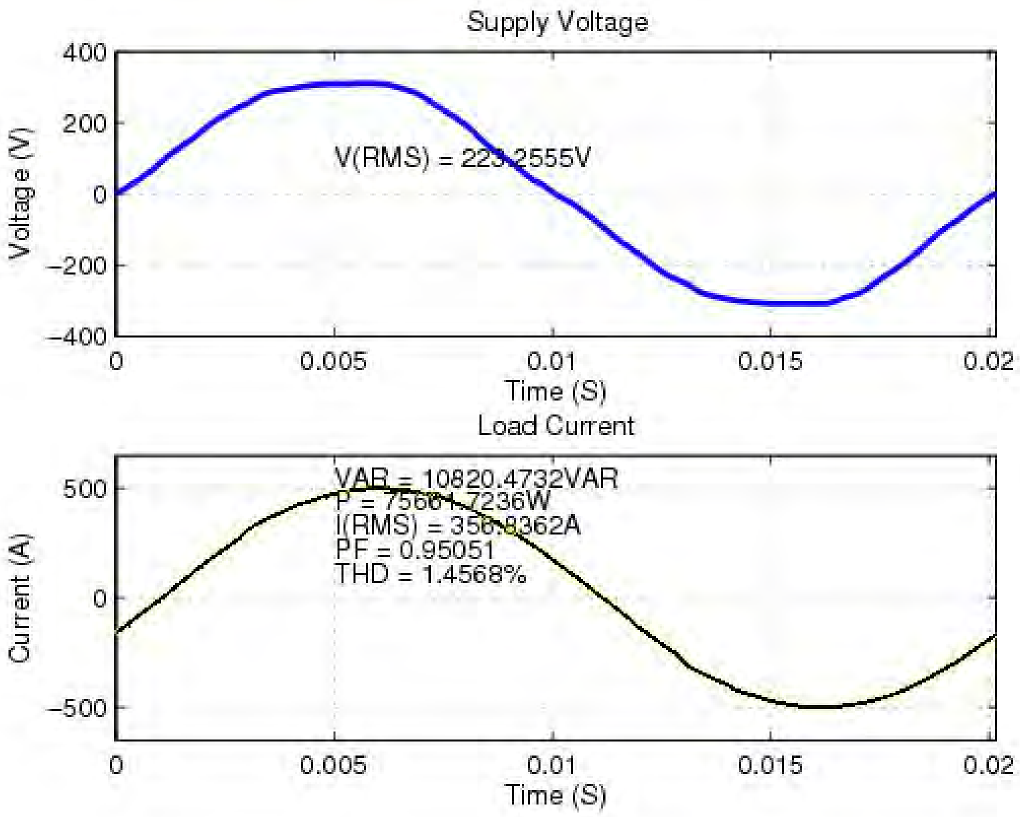

Figure 6.2: Current voltage waveforms for large paint industry

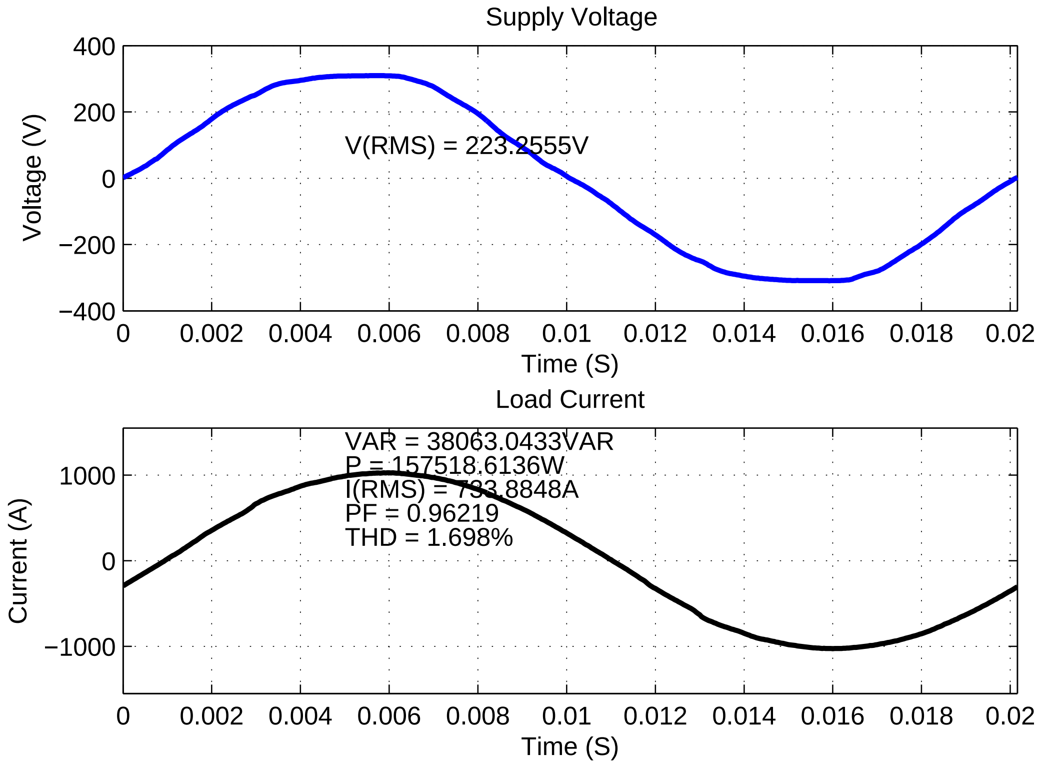

Figure 6.3: Current voltage waveforms for all industries

6.1.3 Summary of Power Parameters in an Industrial Area

The power parameters for an industrial area with a 200KVA transformer shown in Figs. 6.1, 6.2, 6.3. The parameters are summarized in Table 6.3. The overall THD is 1.72 that is much lesser than the IEEE-519 limits.

Table 6.3: Summary of power parameters in a typical industrial area

Para.	Garment Ind.	Paint Ind.	Over all
VAR	2 0535.21	10820.47	38063.04
Total Power	81867.04	75661.72	155691.39
RMS current	385.96	356.84	724.35
PF	0.95	0.95	0.96
Percent THD	1.89	1.46	1.72

6.2 Case Study 2: Semi-Industrial Loads

It is a common scenario that many industries are adjacent to residential and commercial areas. In Bangladesh, many garments industries are located inside commercial area, even some are inside residential areas.

Table 6.4: Semi-Industrial Load

Industry Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Garments	Fan	60	15	900
	Exhust Fan	750	4	3000
	Sewing Machine	100	30	3000
	AC	1500	5	7500
	Washing Machine	750	5	3750
	Iron	1000	5	5000
	Vacuum Cleaner	600	2	12000
	Water Pump	375	2	750
	Lamp	60	10	600
	CFL	23	10	230
	TL with MB	40	50	2000
	TL with EB	40	50	2000
Medium Office	Fan	60	4	240
	Refrigerator	150	1	150
	AC	1500	2	3000
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	3	180
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	2	80
Small Office	Fan	60	4	180
	Refrigerator	150	0	0
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	2	120
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	1	40

Some times small garments industries are located inside a residential area. Also there are some offices and office cum residences inside an industrial area. So we can define a Semi-Industrial area is the area where there are some small industries as well as some commercial offices and residential buildings situated adjacently. We can consider the following loads in a semi-residential area. Here we consider a locality having small garments factory, medium offices and small offices. In the offices there are lighting loads and fans. AC load is also considered for each medium office for cooling purposes.

6.2.1 Semi-Industrial Area from a 200KVA Transformer

In this section we have considered five small garments factory, ten medium offices and fifteen small offices are sharing the same transformer. All the garments factory have their own PFI plant and overall power factor is always maintained over 0.95. A 200 KVA transformer is serving the area and the load distribution is shown in Table 6.5.

Table 6.5: Total Semi-Industrial Load

Load Type	Unit Power Watt	Quantity Pcs	Total Power Watt
Fan	60	175	10500
Refrigerator	150	10	1500
AC	1500	45	67500
WASHING MACHINE FULLY AUTO	500	0	0
IRON	1000	25	25000
Lamp	60	110	6600
CFL	23	125	2875
TL with MB	40	300	12000
TL with EB	40	285	11400
EXHAUST FAN : INDUSTRIAL	750	20	15000
SEWING M/C CLOTH	100	150	15000
VACUUM CLEANER	600	10	6000
WASHING MACHINE FULLY AUTO	750	25	18750
WATER PUMP 0.5 HP	375	10	3750

6.2.2 Current and Voltage Waveforms for Industries and Offices in a Semi-Industrial Area

Here is a presentation of input voltage and output load current waveform for different type offices and small garment industries in a semi-industrial area. The output waveforms are generated by Matlab program using the templates. The output curve also represents the total Power, RMS current, Percent THD, PF , KVAr etc. The first one figure (Fig 6.4) represents the output for the load combination in a garments industry and the next two (Figs. 6.5, 6.6) represents two different type offices and the last one (Fig. 6.7) represents the overall load combination under a 200KVA transformer.

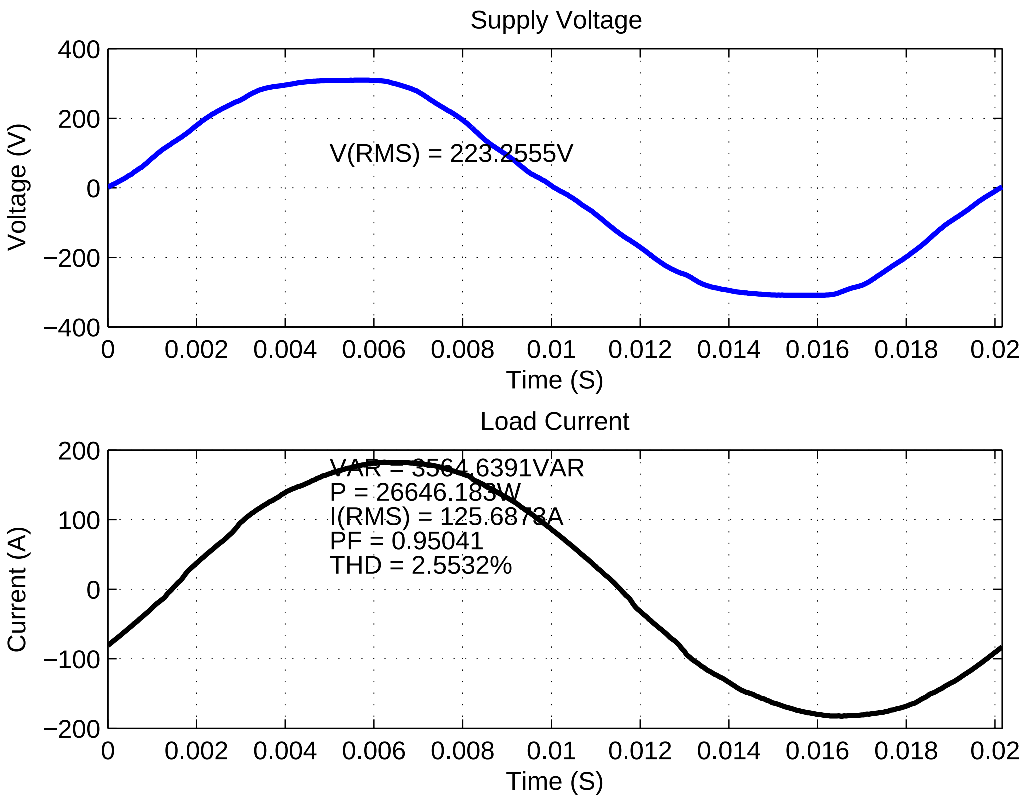

Figure 6.4: Current voltage waveforms for industrial loads in a semi-industrial area

