THESIS

On

Analysis of Non-Technical Losses and its Economic Consequences on Power System

(A Case Study of Punjab State)

Submitted in the partial fulfillment of the requirements for the award of degree of

Master of Engineering

In

Power Systems & Electric Drives

To

Thapar University

Patiala

Submitted by

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DECLARATION

This is to certify that the work presented in the thesis titled **"ANALYSIS OF NON-TECHNICAL LOSSES AND ITS ECONOMIC CONSEQUENCE ON POWER SYSTEM"** by **Tejinder Singh** in partial fulfillment of requirements for the award of degree of Master of Engineering (Power Systems & Electric Drives) submitted in the **Electrical and Instrumentation Engineering Department** at **Thapar University, Patiala** is an authentic record of the work done by undersigned during the period from January 2009 to June 2009 under the esteemed supervision of **Dr. Smarajit Ghosh** and **Dr. P. S. Bimbhra**. The matter presented in this thesis has not been submitted by me in any other university.

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ABSTRACT

India faces endemic electrical energy and peaking shortages. The Power Sector is plagued with mounting commercial losses due to various inefficiencies, colossal commercial and technical losses and increasing subsidy burden on the states. These shortages have had a very detrimental effect on the overall economic growth of the country. As total distribution system losses equals technical losses plus non-technical losses. The reasons cited for such high losses are; lack of adequate T & D capacity, too many transformation stages, improper load distribution and extensive rural electrification etc. A non-technical loss is defined as any consumed energy or service which is not billed because of measurement equipment failure or ill intentioned and fraudulent manipulation of said equipment. Therefore, detection of non-technical losses includes detection of fraudulent users.

Simply Losses could be defined as the difference between the metered units of electricity entering the distribution network and those leaving the network paid for through electricity accounts, whether estimated or metered, in a well defined period of time. When defined by percentage, losses may be referred either to emissions or to withdrawals but the adoption of a common standard is regarded as an important step towards enabling the comparison of losses across network operators. In order to study non technical losses which constitute a portion of the total losses in electrical power systems, the logical first step is to understand the complete picture of power systems losses.

Technical losses are regarded as the electrical system losses which are caused by network impedance, current flows and auxiliary supplies. The sources of technical losses may be directly driven by network investment or by network operation. Non-technical losses, sometimes referred to as commercial losses, arise from several areas including theft, un-billed accounts, estimated customer accounts, errors due to the approximation of consumption by un-metered supplies and metering errors. The purpose of this thesis is to perform an introductory investigation of Non Technical Losses with the help of a case study in power systems. These are losses in power systems that cannot be predicted or calculated beforehand because the main reason for non technical loss is Electricity theft. Electricity theft is part of a phenomenon known as “Non-Technical Losses” (NTL) in electrical power systems. It is estimated that electricity theft costs in our country is in billions a year. Such estimates are the beginning of this work.

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CHAPTER 1

INTRODUCTION

In its earliest incarnations, electricity was a kind of magical force, something to be exhibited at the sideshow to curious awestruck onlookers. But it quickly became an essential part of daily life, something now taken for granted by almost everyone in the industrialized world. At its most fundamental level, what it does is give us light and heat when it is dark and cold. That is, electricity liberates humanity from the constraints of nature and contravenes the ordering of day and night. The power that travels through poles and wires is an invisible yet vital force that connect us each to the other. Power is about the way in which electricity is generated and distributed. The way decisions about the generation and distribution of electricity are made affects us all.

There are certain losses which affect the economy of the power system. In India the percentage of transmission and distribution losses has been quite high. The term “distribution losses” refers to the difference between the amount of energy delivered to the distribution system and the amount of energy customers is billed. Distribution line losses are comprised of two types: technical and non-technical. The aim of the thesis work is to investigate the nature of non-technical losses in power systems, their sources, the measurement of non-technical losses, some measures taken by selected utilities to reduce them, and possibly their impact on the system. In general, system losses increase the operating costs of electric utilities and typically result in higher cost of electricity. The increase in the electricity price to customers will depend on the regulatory treatment of the losses in the tariff. The reduction of system losses in any utility is important because of its economic, financial and social repercussions for the electric utility, the customers and even the operating country.

System losses by and large pose a major challenge for regulatory agencies. Depending on the regulatory arrangement, losses can have adverse and varying levels of financial effects on the customers and the utility. On one extreme, if the utilities were allowed to pass on its entire loss burden to the customers, irrespective of the magnitude of loss, there would be no incentives for it to enact loss reduction measures. This may not be fair to the customers because certain operating inefficiencies of the utility that impacts the system losses could be passed on to them. On the other extreme, it would be unfair for the utility to shoulder all the responsibility of the system losses.

1.1 LOSSES IN ELECTRICAL POWER SYSTEMS

Technical losses on distribution systems are primarily due to heat dissipation resulting from current passing through conductors and from magnetic losses in transformers. Technical losses occur during transmission and distribution and involve substation, transformer, and line related losses. These include resistive losses of the primary feeders, the distribution transformer losses (resistive loses in windings and the core losses), resistive losses in secondary network, resistive losses in service drops and losses in kWh meter [1]. Losses are inherent to the distribution of electricity and cannot be eliminated. Technical losses are due to current flowing in the electrical network and generate the following types of losses:

- Copper losses those are due to I^2R losses that are inherent in all inductors because of the finite resistance of conductors
- Dielectric losses that are losses that result from the heating effect on the dielectric material between conductors
- Induction and radiation losses that are produced by the electromagnetic fields surrounding conductors.

Technical losses are possible to compute and control, provided the power system in question consists of known quantities of loads. The following are the causes of technical losses:

- Harmonics distortion
- Improper earthing at consumer end
- Long single phase lines
- Unbalanced loading
- Losses due to overloading and low voltage
- Losses due to poor standard of equipments.

Technical losses are naturally occurring losses (caused by actions internal to the power system) and consist mainly of power dissipation in electrical system components such as transmission lines, power transformers, measurement systems, etc. Technical losses are possible to compute and control, provided the power system in question consists of known quantities of loads.

Non-technical losses (NTL), on the other hand, occur as a result of theft, metering inaccuracies and unmetered energy. NTLs, by contrast, relate mainly to power theft in one form or another. They are related to the customer management process and can include a number of means of consciously defrauding the utility concerned [2]. Theft of power is energy delivered to customers that is not measured by the energy meter for the customer. This can happen as a result of meter tampering or by bypassing the meter. Losses due to metering inaccuracies are defined as the difference between the amount of energy actually delivered through the meters and the amount registered by the meters. All energy meters have some level of error which requires that standards be established. The most probable causes of Non Technical Losses (NTL) are:

- Tampering with meters to ensure the meter recorded a lower consumption reading
- Errors in technical losses computation
- Tapping (hooking) on LT lines
- Arranging false readings by bribing meter readers
- Stealing by bypassing the meter or otherwise making illegal connections
- By just ignoring unpaid bills

- Faulty energy meters or un-metered supply
- Errors and delay in meter reading and billing
- Non-payment by customers.

Non Technical Losses (NTLs) are caused by actions external to the power system, or are caused by loads and conditions that the technical losses computation failed to take into account. NTL are more difficult to measure because these losses are often unaccountable. The aim in this thesis work is to first compute the technical losses and then impact of non technical losses on them is shown. Technical losses will be simply calculated using load flow method of power system. This will be done because non technical losses are more difficult to measure. As NTL cannot be computed and measured easily, but it can be estimated from preliminary results, i.e. the result of technical losses are first computed and subtracted from the total losses to obtain the balance as NTL. The technical losses are computed using appropriate load-flow studies simulated under Matlab environment.