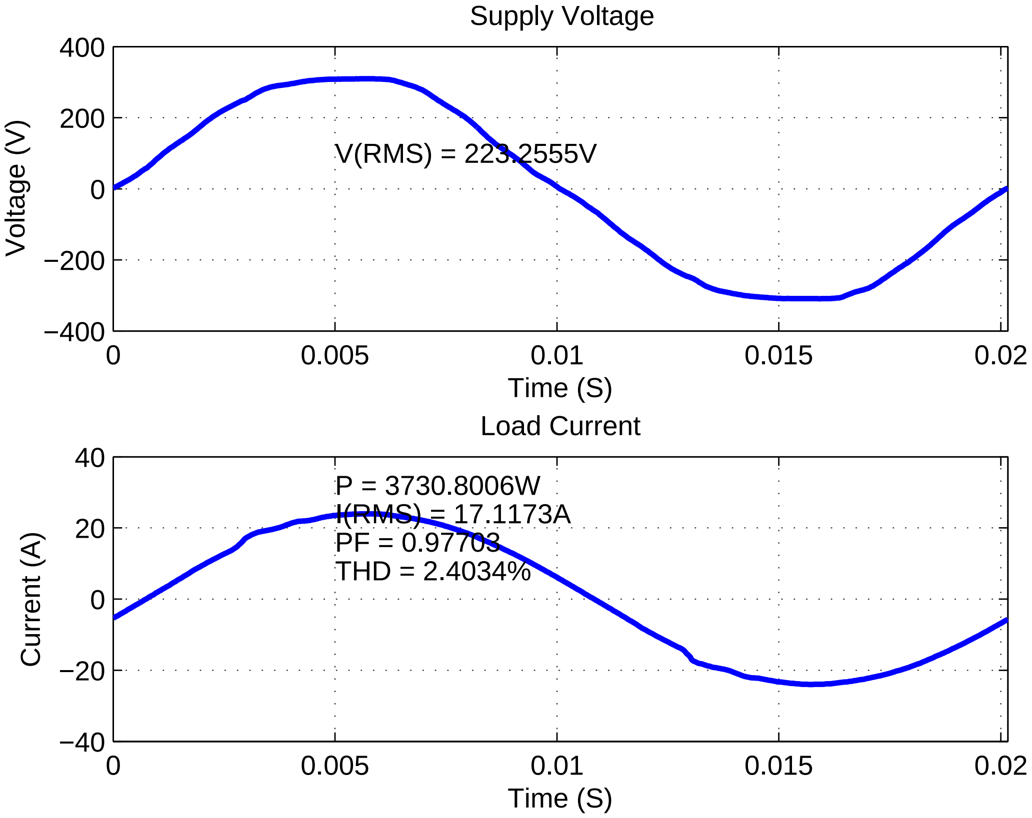

Figure 6.5: Current voltage waveforms for medium office loads in a semi-industrial area

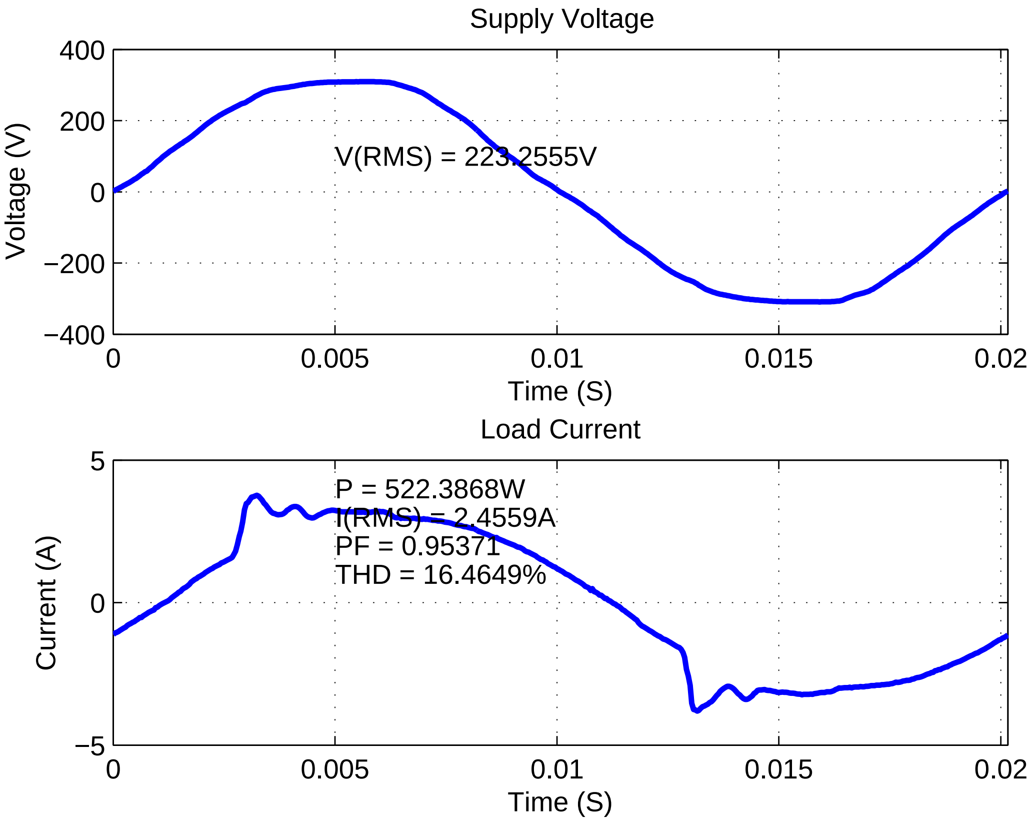

Figure 6.6: Current voltage waveforms for small office loads in a semi-industrial area

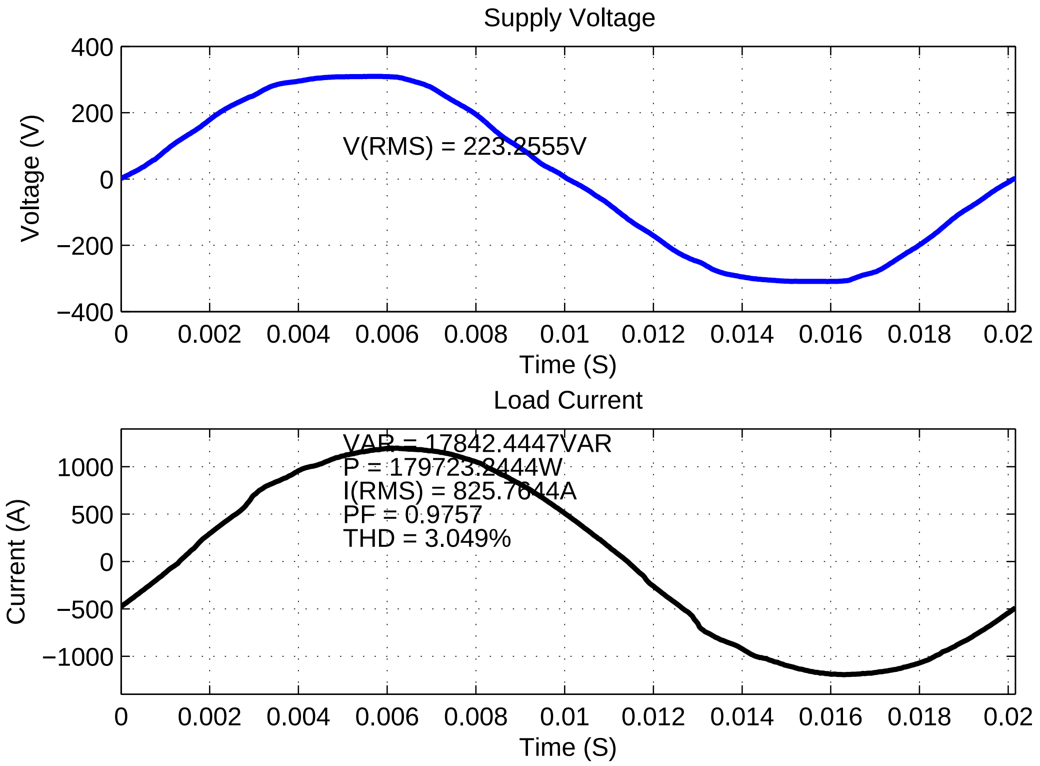

Figure 6.7: Current voltage waveforms for combined loads in a semi-industrial area

6.2.3 Summary of Power Parameters in a Semi-Industrial Area

The power parameters for a semi-industrial area with a 200KVA transformer shown in Figs. 6.4, 6.5, 6.6, 6.7. The parameters are summarized in Table 6.6. The overall THD is 3.05 that is also lesser than the IEEE-519 limits.

Table 6.6: Summary of power parameters in a typical semi-residential area.

Para.	Garments Ind.	Medium Off.	Small Off.	Over all
VAR	3564.63			17842.44
Total Power	266646.18	3730.80	522.39	179723.24
RMS current	125.69	17.11	2.45	825.75
PF	0.95	0.98	0.95	0.98
Percent THD	2.55	2.4	16.46	3.05

6.3 Case Study 3: Loads in Commercial Area

Commercial areas in a city normally take up small portion of a city area. It is used for commercial activities.

Table 6.7: Commercial load.

Office Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Restaurant	Fan	60	12	720
	Refrigerator	150	3	450
	AC	1500	3	4500
	Washing Machine	500	0	0
	Heater	1000	3	3000
	Lamp	60	4	240
	CFL	23	10	230
	TL with MB	40	5	240
	TL with EB	40	5	240
Large Office	Fan	60	2	120
	Refrigerator	150	1	150
	AC	1500	6	9000
	Washing Machine	500	0	0
	Heater	1000	2	2000
	Lamp	60	4	240
	CFL	23	10	230
	TL with MB	40	5	200
	TL with EB	40	5	200
Medium Office	Fan	60	4	240
	Refrigerator	150	1	150
	AC	1500	2	3000
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	3	180
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	2	80
Small Office	Fan	60	4	180
	Refrigerator	150	0	0
	AC	1500	0	0
	Washing Machine	500	0	0
	Heater	1000	0	0
	Lamp	60	2	120
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	1	40

These activities include the buying and selling of goods and services in retail businesses, wholesale buying and selling, financial establishments, and wide variety of services that are broadly classified as “business”. We consider the following loads (as shown in Table 6.7) are used in a commercial area. In this section, total load consumption in a commercial area is calculated. In a commercial area, most of the offices having common office equipments required for daily office works. We have considered different lighting loads in every offices. Also AC and fans are considered for room cooling purposes. To avoid complexity we considered three types of offices which have a common load structure. Also three commercial restaurants are considered to be located in this area.

6.3.1 Commercial Area from a 200KVA Transformer

In Table 6.7 there is a presentation of various types of electrical loads used in different offices in a commercial area. In this section we consider three commercial restaurants, 8 big offices, 15 medium offices and 30 small offices in a particular area. A 200KVA transformer is serving the area. The overall load is shown in Table 6.8.

Table 6.8: Total commercial load

Load Type	Unit Power Watt	Quantity Pcs	Total Power Watt
Fan	60	232	13920
Refrigerator	150	32	4800
AC	1500	87	130500
Washing Machine	500	0	0
Heater	1000	25	25000
Lamp	60	149	8940
CFL	23	245	5635
TL with MB	40	145	5800
TL with EB	40	115	4600

6.3.2 Current and Voltage Waveforms for Industries and Offices in a Commercial Area

The first three figures (Figs. 6.8, 6.9, 6.10) represents the output for the load combination in three different type offices and the last one (Fig. 6.11) represents the overall load combination under a 200KVA transformer.