Although some electrical power loss is inevitable, steps can be taken to ensure that it is minimized. Several measures have been applied to this end, including those based on technology and those that rely on human effort and ingenuity. Reduction of NTLs is crucial for distribution companies. As these losses are concentrated in the low-voltage network, their origins are spread along the whole system and are most critical at lower levels in the residential and small commercial sectors. Overcoming and recovering NTLs is essential and requires significant investment in the means of doing so.

1.2 PROBLEMS IN DISTRIBUTION SYSTEMS

The main issue in Distribution systems or rather more appropriately the issue confronting the power sector as a whole, is the reduction of Transmission and Distribution (T & D) losses to acceptable minimum levels. The all-India T & D losses, which were about 15% till 1966-67, increased gradually and are now at 24.79% (1997-98). During the last few years, some of utilities variously estimated the losses in the range over 30% to 50% much higher than the preceding years. T & D losses in developed countries are around 7-8% only. Taking into consideration the Indian conditions such as far-flung rural areas, nature of loads, system configuration etc. the reasonable permissible (technical) energy losses should be about 10%-15% in different states.

While the losses in EHV (Extra High Voltage) network are about 4%-5%, bulk of the losses occurs in T & D system. It is well known that these losses in distribution systems include non-technical or commercial losses and that of power by various users with or without connivance of utility staff. These constitute a large component of overall losses. There are also losses on account of defective (slow) meters, stuck up/burnt meters etc. Further on account of estimation involved in agriculture sector consumption (30% of total), absence of adequate metering at the system level, deficiencies in consumer metering the validity of figure of T & D losses being reported become questionable. General conclusions are that the reported losses are under estimated and cover up large commercial losses (theft), actual figures are higher, technical losses are also high and bulk of the losses occur in sub-transmission and distribution systems. Inefficiency, frequent interruptions, flickers and poor voltage also characterize distribution systems. In addition the billing and revenue collections are very poor leading to combined state utility financial losses of Rs. 26, 0000 crores every year. If the current trend continues, in another three years, state utility financial losses will reach Rs. 45,000 crores a year. It is, therefore, necessary to bring about improvements in planning implementation and operation of T & D systems in a scientific and efficient manner. The present traditional reactive and ad-hoc approach to network development should be replaced by an approach based on technical and reliability requirements, economic considerations of costs of energy loss and expansion of system to meet the growth of prospective demand with least cost [3]

1.3 ELECTRICITY THEFT

A non-technical loss is defined as any consumed energy or service, which is not billed because of measurement equipment failure or ill-intentioned and fraudulent manipulation of said equipment. Therefore, detection of non-technical losses includes detection of fraudulent users. Electricity theft is defined as a conscience attempt by a person to reduce or eliminate the amount of money he will owe the utility for electric energy. This could range from tampering with the meter to create false consumption information used in billings, to making unauthorized connections to the power grid. Non-payment, as the name implies, refers to cases where customers refuse or are unable to pay for their electricity consumption.

It is estimated that electricity theft costs in our country is in crores in a year. Electricity theft is part of a phenomenon known as “Non-Technical Losses” (NTL) in electrical power systems.

This thesis aims to investigate the nature of non-technical losses in power systems, their sources, the measurement of non-technical losses, some measures taken by selected utilities to reduce them, and possibly their impact on the power system. Power flow calculations of load flow studies are used to discuss relevant aspects of technical losses and the effects of adding NTL in a simplified power system. The results of those simulations are presented.

1.4 ECONOMIC CONSEQUENCES OF LOSSES ON COMMUNITY

In an important information provided under RTI Act by Central Electricity Authority regarding transmission loss it was reported that in 2004-05 the transmission losses were to the tune of 175534.96 million units. If we multiply the cost per unit as Rs 2, then the total loss in financial term will Rs 35000 crores (Approx.) [4]. This is only one year figure. If we add 10 years transmission loss it will be around 3 to 4 lakhs rupees, enough money to build Delhi like metros in all major cities of India, enough money to build roads to take village kids to nearby town schools, enough money to build hospitals to take care our elderly people. The people who use ACs but do not pay for its use, they have factories but in connivance with electrical board people do not keen to pay as per their use. The reason for the significant amount of non-payment is political and economic changes and the response of the governments and the public to those changes. Payment default at the consumer end resulted in T & D companies defaulting on their dues to the generating companies, which in turn accumulate unpaid debts to energy suppliers, banks, and employees. The following are the reasons and their consequences on the whole system:

- The inability to pay for energy has led to rationing, which allows only for a few hours of electricity supply each day
- Political and economic changes, economic collapse or severe contraction in many countries

- Declining incomes, high inflation, high unemployment and rising energy prices severely eroded the ability of households to pay for energy and heat
- In an extreme example, some customers in some countries had threatened to shoot utility officials for attempting to disconnect supplies
- In most countries, the absence of adequate metering and poor location of meters effectively prevented any action against theft and non-payment.

Thus the assessment of non-technical losses in the Punjab state will help to provide Punjab State Electricity Board (PSEB) policy makers important assistance in making their analysis of the incremental costs and impacts of different combinations of loss reduction options.

CHAPTER 2

ELECTRICITY SECTOR IN INDIA

The electricity sector in India is predominantly controlled by government sector entities via central public sector corporations, such as: National Hydroelectric Power Corporation, National Thermal Power Corporation and various state level corporations (state electricity boards - SEBs). The transmission and distribution is managed by the State Electricity Boards (SEBs) or private companies. The current per capita power consumption is about 612 kWh per year while the world average is 2,596 kWh.

India is world's 6th largest energy consumer, accounting for 3.4% of global energy consumption. Due to India's economic rise, the demand for energy has grown at an average of 3.6% per annum over the past 30 years. More than 50% of India's commercial energy demand is met through the country's vast coal reserves. About 76% of the electricity consumed in India is generated by thermal power plants, 21% by hydroelectric power plants and 4% by nuclear power plants [5].

Electricity is central to achieving economic, social and environmental objectives of sustainable human development. In the present digital age electricity has emerged as the most crucial and critical input for sustaining the process of economic as well as social development. Growth of different sectors of economy is not possible without matching development of the electricity sector. In fact it has become essential ingredient for improving the quality of life and its absence is usually associated with poverty and poor quality of life. Sub-transmission and distribution systems constitute the link between electricity utilities and consumers, their revenue realization segment. For consumers, it represents the face of the utility. Efficient functioning of this segment of the utility is essential to sustain the growth of power sector and the economy. However, the present situation is characterized by unacceptably high losses (both technical and commercial), poor quality and reliability of supply, billing, revenue collection, frequent interruptions in supply and resultant consumer dissatisfaction, etc. Though the Indian power sector has achieved substantial growth during the post-independence era, the sector has been ailing from serious functional problems during the past few decades.

Per capita consumption of electricity in India increased from 178 kWh in 1985-86 to 338 kWh in 1996-97 (GOI, 2002) and to 665 kWh in 2005-06 (General Review, 2007). This level of per capita consumption is less than 1/20 of that prevailing in the US, less than half that in China against the world average of 2400 kWh and the OECD(Organization for Economic Co-operation and Development) average of 6900 kWh (International Energy Agency data) [6]. According to the Government of India reports, inefficiencies were mainly due to:

- Unsatisfactory operational efficiencies, with the availability of thermal plants at less than 80 percent, losses (including theft of power) as high as 20 to 21 percent
- High transmission and distribution losses substantially higher than normal technical standards, with a high component on non-technical losses, accounted for by poor/inadequate metering and high incidence of theft of energy
- Poor billing and collection, because of incorrect reporting and billing, and inadequate collection efforts, tampering with meters and misreporting in collusion with consumers
- Imbalance in the mix of generation sources and undesirable proliferation of captive generating units
- Unmanageable size and monolithic structure, making it unwieldy, inefficient and unresponsive to change as well manpower related problems; poor productivity, low skills and lack of training for up gradation, low motivation levels.

Some 400 million Indians have no access to electricity primarily due to power shortages. While 80 percent of Indian villages have at least an electricity line, just 44 percent of rural households have access to electricity. According to a sample of 97,882 households in 2002, electricity was the main source of lighting for 53% of rural households compared to 36% in 1993.Some half of the electricity is stolen, compared with 3% in China. The stolen electricity amounts to 1.5% of GDP. Almost all of the electricity in India is produced by the public sector. Power outages are common. Many buy their own power generators to ensure electricity supply. As of 2005 the electricity production was at 661.6 billion kWh. In 2004-05, electricity demand outstripped supply by 7-11% [7].

2.1 GENERATION

Grand Total Installed Capacity is **147,402.81 MW** [8]

2.1.1 THERMAL POWER

Current installed capacity of Thermal Power (as of 12/2008) is **93392.64 MW** which is 63.3% of total installed capacity.

- Current installed base of Coal Based Thermal Power is **77458.88 MW** which comes to 53.3% of total installed base
- Current installed base of Gas Based Thermal Power is **14734.01 MW** which is 10.5% of total installed base
- Current installed base of Oil Based Thermal Power is **1199.75 MW** which is 0.9% of total installed base.

The state of Maharashtra is the largest producer of thermal power in the country

2.1.2 HYDRO POWER

India was one of the pioneering states in establishing hydro-electric power plants, The power plant at Darjeeling and Shimsa (Shivanasamudra) was established in 1898 and 1902 respectively and is one of the first in Asia. The installed capacity as of 2008 was approximately **36647.76**. The public sector has a predominant share of 97% in this sector.

2.1.3 NUCLEAR POWER

Currently, seventeen nuclear power reactors produce **4,120.00 MW** (2.9% of total installed base).

2.1.4 RENEWABLE POWER

Current installed base of Renewable energy is **13,242.41 MW** which is 7.7% of total installed base with the southern state of Tamil Nadu contributing nearly a third of it (4379.64 MW) largely through wind power. Table 2.1 shows the All India region wise generating installed capacity (MW) of power utilities including allocated shares in joint and central sector utilities.

Table 2.1 All India generation capacity

Sl. No.	REGION	THERMAL				Nuclear	Hydro (Renewable)	R.E.S. @ (MNRE)	TOTAL
		COAL	GAS	DSL	TOTAL				
1	Northern	18867.5	3531.19	12.99	22411.68	1180	13425.15	1766.37	38783.2
2	Western	25402.5	6600.72	17.48	32020.7	1840	7448.5	4023.62	45332.82
3	Southern	16682.5	3646.1	939.32	21267.92	1100	10724.18	7047.9	40140
4	Eastern	16446.38	190	17.2	16653.58	0	3933.93	227.41	20814.92
5	N. Eastern	60	766	142.74	968.74	0	1116	171	2255.74
6	Islands	0	0	70.02	70.02	0	0	6.11	76.13
7	**All India**	77458.88	14734.01	1199.75	93392.64	4120	36647.76	13242.41	147402.81

2.2 TRANSMISSION

Transmission of electricity is defined as bulk transfer of power over a long distance at high voltage, generally of 132kV and above. In India bulk transmission has increased form 3,708 km in 1950 to more than 265,000 km today [8]. The entire country has been divided into five regions for transmission systems, namely, Northern Region, North Eastern Region, Eastern Region, Southern Region and Western Region. The Interconnected transmission system within each region is also called the regional grid.

The transmission system planning in the country, in the past, had traditionally been linked to generation projects as part of the evacuation system. Ability of the power system to safely withstand a contingency without generation rescheduling or load-shedding was the main criteria for planning the transmission system. However, due to various reasons such as spatial development of load in the network, non-commissioning of load centre generating units originally planned and deficit in reactive compensation, certain pockets in the power system could not safely operate even under normal conditions. This had necessitated backing down of generation and operating at a lower load generation balance in the past. Transmission planning has therefore moved away from the earlier generation evacuation system planning to integrate system planning.

High Voltage Direct Current (HVDC) technology has also been used for interconnection of all regional grids across the country and for bulk transmission of power over long distances. Certain provisions in the Electricity Act 2003 such as open access to the transmission and distribution network, recognition of power trading as a distinct activity, the liberal definition of a captive generating plant and provision for supply in rural areas are expected to introduce and encourage competition in the electricity sector. Table 2.2 shows the growth of transmission sector since 6th five year plan. These figures are upto Dec, 2008.

Table 2.2 Growth of Transmission sector in India

A. TRANSMISSION LINES (ckm)						
At the end of	**400 kV Transmission lines**			**220 kV Transmission lines**		
	Central	**State**	**Total**	**Central**	**State**	**Total**
6th Plan	1831	4198	6029	1641	44364	46005
7th Plan	13068	6756	19824	4560	55071	59631
8th Plan	23001	13141	36142	6564	73036	79600
9th Plan	29345	20033	49378	8687	88306	96993
10th Plan	50992	24730	75722	9444	105185	114629
11th Plan up to DEC.'08	59761	27323	87084	10045	11705	121750
B. SUB_STATION (MVA)						
At the end of	**400 kV Transmission lines**			**220 kV Transmission lines**		
	Central	**State**	**Total**	**Central**	**State**	**Total**
6th Plan	715	8615	9330	500	36791	37291
7th Plan	6760	14820	21580	1881	51861	53742
8th Plan	17340	23525	40865	2566	81611	84177
9th Plan	23575	36805	60380	2866	113497	116363
10th Plan	40455	52487	92942	4276	152221	156497
11th Plan up to DEC.'08	53240	55127	108367	4476	168137	172613

2.3 DISTRIBUTION

The total installed generating capacity in the country is over 135,000MW and the total number of consumers is over 144 million. Apart from an extensive transmission system network at 500kV HVDC, 400kV, 220kV, 132kV and 66kV which has developed to transmit the power from generating station to the grid substations, a vast network of sub transmission in distribution system has also come up for utilization of the power by the ultimate consumers.

However, due to lack of adequate investment on T&D works, the T&D losses have been consistently on higher side, and reached to the level of 32.86% in the year 2000-01.The reduction of these losses was essential to bring economic viability to the State Utilities [8].

As the T&D loss was not able to capture all the losses in the net work, concept of Aggregate Technical and Commercial (AT&C) loss was introduced. AT&C loss captures technical as well as commercial losses in the network and is a true indicator of total losses in the system.

High technical losses in the system are primarily due to inadequate investments over the years for system improvement works, which has resulted in unplanned extensions of the distribution lines, overloading of the system elements like transformers and conductors, and lack of adequate reactive power support.

The commercial losses are mainly due to low metering efficiency, theft & pilferages. This may be eliminated by improving metering efficiency, proper energy accounting & auditing and improved billing & collection efficiency. Fixing of accountability of the personnel managers may help considerably in reduction of AT&C loss.

With the initiative of the Government of India and of the States, the Accelerated Power Development & Reform Programme (APDRP) was launched in 2001, for the strengthening of Sub –transmission and distribution network and reduction in AT&C losses.

The main objective of the program was to bring Aggregate Technical & Commercial (AT&C) losses below 15% in five years in urban and in high-density areas. The program, along with other initiatives of the Government of India and of the States, has led to reduction in the overall AT&C

loss from 38.86% in 2001-02 to 34.54% in 2005-06. The commercial loss of the State Power Utilities reduced significantly during this period from Rs. 29331 Crore to Rs. 19546 Crore. The loss as percentage of turnover was reduced from 33% in 2000-01 to 16.60% in 2005-06.