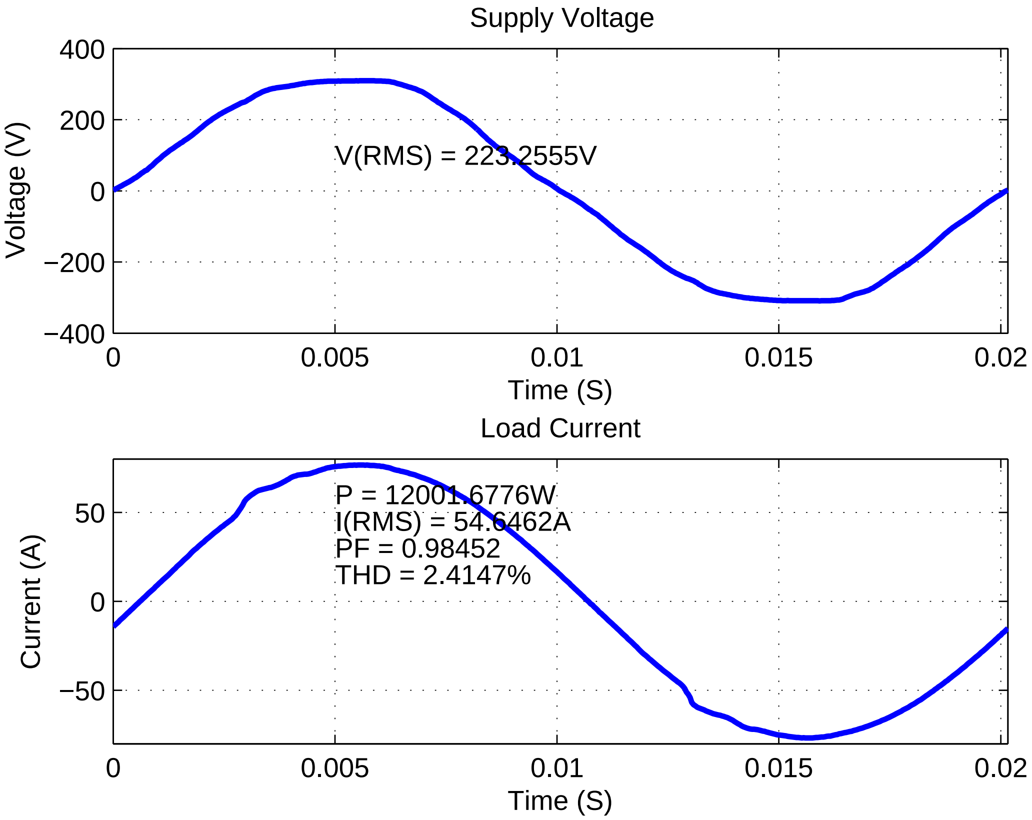

Figure 6.8: Current voltage waveforms for large office loads in a commercial area.

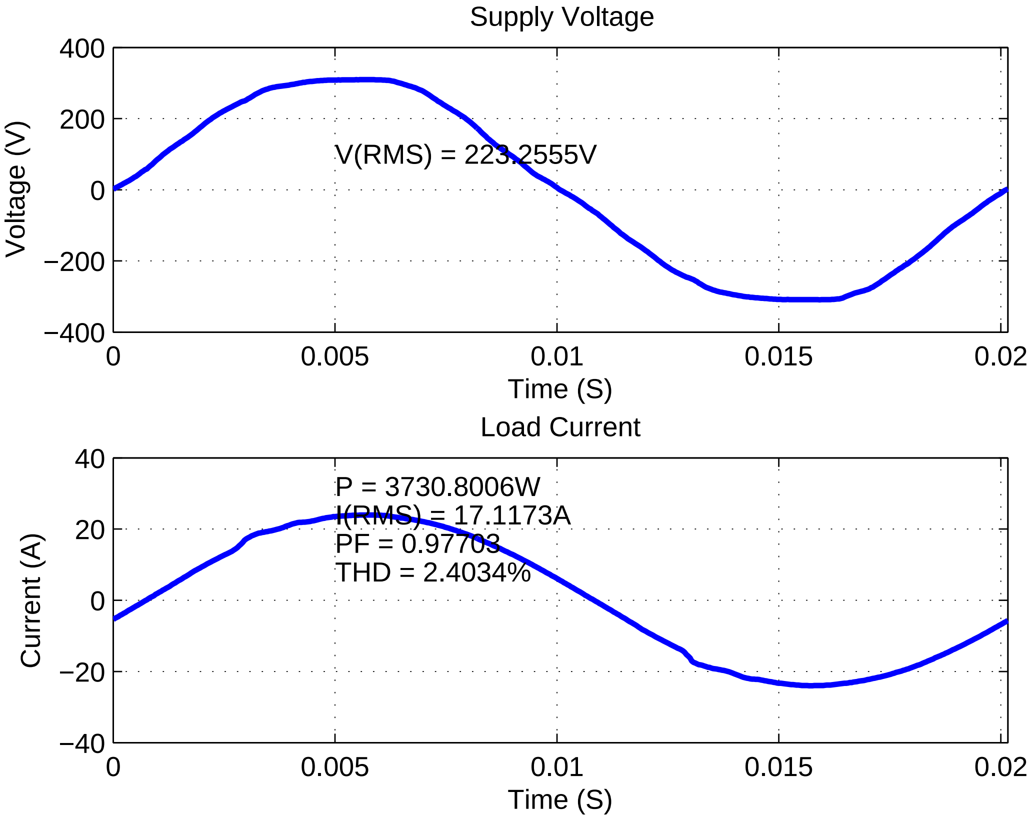

Figure 6.9: Current voltage waveforms for medium office loads in a commercial area

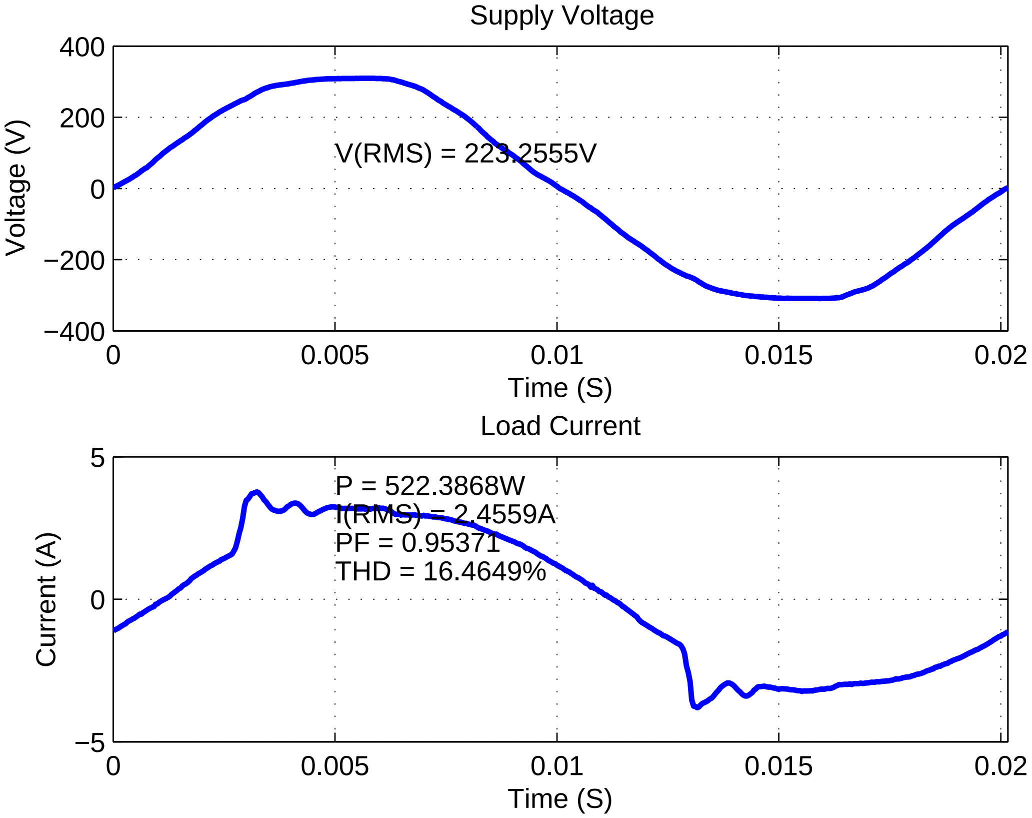

Figure 6.10: Current voltage waveforms for small office loads in a commercial area.

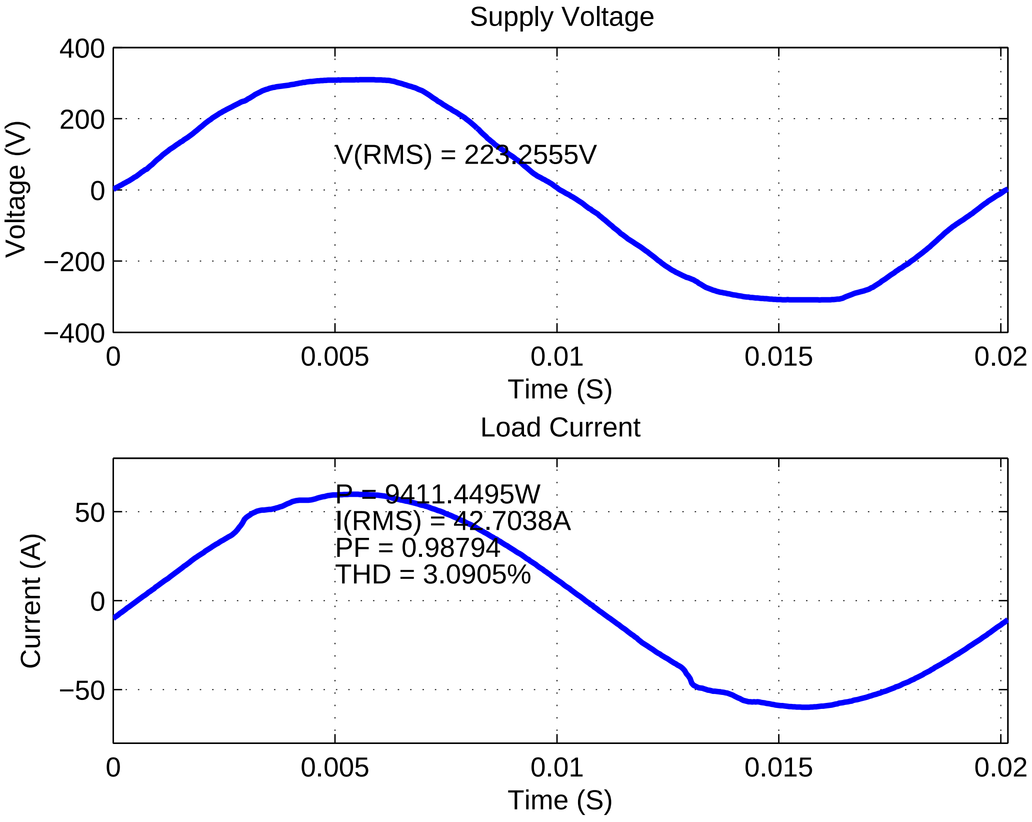

Figure 6.11: Current voltage waveforms for a commercial restaurant loads in a commercial area.