2.4 THE ELECTRICITY ACT, 2003

Recognizing the need for the Reform process covering the entire facets of the electricity sector comprising generation, transmission and distribution to the consumers, a comprehensive Electricity Bill was drafted in 2000 following a wide consultative process [6]. After a number of amendments, the bill finally sailed through the legislative process and was enacted on 10 June, 2003. It replaces the three existing legislations governing the power sector, namely Indian Electricity Act, 1910, the Electricity (Supply) Act, 1948 and the Electricity Regulatory Commissions Act, 1998. The Electricity Act, 2003 mandates that Regulatory Commissions shall regulate tariff and issue of licenses and that State Electricity Boards (SEBs) will no longer exist in the existing form and will be restructured into separate generation, transmission and distribution entities. Regulatory function has been taken away from the purview of the government. The Electricity Act, 2003 mandates licensee-free thermal generation, non-discriminatory open access of the transmission system and gradual implementation of open access in the distribution system which will pave way for creation of power market in India. The main provisions of the act are:

- De-licensing of thermal generation and captive generation.
- Open access in distribution to be introduced in phases
- Provision for license-free generation and distribution in rural areas and provision for management of rural distribution by Panchayats, Cooperative Societies, non-government organizations, franchisees, etc.
- Non-discriminatory open access in transmission
- Multiple licensing in distribution
- Mandatory metering of all electricity supplies

- Adoption of multi-year tariff principles
- Provision for cross-subsidy surcharge on direct sale to consumers
- Power Trading recognized as a distinct activity with ceilings on trading margins to be fixed by the Regulatory Commissions
- Upfront payment of subsidies by the States
- Setting up of an Appellate Tribunal to hear appeals against the decisions of the CERC and the SERCs.

The Act is aimed at providing an investor friendly environment for potential developers in the power sector by removing administrative hurdles in the development of power projects and shall provide impetus to distribution reform to be undertaken in India. Provisions like de-licensing of thermal generation, open access and multiple licensing; no surcharge for captive generation shall be the basis for a competitive environment in the Indian power sector. Provisions of open access would be instrumental in the development of competitive power markets, and multi year tariffs shall bring in necessary incentives for performance improvement and to reduce regulatory risk.

2.5 POWER FOR ALL BY 2012

The Government of India has an ambitious mission of POWER FOR ALL BY 2012. This mission would require that our installed generation capacity should be at least 200,000 MW by 2012 from the present level of 144,564.97 MW. Power requirement will double by 2020 to 400,000MW [6].

2.5.1 OBJECTIVES

- Sufficient power to achieve GDP growth rate of 8%
- Reliable power
- Quality power
- Optimum power cost
- Commercial viability of power industry
- Power for all

2.5.2 STRATEGIES

- Power Generation Strategy with focus on low cost generation, optimization of capacity utilization, controlling the input cost, optimization of fuel mix, Technology upgradation and utilization of non Conventional energy sources.

- Transmission Strategy with focus on development of National grid including Interstate connections, Technology upgradation & optimization of transmission cost.

- Distribution strategy to achieve Distribution Reforms with focus on System upgradation, loss reduction, theft control, consumer service orientation, quality power supply commercialization, Decentralized distributed generation and supply for rural areas.

- Regulation Strategy aimed at protecting consumer interests and making the sector commercially viable.

- Financing strategy to generate resources for required growth of the power sector.

- Conservation strategy to optimize the utilization of electricity with focus on Demand Side management, Load management and Technology up-gradation to provide energy efficient equipments.

- Communication Strategy for political consensus with media support to enhance the general public awareness.

CHAPTER 3
LITERATURE REVIEW

India's power sector is characterized by inadequate and inefficient power supply. Since the country's independence, consumers are confronted with frequent power cuts, and fluctuating voltages and frequencies. In addition, system losses are high throughout India's T&D networks. In addition to these enormous direct losses, the indirect losses in terms of lost productivity and trade, sagging economic activity, rapidly shrinking of domestic and foreign investment in the sector, uneconomical and misallocated investments in captive power, and reduced income generation could be many-fold.

3.1 POWER SECTOR IN PUNJAB

PSEB, in its present form came into existence under Section 5 of the Electricity (Supply) Act-1948 on May 2, 1967 after the reorganization of the State. The Board was set up for generation, transmission and distribution of electricity in Punjab. The installed capacity of electricity in the State increased from 3524 MW in 1996-97 to 4444 MW in 2000-2001 (2130 MW Hydel + 2314 MW Thermal). Thermal generation is 65% and hydro generation is 35% of the total electricity generated by the Board. The Board purchases about 25% of the power available in the State. It served 52 lakhs consumers by supplying 20192 million units of electricity in 2000-01. Electricity consumption per consumer was 3883 units in 2000-01

In 2000-01, there was a shortfall of 12.05% at peak demand and 10.3% in terms of gap between demand and supply of power. Average rate of growth in demand for electricity in the last decade had been around 6% in the State. In 2001-02, the average cost of power supply per unit in Punjab was 285.2 paise, which was among the lowest in the country, in Haryana, Gujarat and Maharashtra it was 411.9 paise, 365.4 and 357.5 paise respectively [9].

The installed capacity generation in Punjab and year wise progress of transmission lines is shown in Table 3.1 and Table 3.2 respectively.

Table 3.1 Installed Capacity Generation

S. No	Name of Project	Detail of Power machines with installed capacity (MWs)	Share of Punjab (MWs)	Generation during 2006-07	Generation upto 31-12-07
I	**OWN PROJECTS**				
a)	HYDRO ELECTRIC PROJECTS				
1	Shanan PHs	4× 15+1×50=110.00	110	495.666	473.199
2	UBDC	3×15+3×15.45 =91.35	91.35	384.607	329.483
3	Anandpur Sahib	4×33.5=134.00	134	666.089	577.064
4	Mukerian	6×15+6×19.5=207.0	207	1170.736	1175.240
5	RSDHEP	4×150=600.00	452.4	1679.476	1305.365
6	Nadampur Micro	2×0.4=0.80	0.8	7.959	6.225
7	Daudhar Micro	3×0.5=1.50	1.5		
8	Rohti Micro	2×0.4=0.80	0.8		
9	Thuhi Micro	2×0.4=0.80	0.8		
10	GGSSTP ROPAR(micro)		1.7		
	Total		1000.350	4404.533	3866.576

b)	THERMAL PROJECTS	No.& Capacity of units(MW)	Total Capacity (MW)	Generation 2006-07	Generation upto 31-12-07
1	GNDTP, BATHINDA	4×110 =440.00	440	2221.127	2326.631
2	GGSSTP, ROPAR	6×210 =1260.00	1260	9770.340	7301.184
3	RSTP, Jalkheri	1x10=10.00	Added in item4 below	Added in item4 below	Added in item4 below

4	GHTP,Lehra Mohabat	2x210=420.00	420	3443.172	2578.407
	Total		2120	15434.639	12206.222
	Total (a) +(b)		3120.350	19839.172	16072.798
II	Share From BBMB Projects		1258	3978.260	3605.735
III	Share from Central Sector Projects		1917	12361.601	14345.573
IV	PEDA & Captive Power Plants		61	233.022	169.243
	G.Total (I+II+III+IV)		6356	36412.055	34193.349

Table 3.2 Year wise Progress of Transmission Lines

S. No.	Year	220 kV Lines (ckm)	132 kV Lines	66 kV Lines	33/66 kV Lines	Total
1	1997-98	225.592	11.006	179.052	45.856	461.506
2	1998-99	532.99	23.642	213.904	35.877	806.413
3	1999-2000	132.736	15.422	237.542	35.678	421.378
4	2000-01	281.977	42.393	212.495	39.518	576.383
5	2001-02	111.35	13.286	177.043	48.578	350.257
6	2002-03	129.405	24.057	44.01	10.783	204.345
7	2003-04	137.915	14.971	148.352	47.142	348.38
8	2004-05	88.814	17.366	183.958	40.01	330.148
9	2005-06	193.287	13.578	203.126	67.105	477.096
10	2006-07	79.650	14.604	507.318	-	601.572
11	Till Dec. 2007	40.868	28.155	417.570	-	486.593

Figure 3.1 shown below represents the year wise progress of transmission lines.