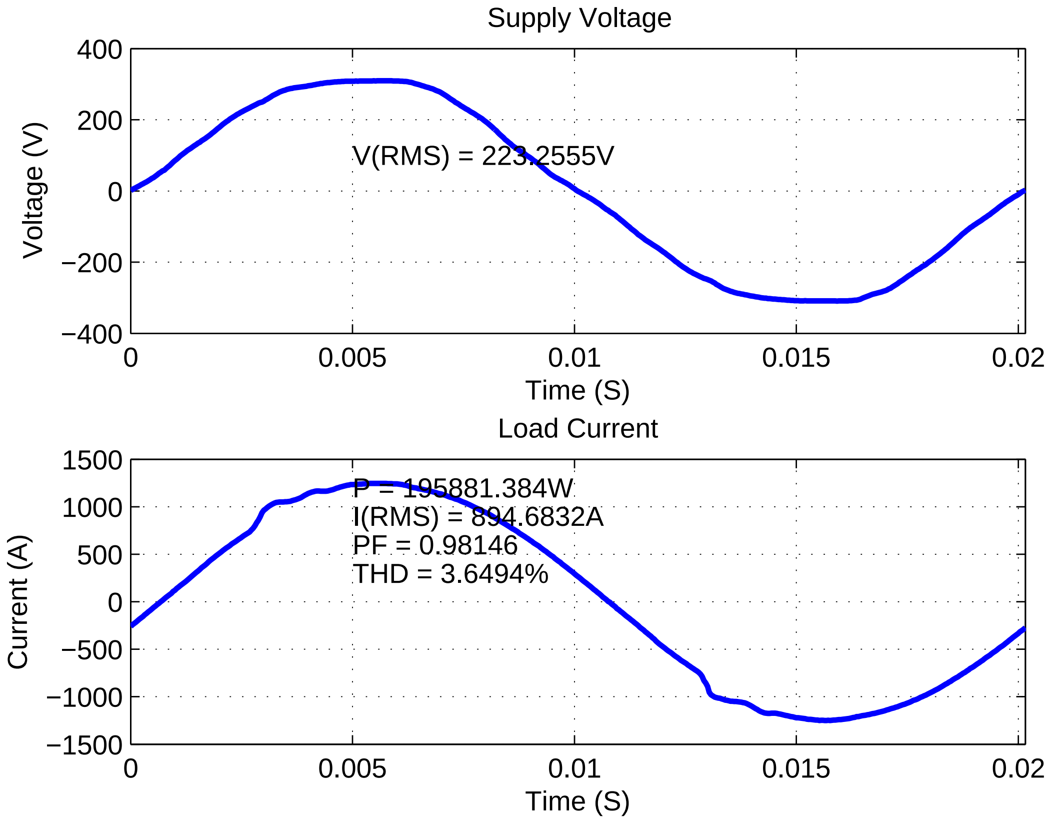

Figure 6.12: Current voltage waveforms for combined load in a commercial area.

6.3.3 Summary of Power Parameters in a Commercial Area

The power parameters for a commercial area with a 200KVA transformer shown in Figs. 6.8, 6.9, 6.10, 6.11, 6.12. The parameters are summarized in Table 6.6. The overall THD is 3.65 that is also lesser than the IEEE-519 limits.

Table 6.9: Summary of power parameters in a typical commercial area.

Para.	Large Off.	Medium Off.	Small Off.	Rest.	Over all
Total Power	12001.68	3730.80	522.38	9411.45	195881.38
RMS current	54.65	17.11	2.45	42.70	894.68
PF	0.98	0.98	0.95	0.99	0.98
Percent THD	2.41	2.40	16.46	3.09	3.65

6.4 Case Study 4: Loads in Semi-Commercial Area

Semi-commercial area means a commercial cum residential area, originally meant for offices as well as posh residences. We can consider the following loads (as shown in Table 6.10) are used in a semi-commercial area.

Table 6.10: Semi-commercial load.

Office/Residence Type	Load Type	Unit Power (Watt)	Quantity (Pcs)	Total Power (Watt)
Restaurant	Fan	60	12	720
	Refrigerator	150	3	450
	Heater	1000	3	2000
	Lamp	60	4	240
	CFL	23	10	230
	TL with MB	40	5	240
	TL with EB	40	5	240
Medium Office	Fan	60	4	240
	Refrigerator	150	1	150
	AC	1500	2	3000
	Lamp	60	3	180
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	2	80
Small Office	Fan	60	4	180
	Lamp	60	2	120
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	1	40
Medium Residence	Fan	60	4	240
	Refrigerator	150	1	150
	Washing Machine	500	1	500
	Heater	1000	1	1000
	Lamp	60	3	180
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	2	80
Small Residence	Fan	60	3	180
	Refrigerator	150	1	150
	Lamp	60	2	120
	CFL	23	3	69
	TL with MB	40	2	80
	TL with EB	40	1	40

Both commercial offices and residential buildings are situated in this type of area. Some time small offices are located with residential buildings. In Bangladesh, the increasing crowd of commercial offices and shopping complexes as well as different small offices in some posh city area change it to semi-commercial area. In this section, total load consumption in a semi-commercial area is calculated. In a semi-commercial area, most of the offices having common office equipments required for daily office works.

We have considered different type lighting loads in every offices and residences. Also AC and fans are considered for room cooling purpose. To avoid complexity we considered two types of offices and residential house which have a common load type. Also two commercial restaurants are considered in this area. Finally, the over all consumption of this area is computed combining these types of offices and residences.

6.4.1 Semi-Commercial Area from a 200KVA Transformer

In this section we consider two small commercial restaurants, 30 medium houses, 60 small houses, 15 medium offices and 30 small offices are available in a particular area. A 200KVA transformer is serving the area where the total consumption by different loads are shown in Table 6.11.

Table 6.11: Total semi-commercial load

Load Type	Unit Power Watt	Quantity Pcs	Total Power Watt
Fan	60	232	13920
Refrigerator	150	32	4800
AC	1500	87	130500
Washing Machine	500	0	0
Heater	1000	25	25000
Lamp	60	149	8940
CFL	23	245	5635
TL with MB	40	145	5800
TL with EB	40	115	4600

6.4.2 Current and Voltage Waveforms for Industries and Offices in a Semi-Commercial Area

The first two figures (Figs. 6.13, 6.14) represents the output for the load combination of two different type offices, the next two figures (Figs. 6.15, 6.16) represents two different type houses, the next one represents the output for a commercial load and the last one (Figs. 6.17) represents the overall load combination under a 200 KVA transformer.

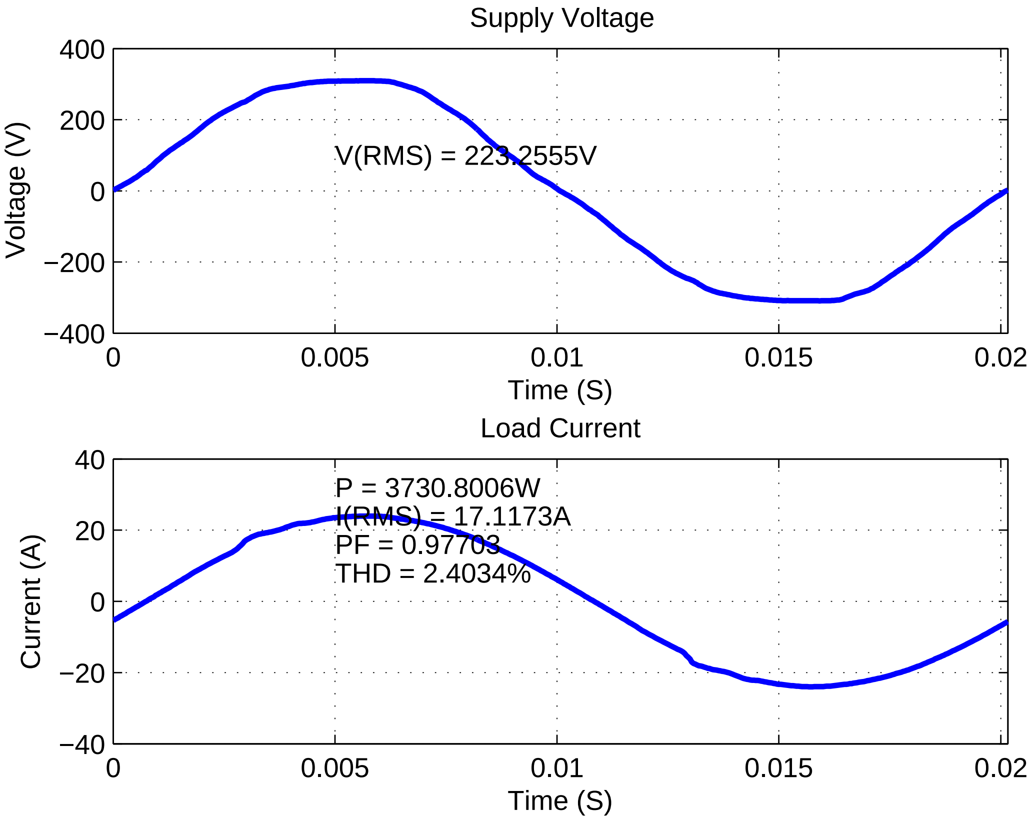

Figure 6.13: Current voltage waveforms for medium office loads in a semi-commercial area.

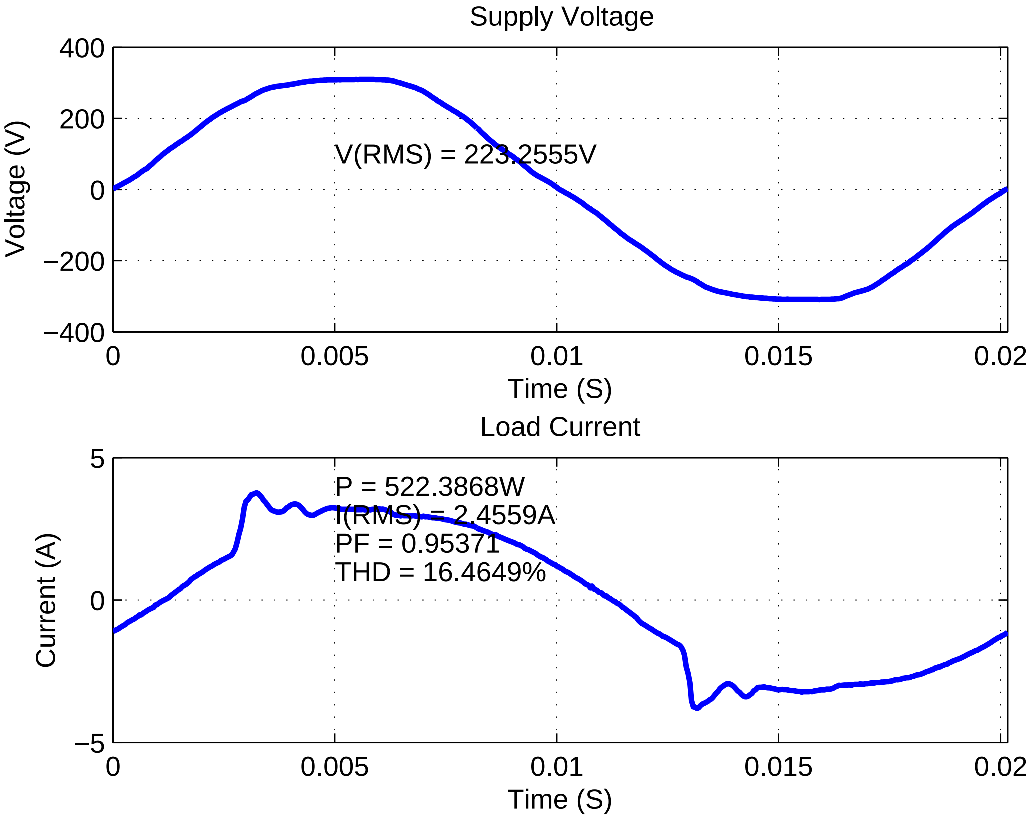

Figure 6.14: Current voltage waveforms for small office loads in a semi-commercial area.