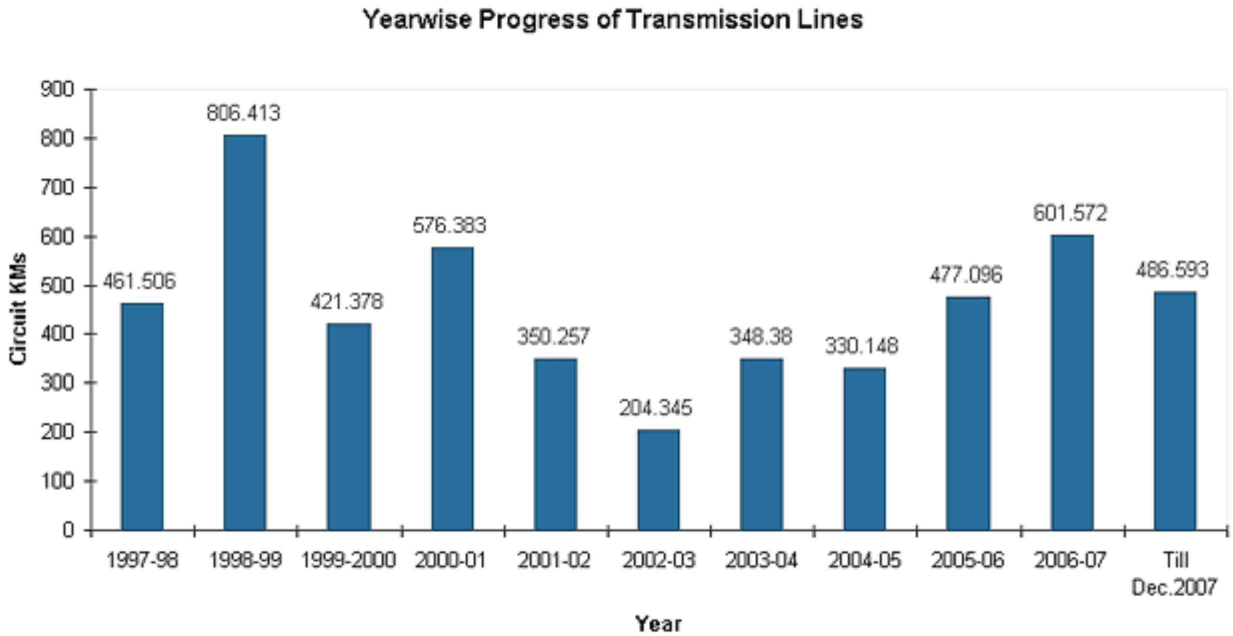

Figure 3.1 Year wise progress of transmission lines

3.2 TRANSMISSION & DISTRIBUTION LOSSES

Transmission and Distribution (T&D) losses of the Board include unavoidable losses inherent in the process as well as avoidable ones due to poor engineering, poor maintenance and theft. These were estimated to be 17.8% in 1999-2000 and 17.2% in 2000-01. T&D losses in Punjab in 2001-02 have been estimated at 17.5%, while the average losses of all the SEBs were 27.8%, indicating that the losses in Punjab have been grossly underestimated. Non-metering of agricultural supply makes it difficult to estimate T&D losses accurately. In public perception, the Board shows a lower figure of T&D losses, by counting theft (pilferage) as part of agricultural consumption. According to the statistics of the Board, non-technical losses including theft were 9.3% in 2000-01. As per CAG (Comptroller and Auditor General) Report in 1999-2000, 12.17% electricity with potential revenue of Rs.600 crore was lost through pilferage. Total debt of the Board increased from Rs. 4617.44 crore in 1996-97 to Rs. 8973.61 crore in 2000-01. Debt servicing liability of PSEB increased from Rs.308 crore in 1996-97 to Rs.968

crore in 2000-01. Share of interest on borrowings in total cost in 2001-02 was 19.19% in Punjab, whereas it was 7.83% in Haryana, 9.22% in Gujarat, 8.76% in Maharashtra and 11.17% for all 19 SEBs. Thus of the total expenditure, interest payment account for 20%, employee cost 21% and purchase of power from other agencies at 16% [9].

Table 3.3 Average Tariffs in Selected SEBs in India, 2001-02

(In paise per kWh)

S. No	SEBs	Domestic Consumers	Commercial Consumers	Agricultural Consumers	Industrial Consumers	Average Tariff
1	Punjab	216.86	374.81	0.00	306.48	184.10
2	Haryana	280.51	451.14	47.71	477.94	225.37
3	Gujarat	265.00	501.00	62.00	476.67	243.00
4	Maharashtra	248.02	456.39	82.28	208.84	270.02
5	All 19 SEBs	196.80	429.21	41.54	381.14	240.34

Source: Planning Commission, Annual Report on the working of State Electricity Boards & Electricity Department, May, 2002.

Table 3.4 represents the T & D losses in Punjab. These figures are calculated annually by every state electricity boards.

Table 3.4 T & D Losses

S. No.	Description	2003-04	2004-05	2005-06	2006-07	up to 31-12-2007
1	Energy Loss (MUs)	7577.664	7301.48	8187.48	8367.09	Calculated annually
2	Percentage of T &D Losses	25.33	24.27	25.07	23.92	Calculated annually

3.3 VARIOUS TECHNIQUES ADOPTED FOR MEASUREMENT OF NON-TECHNICAL LOSSES

Nontechnical losses represent a significant proportion of electricity losses in both developing and developed countries. NTLs occur not only in developing countries, but also in developed countries. For example, in the United States, NTLs were estimated as between 0.5% and 3.5% of gross annual revenue. These figures appear relatively low when compared to the losses faced by utilities in developing countries such as Bangladesh, India and Pakistan. Nevertheless, the loss amounted to between USD 1 billion and USD 10 billion given that utility companies in the US had revenues around USD 280 billion in 1998 [10]. It is apparent that knowing how to identify cases of NTL accurately is vital for many utility companies worldwide. Such identification provides a means of devising and implementing suitable preventative and corrective means of reducing the losses involved. Knowledge of electricity customers that provides an understanding of their behaviour has become increasingly important in the electricity industry, especially in deregulated markets. With this knowledge to hand, individual electricity service providers can improve their decision making generally as well as develop innovative strategies and products based on customer demand as a means of differentiating themselves from their competitors.

Nizar et al. [11] presented a new approach to nontechnical loss (NTL) analysis for utilities using the modern computational technique extreme learning machine (ELM). Nontechnical losses represent a significant proportion of electricity losses in both developing and developed countries. The ELM-based approach presented here uses customer load-profile information to expose abnormal behavior that is known to be highly correlated with NTL activities. This approach provides a method of data mining for this purpose, and it involves extracting patterns of customer behavior from historical kWh consumption data. The results yield classification classes that are used to reveal whether any significant behavior that emerges is due to irregularities in consumption. In this paper, ELM and online sequential-ELM (OS-ELM) algorithms were both used to achieve an improved classification performance and to increase accuracy of results. A comparison of this approach with other classification techniques, such as the support vector machine (SVM) algorithm, was also undertaken and the ELM performance and accuracy in NTL analysis was shown to be superior.

In this paper, SVM had emerged as one of the most popular and useful techniques for data classification .The objective of SVM is to produce a model that predicts the target value of data instances in the testing set in which only attributes are given. The classification goal in SVM is to separate the two classes by means of a function devised from available data and thereby to produce a classifier that will work well on further unseen data. The simplest form of SVM classification is the maximal margin classifier. It was used to solve the most basic classification problem, namely the case of a binary classification with linear separable training data. In real-world problems, training data are not always linear separable. In order to handle the nonlinearly separable cases some slack variables have been introduced to SVM so as to tolerate some training errors, with the influence of the noise in training data thereby decreased. This classifier with slack variables is referred to as a soft-margin classifier.

ELM was proposed by Huang for single hidden layer feed forward neural networks (SLFNs), but it was so devised as to produce superior performance. The learning speed of the feed forward neural network has been claimed to be slower due to the fact that a slow gradient-based iterative learning algorithm is used extensively to train neural networks. Unlike many other popular learning algorithms, little human involvement is required in ELM. Except the number of the hidden neurons (which is insensitive to ELM as well), no other parameters need to be tuned manually by users. Usually SLFN has three kinds of input parameters: the input weight, the hidden neuron biases and the output weight. Conventional learning algorithms of SLFNs have to tune three types of parameters. However, ELM just randomly generates the input weight and the hidden neuron biases and then analytically calculates the output weight. No further learning is required for SLFNs trained by ELM. That is it for ELM. ELM is a general learning algorithm for SLFNs, which works for function approximations, classifications, and online prediction problems. It can generally work well for different type of applications.

Inigo Monedero et al. [12] presented a data mining technique which involves the use of sophisticated data analysis tools to discover previously unknown, valid patterns and relationships in large data sets. Nowadays, datamining is being applied to multiple fields and detection of non-technical losses is one field in which it has met with success recently. According to him, a non-technical loss is defined as any consumed energy or service which is not billed because of measurement equipment failure or ill-intentioned and fraudulent manipulation of said equipment. Therefore, detection of non-technical losses includes detection of fraudulent users. This datamining field involves identifying non-technical losses as quickly as possible once it has been happened. Normally, cases of non-technical loss have to be detected from huge data sets such as the logged data and user behavior. The workforce is thus not sufficient to analyze these huge data sets and datamining techniques are the only tools which make it possible to study all the data in an acceptable time. The main research and applications in the non-technical losses and fraud detection field have been carried out on credit cards, telecommunications, and computer applications.

Carlos A. Dortolina and Ramón Nadira [13] proposed a top-down/bottom-up approach for accurately estimating technical losses in power distribution systems when a complete set of modeling data is not available. According to them, the results yielded by the top-down and bottom-up approaches must be in agreement with each other. Otherwise, additional analysis needs to be conducted in order to reconcile the differences.

Top-down approaches can be described as classification and interpolation methods and generally consist of the following three steps.

***Step 1: Feature Extraction**:* This step involves the definition and valuation of explanatory variables, i.e., variables that contain enough information to be able to explain a certain dimension of the performance of the distribution system (see Fig. 1). For example, the kilowatthour per customer and/or the number of customers per length of feeder of a distribution system are explanatory variables for the distribution technical losses; that is, the higher the kilowatthour per customer and/or the higher the number of customers per length of feeder, the smaller the loss ratio should be.

***Step 2: Clustering Analysis**:* This step involves the determination of “closeness” of the specific distribution system under consideration to other distribution systems whose characteristics are known with certainty. Closeness is generally measured in terms of the explanatory variables.

***Step 3: Estimation of Losses**:* This step assumes that similar distribution systems will have comparable technical losses (on a percentage basis). As such, technical losses of the distribution system under consideration are estimated from those of the systems close to it (i.e., in the same cluster) The top-down approaches are often referred to as “benchmarking.”

In bottom-up approach, analysis is conducted to determine what specific actions (e.g., building new circuits) would be required to bring the performance of the distribution company to a given (predetermined) level. In its purest form, bottom up entails a complete and detailed system planning. Needless to say, bottom-up analysis requires much more data and is more time consuming that it's top-down counterpart. In bottom-up analysis, losses can be computed with relative accuracy using specialized software, assuming that the extensive set of required data is available. If not, a "virtual system" is used (see Figure 3.2). This entails the calculation of the losses that an "efficient" model system (i.e., the "virtual" system) would incur when providing electricity service to the load of the specific distribution system under consideration.

The two approaches can be clearly understood with the help of Figure 3.2.

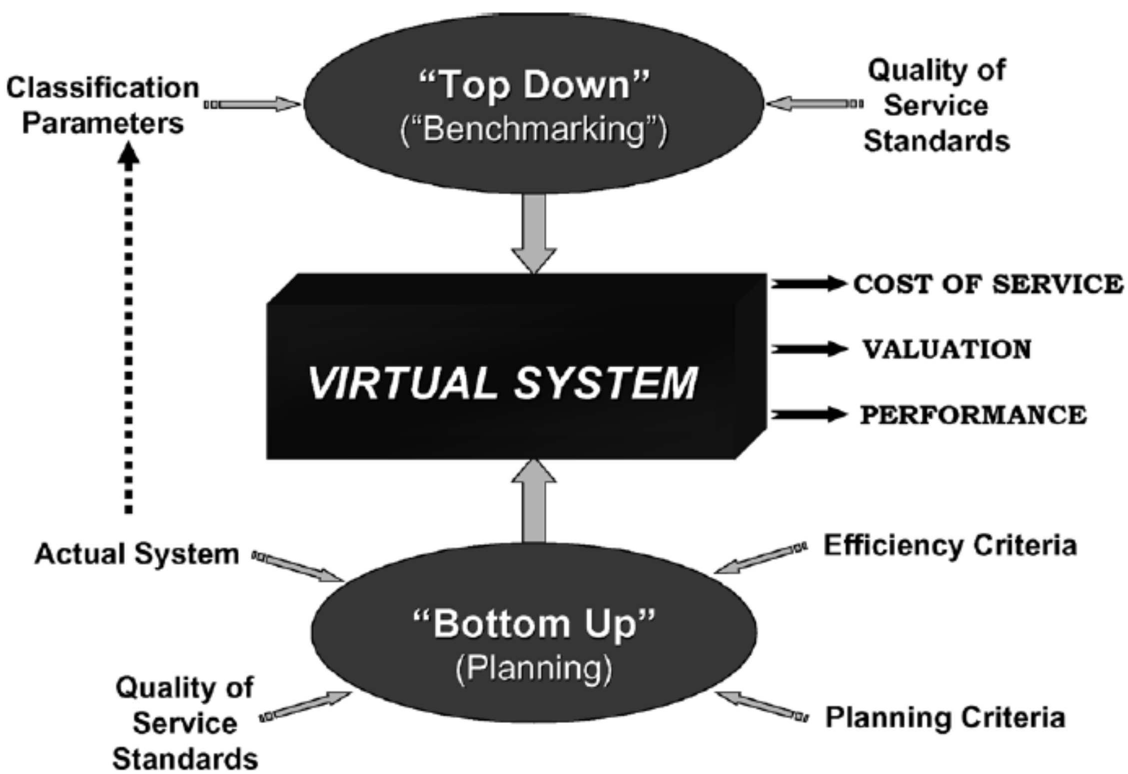

Figure 3.2 Flowchart representing the two approaches

Then a Hybrid Approach had been described which assumes that sufficient data are available for certain portions (or regions) of the system and are not available for the rest. In order to obtain an accurate assessment of the existing technical losses in a system with such incomplete data, losses may be computed for those regions where a complete set of information is available. Then, technical losses for the rest of the regions can be estimated by means of clustering techniques. This is a combination of the top-down and bottom-up approaches described above. The advantage of the hybrid approach is that it is relatively less time consuming than the bottom-up approach and more accurate than the top-down approach. The disadvantage is that it requires more detailed information than top-down methods while yielding results that may not be as accurate as those of a bottom-up approach.