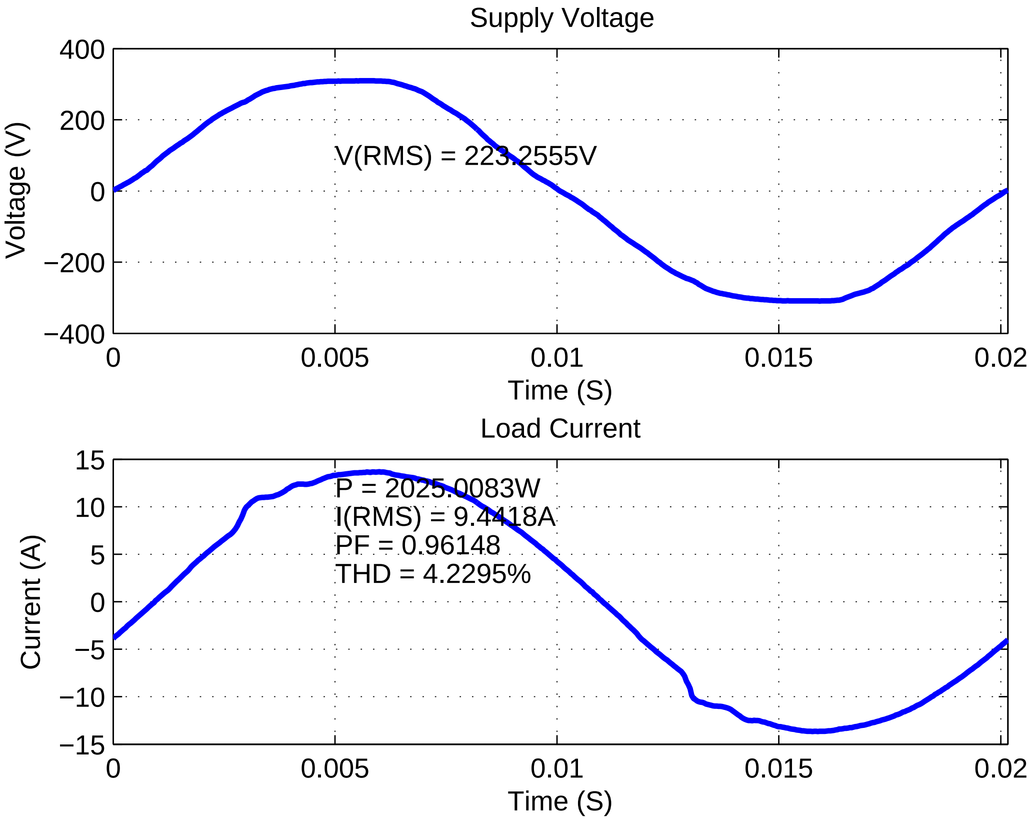

Figure 6.15: Current voltage waveforms for medium house loads in a semi-commercial area.

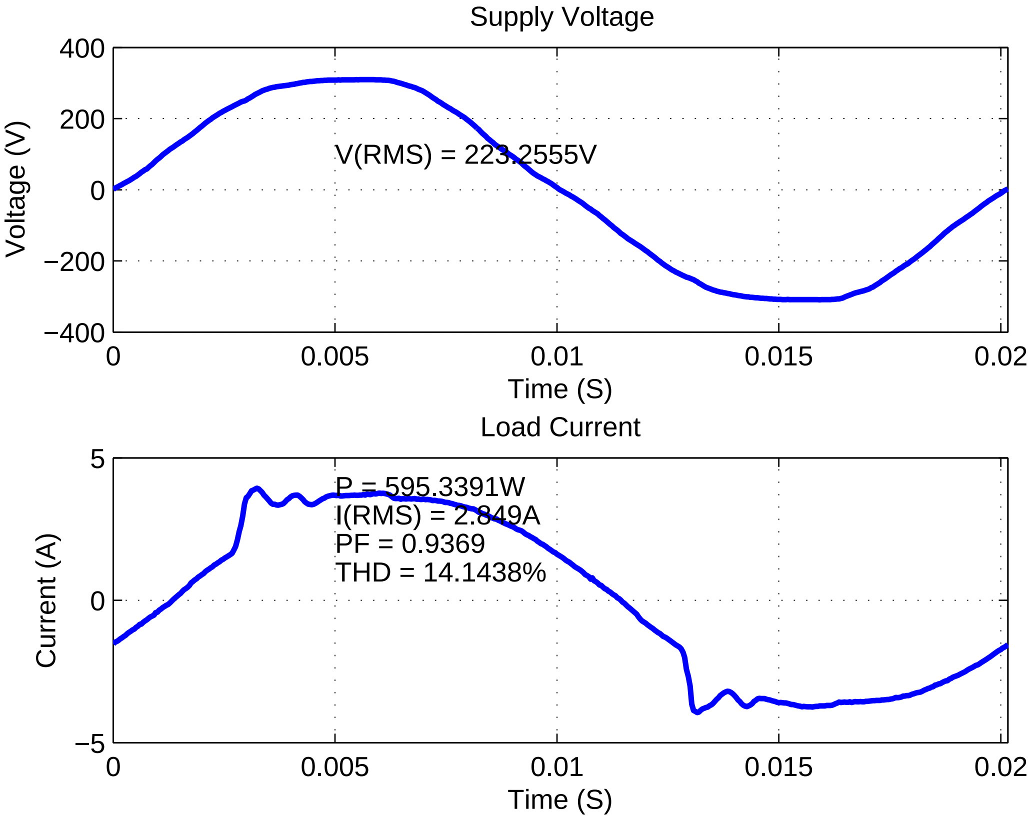

Figure 6.16: Current voltage waveforms for small house loads in a semi-commercial area.

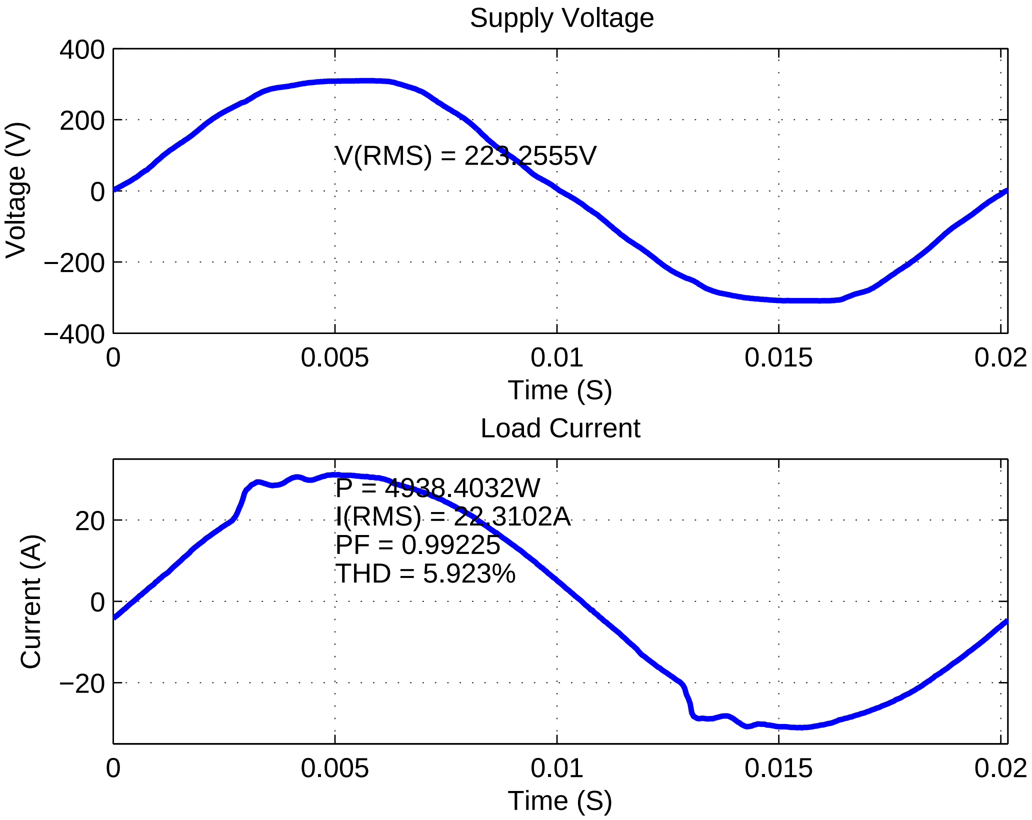

Figure 6.17: Current voltage waveforms for commercial restaurant loads in a semi-commercial area.

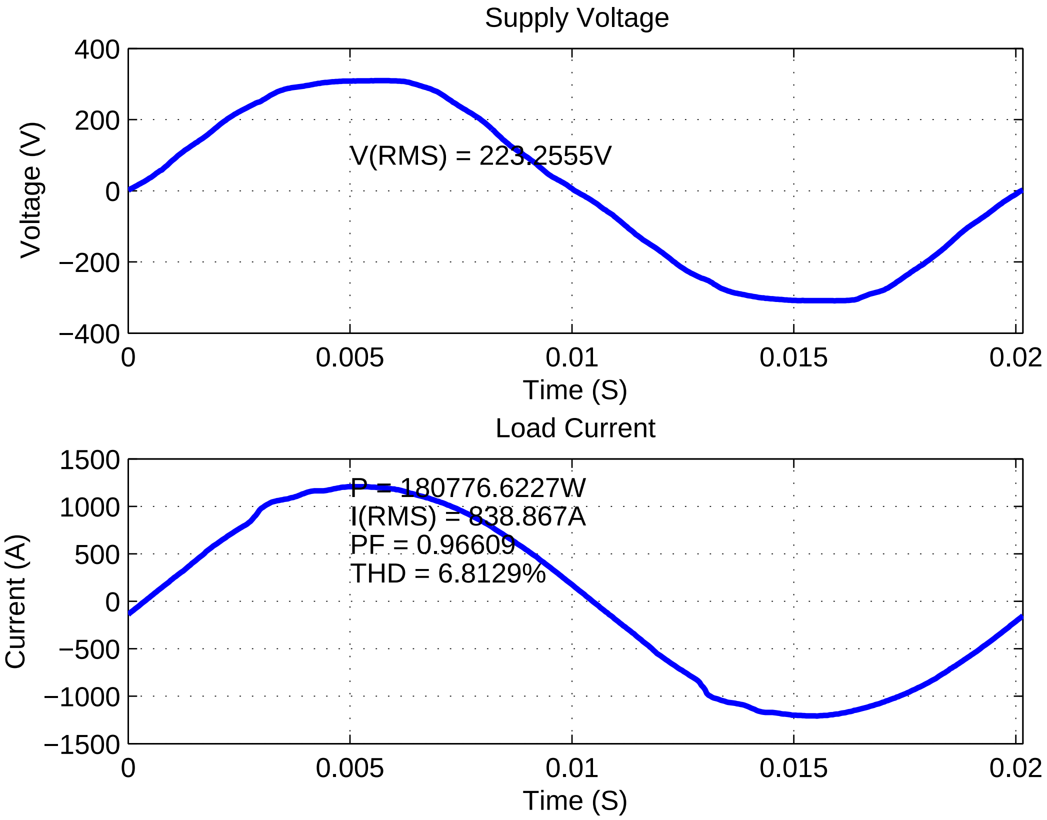

Figure 6.18: Current voltage waveforms for combined loads in a semi-commercial area.

6.4.3 Summary of Power Parameters in a Semi-Commercial Area

The power parameters for a semi-commercial area with a 200KVA transformer shown in Figs. 6.13, 6.14, 6.15, 6.16, 6.17, 6.18. The parameters are summarized in Table 6.12. The overall THD is 5.54% that is little bit higher in magnitude but is still within the IEEE-519 limits.

Table 6.12: Summary of power parameters in a typical semi-commercial area.

Para.	Medium Off	Small Off	Medium Res.	Small Res.	Rest.	Over all
Total Power	3730.80	522.38	2025.19	595.33	4938.40	180271.82
RMS current	17.11	2.45	9.44	2.85	22.31	838.87
PF	0.98	0.95	0.96	0.94	0.99	0.96
Percent THD	2.40	16.46	4.23	14.14	5.92	5.54

Chapter 7

Power Quality in Substation End for Different Load Types

In this chapter we focus on substation load that is an accumulation of the different local loads as described in previous sections. A substation is thus considered to supply the following feeders:

i) One posh residential area

ii) One suburb residential area

iii) One common city residential area

iv) One commercial area

v) One semi-commercial area

vi) One industrial area

vii) One semi-industrial area

viii) One rural area

The total KVA rating is 1.6MVA. The overall power quality of the total supply from the substation are evaluated without adding transformer and feeder losses. We also analyzed the effects of bulk scale replacement of a energy inefficient lamps with efficient ones.

7.1 Case Study: Overall Impact in a Substation

7.1.1 Case 1: Loads are Normal

Here we consider a substation having eight different types of loads presented in earlier sections. The overall voltage and current waveforms on per phase basis are shown in Fig. 7.1.

7.1.2 Case 2: IL's Phased Out by CFL's

Sine there is a Government policy of replacing IL by CFL's, we considered three cases where IL's are phased out in bulk scale by a factor of 25%, 50%, 75% and 100% respectively. Other loads are considered remain the same as in case 1. Figs. 7.2, 7.3, 7.4 and 7.5 shows overall waveforms for replacement of IL in bulk scale of 25%, 50%, 75% and 100% respectively by CFL's.

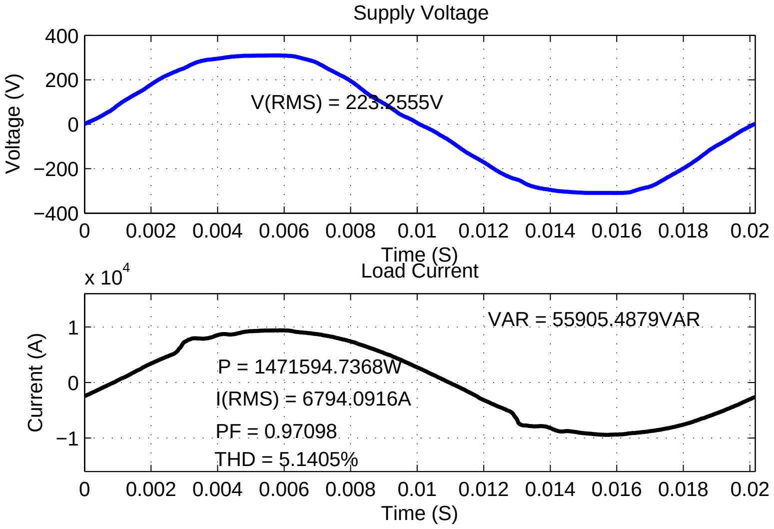

Figure 7.1: Current voltage waveforms for all loads

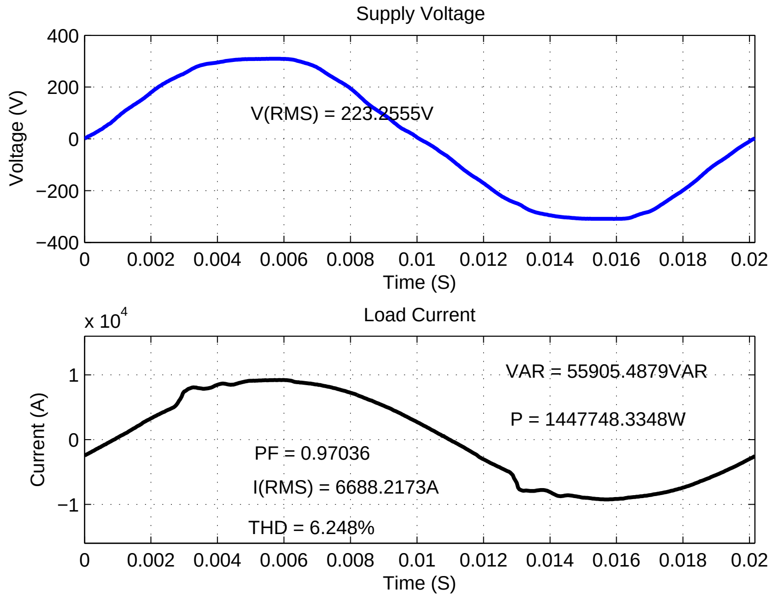

Figure 7.2: Current voltage waveforms for all loads after replacing twenty five percent IL

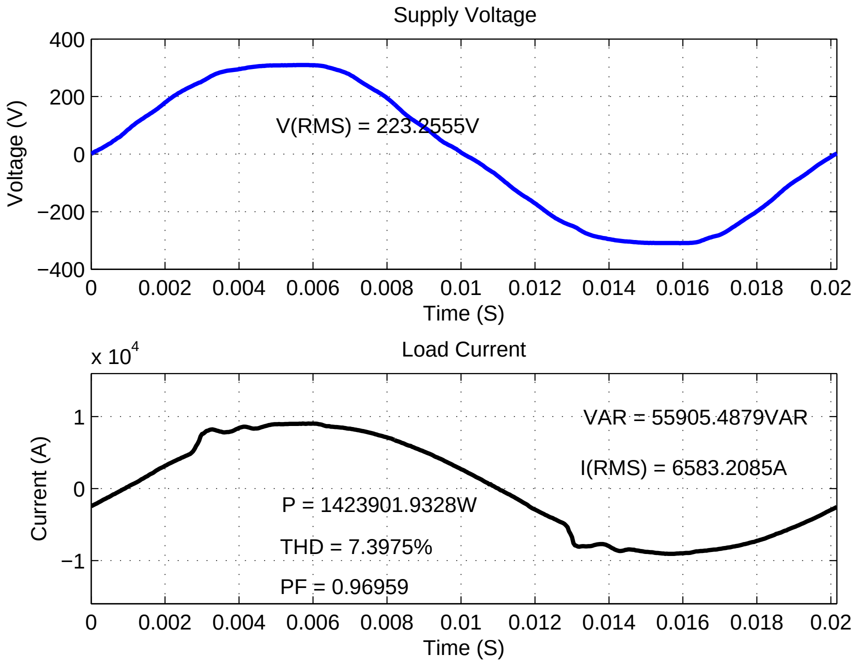

Figure 7.3: Current voltage waveforms for all loads after replacing fifty percent IL

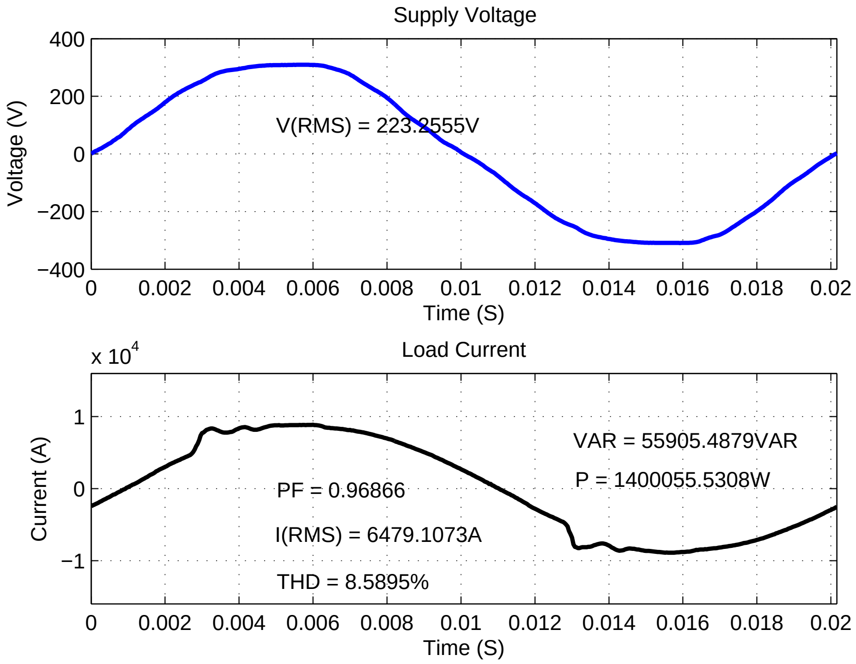

Figure 7.4: Current voltage waveforms for all loads after replacing seventy five percent IL

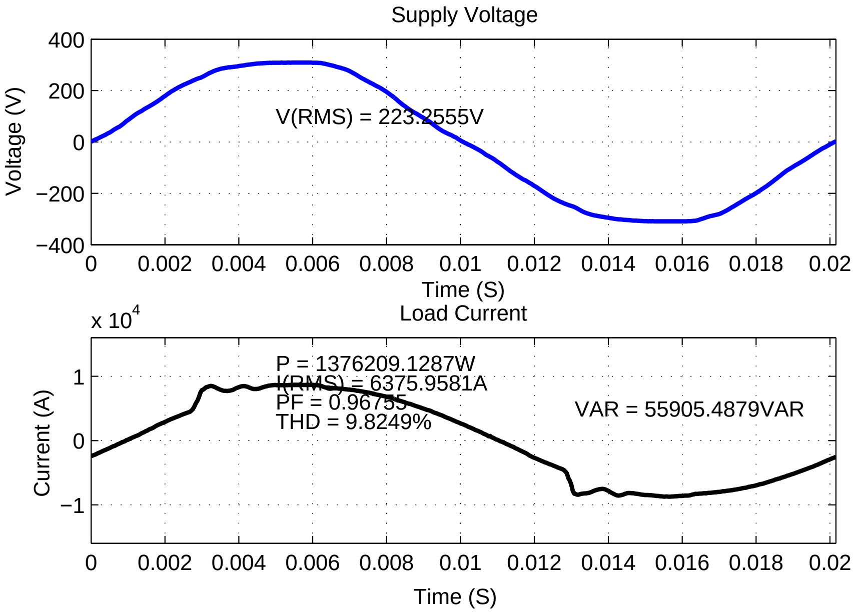

Figure 7.5: Current voltage waveforms for all loads after replacing all ILs

7.1.3 Case 3: Replacing Magnetic Ballast with Electronic Ballasts in Bulk Scale

Replacement of IL's with CFL's are easy options as both can be plugged in a common bulb holder. CFL's are no longer considered alternative to conventional FL's. However conventional FL's can be easily driven by electronic ballasts by just replacing the choke and starter. Here we consider few cases where the magnetic ballast and starter are replaced by electronic ballast in FL's. We consider 25%, 50%, 75% and 100% replacements of MB's with EB's. Figs. 7.6, 7.7, 7.8 and 7.9 shows the overall waveforms for 25%, 50%, 75% and 100% replacements of MB's with EB's. Other loads are considered to remain same as before with all IL's replaced by CFL's.

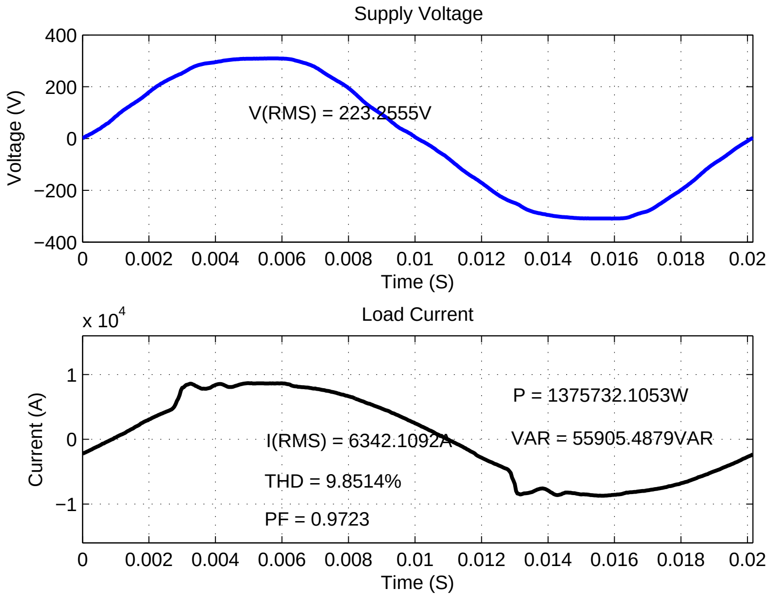

Figure 7.6: Current voltage waveforms for all loads after replacing twenty five percent FL running by MB