Nizar et al. [14] presented a comprehensive review on nontechnical losses, load profiles and data mining techniques that currently being used in effort to minimize the non-technical loss activities. It also presented on the contributing factors in load profiles of electricity customers, using the knowledge discovery in databases procedure, to determine the load profiles for different types of customers. In this paper, the customer load profiles were compared based on the type of day, by analyzing their differences in their consumption behavior. The objective of this study was to use the load profiling methods and data mining techniques to classify, detect and predict non-technical losses in the distribution sector, due to faulty metering and billing errors, as well as to gather knowledge on customer behavior and preferences so as to gain a competitive advantage in the electricity market.

This paper focused mainly on the development of framework analysis of the customer behavior due to non-technical activities. Based on these preliminary results, they investigate the outlier detected whether the outlier is mainly related to the non-technical activities. The onsite investigation team can directly inspect the particular customer and confirm whether the outlier was caused by NTL. If the detected outlier confirmed due to NTL activities, then they update this profile as a new reference for NTL pattern. The reference can be used as a training input to built NTL forecasting model by considering other relevant external features as described in customer characterization section.

Dong et al. [15] presented load profiles of electricity customers, using the knowledge discovery in databases (KDD) procedure, a data mining technique, to determine the load profiles for different types of customers. In this paper, the current load profiling methods were compared using data mining techniques, by analyzing and evaluating these classification techniques. The objective of this study was to determine the best load profiling methods and data mining techniques to classify, detect and predict non-technical losses in the distribution sector, due to faulty metering and billing errors, as well as to gather knowledge on customer behaviour and preferences so as to gain a competitive advantage in the deregulated market. This paper focused mainly on the comparative analysis of the classification techniques selected. Therefore, in future, the irregularities or abnormalities in this consumption pattern will trigger an alert to the system.

Doorduin et al. [16] presented a method for determining the optimum connected time for a Mobile Remote Check Meter using a probabilistic approach. The resolution of illegal consumers detected depends on the deviation of the losses and the connected time of the check meter. As the current developments in the telecommunications industry make it possible to implement a mobile remote check meter. Hence data collection infrastructure and data mining software combined with check metering can provide valuable information regarding the network. Before devices are placed in the field, a study *is* conducted to determine the optimum stationary time period for detecting electricity theft in the areas based on available consumption data in the area. This paper discussed simulations and models based on data from pre-paid meters in order to determine the feasibility and method of operation for a remote check meter.

J.W. Fourie and J.E. Calmeyer [17] developed a model which minimizes the non-technical electrical energy losses of an electrical distribution network. This model simulated the electrical distribution network and includes different parameters that calculate the estimated technical losses of the electrical distributed network. The model was used as a bare for developing a strategy that minimizes the electrical energy losses of an electrical distribution network. Using the model it was possible to forecast the technical energy losses of a section in the electricity distribution network and this enables one to develop a strategy to minimize the energy losses. The development of this model will enable municipalities in South Africa to estimate energy losses in their electrical supply networks and the benefits obtained are:

- A reduction in energy generation and a increase in system capacity
- A reduction in the cost of energy to the consumer.

Cabral et al. [18] described an application of rough sets in the fraud detection of electrical energy consumers. From an information system, rough sets concept was used to reduce the number of conditional attributes and the minimal decision algorithm (MDA) was used to reduce some values of conditional attributes. The reduced information system derives a set of rules that reaches consumers behaviour allowing the classification rule system to predict many fraud consumers' profiles. The main difficulty to detect fraudulent electrical energy profiles is the reason between normal and fraudulent examples. To aggravate this disadvantage, many fraudulent consumers behavior seems like normal behavior. This fact makes that many fraudulent examples belong to the lower approximation.

The rough sets theory was proposed in 1982 by Pawlak [19]. Considering that real life is not accurate or precise (crisp), the data that represent this universe can be indiscernible or uncertain (rough). Rough sets try to prove these uncertainties in data, aiming at the difficulty to transform data to knowledge. It uses the indiscernible relation between examples in databases, where this relation is associated to values of attributes that compose the database. Rough sets have often been compared to fuzzy sets sometimes considering that are competing models of imperfect knowledge [20]. However this comparison is miscounted because indiscernible and vagueness are distinct facets of imperfect knowledge.

So we have studied that In order to analyze customer behavior in a manner that allows the detection of NTL activities, many statistical methods had been used. Among these, load profiling is one of the most widely used methods. A load profile is defined as the pattern of electricity demand of a customer or a group of customers over a period of time. In my work, first I have described a detailed analysis of 66 kV substation and have calculated the extent of non-technical losses in that system. Then a simple two bus system has been taken which is representing an industrial load and residential load respectively. Then simple load flow method of Newton-Raphson is used to calculate the various parameters of the system. NTL constitute 2-3% of the total system losses [21]. Thus calculations have been shown by adding 3% of the original kVA demand to one of the bus and the modified results have been shown using Matlab simulation. These losses indicate the total increase in losses.

CHAPTER 4

NTL MEASUREMENT AND ITS MINIMIZATION

The way to obtain a fairly accurate value of average load demand is to utilize the information the utilities use to calculate the electric bills. The calculation requires energy consumption accumulated up to the beginning of the time period and the consumption accumulated at the end of the time period. The accumulated consumption at the end of the period is subtracted by the accumulated consumption at the beginning of the period. The result is the total consumption during the time period in kilowatt-hours, and the portion of the bill for energy consumption is based on this number. This has been clearly shown in the following case study.

4.1 CASE STUDY

In this work, a case study of 66 kV substation, Golewala was undertaken. Golewala is situated at a distance of about 12 km from district headquarters Faridkot. It is a 66/11 kV substation. The main incoming lines of 66 kV are coming from Sadik. There are two step down transformers in the substation which step downs the 66 kV incoming voltage to 11 kV. There are total 13 outgoing 11 kV feeders from the substations details of which are as prescribed below in Tables 4.1(a) and 4.1(b):

Table 4.1 (a) Details of transformer T1

S. No.	Name of feeder	Type of feeder
1	Saadhan wala	Rural
2	Golewala	Urban
3	Pipli	Rural
4	Rayian wala	Urban pattern supply
5	Rajowala	Rural
6	Sayian wala	Rural
7	Ghugyana	Urban pattern supply
8	Beguwala	Rural

Table 4.1 (b) Details of transformer T2

S. No.	Name of feeder	Type of feeder
1	Dallewala	Rural
2	Hardeyale wala	Rural
3	Kabal wala	Rural
4	Burj masta	Rural
5	Nicer paper mill	Continuous process

The readings have been taken from the 11 kV energy meters installed at substation. The readings of whole one month have been collected which are shown in Table 4.2. The busbar losses in terms of percentage have been calculated. After that total losses have been shown which includes sum of transmission, distribution and non technical losses. For simplicity sake, only one outgoing 11 kV feeder of Golewala has been considered for case study. Similar technique can be applied to any of the substation in Punjab to calculate the losses. The losses have been calculated by the difference of the units supplied to Golewala and units which had been consumed or billed in that particular area. The P.S.E.B. has proper record of all the incoming and outgoing units in the form of a log sheet. For this, we have to first find out the total number of consumers in that particular area and their type i.e. whether they are domestic, commercial or small power units. Then units consumed in each area have been calculated and have been added up. This sum has been subtracted from the actual incoming units given to that area. The difference will give the idea of transmission, distribution and non technical losses. Generally major portion of this sum is covered by nontechnical losses, because transmission and distribution losses are generally less in nature than nontechnical losses. Table 4.2 shows the detailed analysis of incoming and outgoing units from the main 66 kV substation.