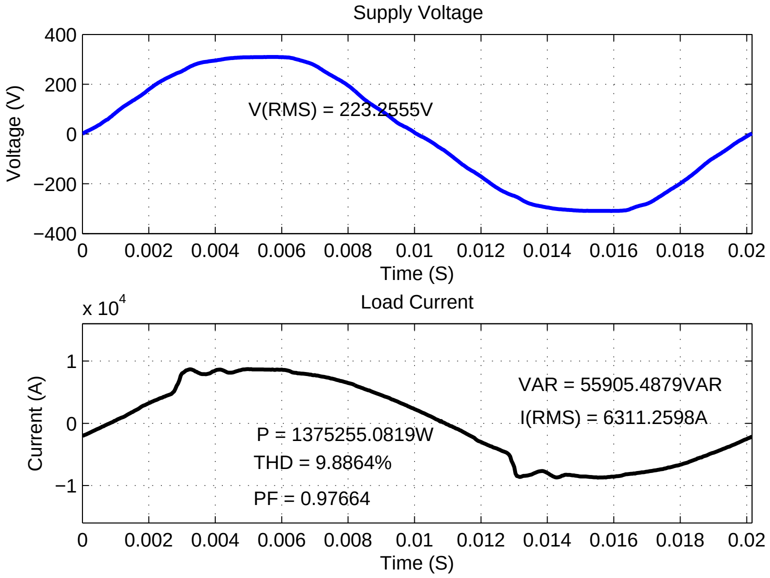

Figure 7.7: Current voltage waveforms for all loads after replacing fifty percent FL running by MB

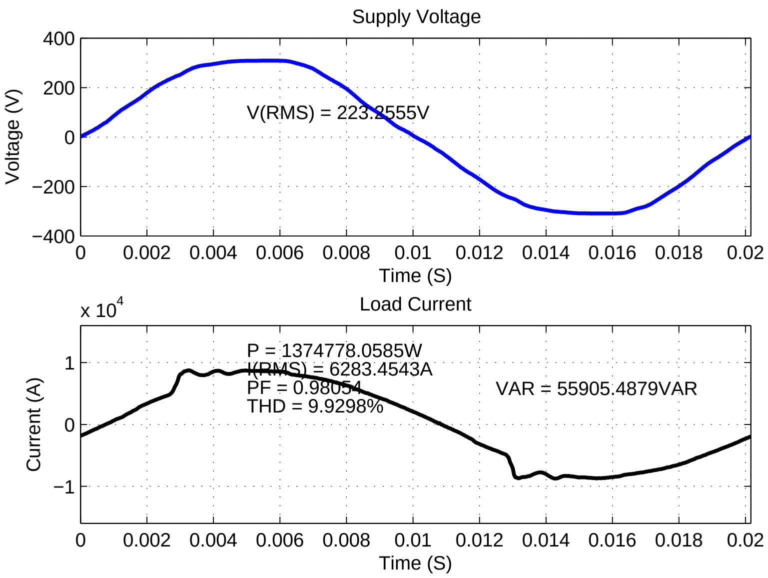

Figure 7.8: Current voltage waveforms for all loads after replacing seventy five percent FL running by MB

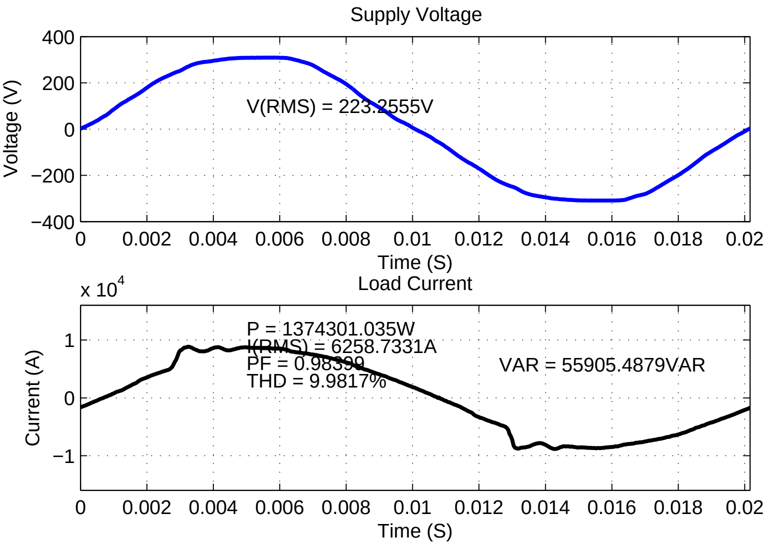

Figure 7.9: Current voltage waveforms for all loads after replacing all FLs running by MB

7.2 Summary of Substation Power Quality Scenario

Table 7.1 shows the overall scenario of the power and quality parameters for a substation where IL's are replaced by CFL's in bulk scale. Replacing 25% of the IL's with CFL's save 24KW power but increases the THD from 5.14% to 6.25%. Replacement of 100% IL by CFL saves power of 95.38 KW that is a huge saving sacrificing a THD rise from 5.14% to 9.82%. This THD is below the limit of IEEE-519. It is interesting to note that power saving by CFL have insignificant affect on the PF.

Table 7.1: Impacts of changing IL's by CFL's in bulk scale

Load Type	Power KW	I(RMS) KA	Power Factor	THD Percent
Full load	1471.59	6.79	0.97	5.14
Replacing 25 Percent of IL	1447.74	6.68	0.97	6.25
Replacing 50 Percent of IL	1423.9	6.58	0.969	7.39
Replacing 75 Percent of IL	1400.06	6.47	0.968	8.58
Replacing 100 Percent of IL	1376.21	6.37	0.967	9.82

The impact of replacing MB's with EB's are summarized in Table 7.2. It is observed that replacement of 100% MB's with EB's improves the PF from 0.967 to 0.983. There is slight increase in THD from 9.82% to 9.98% and negligible power saving of 1.91 KW.

Table 7.2: Impacts of changing MB's by EB's in bulk scale

Load Type	Power KW	I(RMS) KA	Power Factor	THD Percent
Full load	1376.21	6.37	0.967	9.82
Replacing 25 Percent of FL run by MB	1375.73	6.34	0.972	9.85
Replacing 50 Percent of FL run by MB	1375.25	6.31	0.976	9.89
Replacing 75 Percent of FL run by MB	1374.77	6.28	0.981	9.93
Replacing 100 Percent of FL run by MB	1374.3	6.25	0.983	9.98

Chapter 8

Conclusion

A new approach is presented in this thesis where loads are modeled in terms of waveform templates. The templates are obtained from processing captured real time waveforms. These templates are used to determine the power quality parameters of a distribution system having different types of load combinations. The individual current waveform of CFL are found to contain THD of more than hundred and twenty percent. An electronic ballast have THD of near about twenty percent. These individual harmonic distortions of CFL and electronic ballast are very high. When a lamp is replaced by a CFL the total power scale down to almost twenty percent of the lamp load. However, the power factor changes from unity to 0.57 (leading). On the other hand replacement of a tube light with magnetic ballast by an electronic ballast does not change the power significantly. However, improves the power factor from 0.57 (lagging) to almost unity. For tube light loads changing the ballast (from conventional magnetic ballast to electronic ballast) does not significantly affect the THD. Case studies on bulk scale use of non linear but energy efficient lighting loads show that the overall current THD increases, however remain within the recommended limits of 20% as specified in IEEE 519 standard. From these case study it can be concluded that bulk scale use of CFL and electronic ballast would not pose any problem in distribution network.

8.1 Future work

In this research we concentrated our focus on power quality considering non-linear lighting loads only. Bulk scale use of power electronic loads like rectifiers, inverter driven drives, arc furnaces, induction heating etc are not considered. Issues like visual effects of CFL and effects of radio frequency harmonics on health are also not considered in this work. Literatures are inadequate on health hazards by CFL and Electronics Ballasts. There are ample scope of conducting research on health hazard cause by bulk scale use of CFL.

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Appendix

Sample M-File for data import

```
clear all
clc  % clear command window
filepath = ’c:\Users\sony\Desktop\MUNIM\THESIS\data\’;
sourcetextfile = ’Jan_01_2010_Friday_104816AM6EB’;

filename = strcat(filepath,sourcetextfile,’.txt’);
x = importdata(filename);

alfa_V = 71;
alfa_I = 10;


v = alfa_V*x(:,1);
i1 = -alfa_I*x(:,2);




ZCF = 0;
for i=2:length(v)
    if v(i-1) <0 && v(i)>0
        ZCF = ZCF+ 1;
        if ZCF ==1
        count1 = i;
        end
        if ZCF ==2
            count2=i;
        end
    end
end
```

```
Nmax = count2-count1;
v_1_cycle = v(count1:count2);
i_1_cycle = i1(count1:count2);

frequency = 25000/Nmax
dt = 1/25000;
t = 0:dt:(length(v)-1)*dt;
VRMS = sqrt(mean(v(1:Nmax).*v(1:Nmax)));
VFFT = 2.0*fft(v(1:Nmax))/Nmax;
V1RMS = abs(VFFT(2))/sqrt(2);
theta_V = angle(VFFT(2))*180/pi;
THD_V = 100*sqrt(power(VRMS,2)-power(V1RMS,2))/V1RMS

IRMS = sqrt(mean(i1(1:Nmax).*i1(1:Nmax)));
I1FFT = 2.0*fft(i1(1:Nmax))/Nmax;
I1RMS = abs(I1FFT(2))/sqrt(2);
theta_I = angle(I1FFT(2))*180/pi;
THD_I = 100*sqrt(power(IRMS,2)-power(I1RMS,2))/I1RMS
theta = theta_V-theta_I
Disp_Factor = cos(theta*pi/180)
Power_Factor = I1RMS*Disp_Factor/IRMS

P = mean(v(1:Nmax).*i1(1:Nmax))

t1 = 0:dt:(length(v_1_cycle)-1)*dt;

hold off;
subplot(211), plot(t1,v_1_cycle,'red','LineWidth',2);
grid on;
title('Supply Voltage');
text(.005,200,['THD = ',num2str(THD_V), '%']);
text(.005,100,['V(RMS) = ',num2str(VRMS), 'V']);
axis([0 max(t1) -400 400]);
ylabel('Voltage (V)');
xlabel('Time (S)');

subplot(212), plot(t1,i_1_cycle,'blue','LineWidth',2);
hold on;
grid on;
```

```
axis([0 max(t1) -3 3]);
title('Load Current for 4x40W Electronic Ballasts');
ylabel('Current (A)');
xlabel('Time (S)');
text(.005,.5,['THD = ',num2str(THD_I), '%']);
text(.005,.9,['PF = ',num2str(Power_Factor)]);
text(.005,1.3,['I(RMS) = ',num2str(IRMS), 'A']);
text(.005,1.7,['P = ',num2str(P), 'W']);

% set(gcf, 'PaperType', 'A4');
% set(gcf, 'PaperPositionMode', 'manual');
% set(gcf, 'PaperUnits', 'inches');
% set(gcf, 'PaperPosition', [.25 .25 7.77 11.19]);
 hgsave(sourcetextfile);
```

Example Matlab Program for Equalizing Per-Cycle Sample Sequences

```
clear all;
clc;
N_CFL = 120;
N_MB = 120;
N_EB = 120;
[data1,v1,iload1] = CFL(N_CFL);
[data2,v2,iload2] = EB(N_EB);
[data3,v3,iload3] = MB(N_MB);



v2fft = fft(v2);
iload2fft = fft(iload2);
for n=1:248
    v2fft_(n) = v2fft(n);
    iload2fft_(n) = iload2fft(n);
end
for n=249:257
    v2fft_(n) = 0;
    iload2fft_(n) = 0;
end
v2fft_(249) = v2fft(249);
iload2fft_(249) = iload2fft(249);
```

```
for n=258:505
    v2fft_(n) = v2fft(n-8);
    iload2fft_(n) = iload2fft(n-8);
end

v2_ = (ifft(v2fft_))’;
iload2_ = (ifft(iload2fft_))’;
%sum = v1 + v2_ + v3;
i_sum = iload1 + iload2_+iload3;
```

Sample M file used to get the output of combination of different type loads in a distribution network using the data template.

```
clear all;
clc;
N_R = 0;  N_CFL = 4;
N_MB = 0; N_EB =4 ;
N_F = 0;  pf_F= 1;
N_Rf = 0; pf_Rf= 1;
N_W = 0;  pf_W= 1;
N_AC = 0; pf_AC= 1;
[data1,v1,iload1] = CFL(N_CFL);
[data2,v2,iload2] = EB(N_EB);
[data3,v3,iload3] = MB(N_MB);
[data4,v4,iload4] = R(N_R);
[iload5] = L(N_F,pf_F);
[iload6] = L(N_Rf,pf_Rf);
[iload7] = L(N_W,pf_W);
[iload8] = L(N_AC,pf_AC);
i_sum = iload1 + iload2 + iload3+ iload4+ iload5+ iload6;
P_total = mean(v1.*i_sum);
i_array = [iload1;iload2;iload3];

f = 50;
dt = 1/(f*length(v1));
t = dt:dt:1/f;

Nmax = length(v2);
```

```
frequency = 50;
dt = 1/25000;
t = 0:dt:(length(v1)-1)*dt;
VRMS = sqrt(mean(v1(1:Nmax).*v1(1:Nmax)));
VFFT = 2.0*fft(v1(1:Nmax))/Nmax;
V1RMS = abs(VFFT(2))/sqrt(2);
theta_V = angle(VFFT(2))*180/pi;
THD_V = 100*sqrt(power(VRMS,2)-power(V1RMS,2))/V1RMS

IRMS = sqrt(mean(i_sum(1:Nmax).*i_sum(1:Nmax)));
I1FFT = 2.0*fft(i_sum(1:Nmax))/Nmax;
I1RMS = abs(I1FFT(2))/sqrt(2);
theta_I = angle(I1FFT(2))*180/pi;
T_I = 100*sqrt(power(IRMS,2)-power(I1RMS,2))/I1RMS
theta = theta_V-theta_I
Disp_Factor = cos(theta*pi/180)
Power_Factor = I1RMS*Disp_Factor/IRMS

P = mean(v1(1:Nmax).*i_sum(1:Nmax))
hold off;
subplot(211),plot(t,v1,'blue','LineWidth',2);
grid on;
title('Supply Voltage');
text(.005,200,['THD = ',num2str(THD_V), '%']);
text(.005,100,['V(RMS) = ',num2str(VRMS), 'V']);
axis([0 max(t) -400 400]);
ylabel('Voltage (V)');
xlabel('Time (S)');

subplot(212),plot(t,i_sum,'yellow','LineWidth',2);
hold on;
grid on;
axis([0 max(t) -2 2]);
title('Load Current for 200 KVA Residentail Laod');
ylabel('Current (A)');
xlabel('Time (S)');
text(.005,.5,['THD = ',num2str(THD_I), '%']);
text(.005,1,['PF = ',num2str(Power_Factor)]);
text(.005,1.4,['I(RMS) = ',num2str(IRMS), 'A']);
```

```
text(.005,1.8,['P = ',num2str(P), 'W']);
```

Program for calculating Output curve

```
clear all;
clc;
N_F = Number of Fan;
pf_F= PF of Fan;
N_Rf = Number of Refrigerator;
pf_Rf= PF of Refrigerator;
N_AC = Number of AC;
pf_AC= PF of AC;
N_W = Number of Washing Machine;
pf_W= PF of Washing Machine;
N_H = Number of Heater/Iron;
N_IL = Number of IL;
N_CFL = Number of CFL;
N_MB = Number of FL run by MB;
N_EB = Number of FL run by EB;
N_EF = Number of Exhaust Fan;
pf_EF= PF of Exhaust Fan;
N_Wi = Number of Washing Machine Industrial;
pf_Wi= PF of Washing Machine Industrial;
N_VC = Number of Vacuum Cleaner;
pf_VC= PF of Vacuum Cleaner;
N_WP = Number of Water Pump;
pf_WP= PF of Water Pump;
N_MMb=Number of Big Mixer Machine;
pf_MMb=PF of Big Mixer Machine;
N_MMs=Number of Small Mixer Machine;
pf_MMs=PF of Small Mixer Machine;
N_S=Number of Sewing Machine ;
pf_S=PF of Sewing Machine;

%Function(1) for retrieving the stored templates

[data1,v1,iload1] = IL(N_IL);
[data2,v2,iload2] = CFL(N_CFL);
[data3,v3,iload3] = EB11(N_EB);
```

```
[data4,v4,iload4] = MB(N_MB);

%Finding the highest data length
nmax = max(max(max(length(v1),length(v2)),length(v3)),length(v4));
%v2fft = fft(v2);
%sum = v1 + v2_ + v3;
% Function(2) for equalizing all data length
[v1_,iload1_] = new(nmax,v1,iload1);
[v2_,iload2_] = new(nmax,v2,iload2);
[v3_,iload3_] = new(nmax,v3,iload3);
[v4_,iload4_] = new(nmax,v4,iload4);

%Function(3) for generating load current waveform

[iload5_] = F(N_F,pf_F,nmax);
[iload6_] = Rf(N_Rf,pf_Rf,nmax);
[iload7_] = W(N_W,pf_W,nmax);
[iload8_] = AC(N_AC,pf_AC,nmax);
[iload10_] = R(N_R,nmax);
[iload11_] = H(N_H,nmax);
[iload12_] = EF(N_EF,pf_EF,nmax);
[iload13_] = Wi(N_Wi,pf_Wi,nmax);
[iload14_] = VC(N_VC,pf_VC,nmax);
[iload15_] = WP(N_WP,pf_WP,nmax);
[iload16_] = MMb(N_MMb,pf_MMb,nmax);
[iload17_] = MMs(N_MMs,pf_MMs,nmax);
[iload18_] = S(N_S,pf_S,nmax);

%Load calculation

i_sum =  iload2_ +  iload3_+  iload4_+iload5_+iload6_+iload7_
+iload8_+iload10_+iload11_+iload12_+iload13_+iload14_+iload15_
+iload16_+iload17_+iload18_;



P_total = mean(v1_.*i_sum);

% Frequency calculation
```

```
frequency = 25000/nmax;
dt = 1/25000;
t = 0:dt:(nmax-1)*dt;

%Output Voltage Wave

VRMS = (sqrt(mean(v1_(1:nmax).*v1_(1:nmax))));
VFFT = (2.0*fft(v1_(1:nmax))/nmax);
V1RMS = abs(VFFT(2))/sqrt(2);
theta_V = angle(VFFT(2))*180/pi;
THD_V = 100*sqrt(power(VRMS,2)-power(V1RMS,2))/V1RMS

%Output Current Wave

IRMS = (sqrt(mean(i_sum(1:nmax).*i_sum(1:nmax))));
I1FFT = (2.0*fft(i_sum(1:nmax))/nmax);
I1RMS = abs(I1FFT(2))/sqrt(2);
theta_I = angle(I1FFT(2))*180/pi;
THD_I = 100*sqrt(power(IRMS,2)-power(I1RMS,2))/I1RMS

%Power calculation Without PFI plant

theta = (theta_V-theta_I)
Disp_Factor = cos(theta*pi/180)
Power_Factor = I1RMS*Disp_Factor/IRMS
P = (mean(v1_(1:nmax).*i_sum(1:nmax)))

%Function(4) to calculate VAR to maintain PF .95

[iload9_,KVAR1] = PFIN(P2,Power_Factor2,nmax);

%Calculation after PF Improvement

i_sum_ = i_sum +  iload9_+  iload91_+  iload92_;

IRMS_ = (sqrt(mean(i_sum_(1:nmax).*i_sum_(1:nmax))));
I1FFT_ = (2.0*fft(i_sum_(1:nmax))/nmax);
I1RMS_ = abs(I1FFT_(2))/sqrt(2);
theta_I_ = angle(I1FFT_(2))*180/pi;
```

```
THD_I_ = 100*sqrt(power(IRMS_,2)-power(I1RMS_,2))/I1RMS_
theta_ = (theta_V-theta_I_)
Disp_Factor_ = cos(theta_*pi/180)
Power_Factor_ = I1RMS_*Disp_Factor_/IRMS_

KVAR_=KVAR;
P_ = (mean(v1_(1:nmax).*i_sum_(1:nmax)))
hold off;

% Curve Fitting

subplot(211),plot(t,v1_,'blue','LineWidth',2);
grid on;
title('Supply Voltage');
%text(.005,200,['THD = ',num2str(THD_V), '%']);
text(.005,100,['V(RMS) = ',num2str(VRMS), 'V']);
axis([0 max(t) -400 400]);
ylabel('Voltage (V)');
xlabel('Time (S)');

subplot(212),plot(t,i_sum_,'yellow','LineWidth',2);
hold on;
grid on;
axis([0 max(t) -16000 16000]);
title('Load Current');
ylabel('Current (A)');
xlabel('Time (S)');
text(.005,3000,['THD = ',num2str((THD_I_)), '%']);
text(.005,6000,['PF = ',num2str((Power_Factor_))]);
text(.005,9000,['I(RMS) = ',num2str((IRMS_)), 'A']);
text(.005,12000,['P = ',num2str((P_)), 'W']);
text(.005,15000,['VAR = ',num2str((KVAR_)), 'VAR']);

% set(gcf, 'PaperType', 'A4');
% set(gcf, 'PaperPositionMode', 'manual');
% set(gcf, 'PaperUnits', 'inches');
% set(gcf, 'PaperPosition', [.25 .25 7.77 11.19]);
% hgsave(sourcetextfile);
```

Function(1)

```
function [data,v,iload] = CFL(n)
 data = load('CFL14.dat');
 v = data(:,1);
 iload = (n*data(:,2));
end
```

Function(2)

```
% function declarations
function [v_,iload_] = new(nmax,v,iload)

m = length(v);
if nmax == m
        v_ = v;
        iload_ = iload;
else
    vfft = fft(v);
iloadfft = fft(iload);
mcheck = mod(m,2);
if mcheck == 0
mout = m ;
halfm = (mout/2);
for n=1:halfm
    vfft_(n) = vfft(n);
    iloadfft_(n) = iloadfft(n);
end
for n=(halfm+1):(halfm+(nmax-m))
    vfft_(n) = 0;
    iloadfft_(n) = 0;
end

vfft_((mout/2)+1) = vfft((mout/2)+1);
iloadfft_((mout/2)+1) = iloadfft((mout/2)+1);

for n=(halfm+(nmax-m)+1):nmax
    vfft_(n) = vfft(n-(nmax-m));
    iloadfft_(n) = iloadfft(n-(nmax-m));
end
```

```
else
mout = (m-1);
halfm = (mout/2);
for n=1:halfm
    vfft_(n) = vfft(n);
    iloadfft_(n) = iloadfft(n);
end
for n=(halfm+1):(halfm+(nmax-m))
    vfft_(n) = 0;
    iloadfft_(n) = 0;
end

vfft_((mout/2)+1) = vfft((mout/2)+1);
iloadfft_((mout/2)+1) = iloadfft((mout/2)+1);

for n=(halfm+(nmax-m)+2):nmax
    vfft_(n) = vfft(n-(nmax-m));
    iloadfft_(n) = iloadfft(n-(nmax-m));
end
end

v_ = (ifft(vfft_))';
iload_ = (ifft(iloadfft_))';
end
end
```

Function(3)

```
function [iload] = EF(n,pf,nmax)
  Vmax = sqrt(2)*220;
  dt = 1/(50*nmax);
 Imax = 750*2*n/(Vmax);
 t = 0:dt:(nmax-1)*dt;
 theta = acos(pf);
 w = 2.0*pi*50;
 i = Imax*sin(w*t-theta);
 iload = i';
end
```

Function(4)

```
function [iload,KVAR] = PFIN(P,Power_Factor,nmax)
  Vmax = sqrt(2)*220;

 dt = 1/(50*nmax);
 t = 0:dt:(nmax-1)*dt;
 w = 2.0*pi*50;

 if Power_Factor >= .95
        Imax=0;
 else
 Imax = 2*P*(tan(acos(Power_Factor))-tan(acos(.95)))/(Vmax);
 end
 i = Imax*sin(w*t+(pi/2));
 iload = i';
 KVAR = Imax*Vmax/2;
end
```