Table 4.2 Incoming and Outgoing Feeders of Substation

S. No.	Name of feeder	Readings as on 25-02-2009	Readings as on 25-01-2009	Difference of readings	Multiplying factor of meter	Total units (kWh)
1	Main-I	148908.7	146895.9	2012.8	1000	2012800
2	Saadhan wala	11259.42	11172.35	87.07	1000	87070
3	Golewala	56934.05	56417.25	516.8	1000	516800
4	Pipli	8189.91	8176.52	13.39	1000	13390
5	Rayian wala	7991.78	7136.00	855.78	500	427890
6	Rajowala	4012.82	3977.78	35.04	1000	35040
7	Sayian wala	19902.26	19854.34	47.92	1000	47920
8	Ghugyana	29125.37	28322.99	802.38	1000	802380
9	Beguwala	24414.09	24324.72	89.37	1000	89370
10	Main-II	52726118	52404961	321154	2	642308
11	Dallewala	14546230	14546230	Nil	---	----
12	Hardeyale wala	14542721	14528900	13821	2	27642
13	Kabal wala	7730686	7709477	21202	2	42404
14	Burj masta	5323320	5302291	21029	2	42058
15	Nicer paper mill	2067.91	1534.53	533.38	1000	533380

Thus

Total outgoing supply from T1 = 87070+516800+13390+427890+35040+47920+802380+89370

= 2019860 kWh

Total outgoing supply from T2 = 27642+42404+42058+533380

= 645484 kWh

Losses of main-I feeder = 2019860-2012800

= 7060 kWh

Percentage losses = 7060/2012800= 0.35%

Losses of main-II feeder = 645484-642308

= 3176 kWh

Percentage losses = 3176/642308 = 0.49%

Thus the busbar losses of both the feeders have been calculated in terms of percentage.

4.2 DETAILED ANALYSIS OF GOLEWALA OUTGOING FEEDER

There are mainly three types of consumers in the region. Their total units consumed/billed have been recorded from the log sheet and the following results have been obtained.

Table 4.3 Details of Billed Units

S. No.	Number of consumers	Type of consumer	Units billed
1	880	Domestic	233338
2	136	Commercial	52253
3	15	Small power	41045

Total units billed= (233338+52253+41045) kWh

= 326636 kWh

Difference = (516800- 326636) kWh

= 190164 kWh

Percentage losses= 190164/516800= **37%**

NTL are widely acknowledged by electricity distribution utilities worldwide, they are estimated to account for up to 30% revenue losses to utilities. [22]. This has been nearly proved as above with the help of above case study. This result contains transmission, distribution and non technical losses. As our main problem of NTL is of great concern, these losses as shown above cannot be measured exactly. When we talk about T&D losses it also includes the theft of electricity, although it is the part of commercial loss but there is no way to segregate theft from the T&D losses. In practice we know the energy billed and we know the input energy the difference between these two is T&D loss. Obviously the theft is included in this loss. When we talk about T&D losses it also includes the theft of electricity, although it is the part of commercial loss but there is no way to segregate theft from the T&D losses. In practice we know the energy billed and we know the input energy, the difference between these two is T&D loss obviously the theft is included in this loss.

Electricity theft is at the center of focus all over the world but electricity theft in India has a significant effect on the Indian economy, as this figure is considerably high. The loss on account of theft is reflected in ARR (*Accounting rate of return*) of the electricity company thus these costs are routinely passed on to the customers in the form of higher energy charges.

4.3 PRACTICAL EXAMPLE OF THEFT

Vigilance team of Government along with checking squad goes to detect a theft on the instructions of the government they find that a dal mill with contracted load of 15.6 kW is running with a 63 kVA transformer in side its premises, (Strictly the transformer has to be out side the premises). There exists other industrial premises with simple commercial connection of single phase; both meters are installed at a place (despite strict guide lines that two connections for different premises cannot be granted at a single premise). Further things are more interesting when it was seen that the 21 HP meter is burnt, the consumer is enjoying electricity with 63 kVA transformer and shows that its load is in fact is more than 35 HP and he has applied for the load extension only 4 days before. Now question is how to book this consumer under theft while it is known that he is involved in theft of course with connivance of the local staff. Further facts are

- He has a valid connection
- His meter is burnt

- The second meter of another consumer is installed at his premises by the distribution licensee
- The 63 kVA transformer giving him access to electricity is also installed by the licensee.

If you argue he says he has submitted the load enhancement application 4 days back, seems he knows in advance that his premises may be raided.

4.4 APPROACHES FOR REDUCTION OF NON TECHNICAL LOSSES

When we talk about T&D losses it also includes the theft of electricity, although it is the part of commercial loss but there is no way to segregate theft from the T&D losses.

World wide the energy loss (and Theft) exceeds the total electricity demand of Germany, UK and France, the third, fourth, and fifth largest economies of the world. It is estimated that utilities of developed countries alone lose 500 million dollars every year by way of T & D losses. The theft of electricity is so rampant. For domestic consumer it may be on account of the small temptation resulting from allurement of the staff of the licensee or any third party agent but for the industries it is many fold as it also enables them to hide their actual production from the department of excise, sales tax, etc. who determine the production based on the actual consumption of energy. The meter inspection is the main method of NTL detection because the utilities consider electricity theft to be the major source of NTL and the majority of electricity theft cases involves meter tampering or meter destruction. The following are the various approaches [23] which must be accomplished in order to reduce the non technical losses at utility and government level:

4.4.1 Approaches at the Utility Level

- **Metering**: Adequate metering is essential to prevent electricity theft and nonpayment at the utility level.
- **Organization of Commercial Functions**:
    - i. Utilities should organize the functions of meter reading, billing and collection, customer accounting, and follow up

ii. These functions should be separated to avoid collusion and to enable greater control

iii. The practice of mailing checks or paying in cash at financial facilities instead of just giving cash to the meter man can reduce the nonpayment.

- **Elimination of Intermediaries**: In some countries utilities widely outsource the meter reading, billing, and collection through resellers. These resellers are being phased out in most areas because of past records of indiscipline.
- **Incentive Mechanisms for Utility Staff**: In some cases where the utility staff members have more incentives to be dishonest, the companies should develop payment schemes to reward good performance in bill collection.
- **Working with Large Consumers**: In some countries the largest consumers were seen as business partners as well as customers by the utilities, which developed payment schedules to suit the customers to ensure payment.
- **Price Discounts**: In addition to regular discounts, some utilities have offered longer supply durations or guaranteed supplies for customers who were willing to pay in advance.

4.4.2 Approaches at the Government Level

- **Broader Focus for Stabilization**: Urging governments to reduce subsidies and implement effective privatization to stabilize and organize the energy market

- **Legal Framework and Exit Policies and Practices**: Changing legal concepts of property, property rights, financial laws and regulations, enterprise laws, banking and trade reforms. The financial chaos is cited as a major reason of the continuation of non-payment problems

- Government agencies and departments should be urged to manage their budgets and their energy consumption, in order to reduce the strain placed on utilities and the power systems

- Legal reform, more clarity in the current laws for most countries, as well as the enforcement of the rule of law are required to provide utilities with the option of disconnecting non-paying customers.

4.5 VARIOUS TYPES OF METERS FOR ENERGY MEASUREMENT

The basic principle for a single-phase energy measurement meter is as follows. First, there are two coils (current coil & potential coil) that produce electromagnetic fluxes: a coil, connected across the two leads, that produces a flux proportional to the voltage and a coil connected in series with one of the leads that produces a flux proportional to the current. The dot product of those two fluxes creates a force proportional to the load power. An illustration of the basic components of the watt-hour meter is shown in Figure 4.1 below.

Figure 4.1 Basic Energy Meter

In early designs, the meters were not enclosed and all the parts and the meter installation were easily accessible to anyone. There were more chances of electricity theft. In response to this the following improvements along with efficiency and accuracy improvements were added in early design meters:

- A dust- and insect-proof cover
- A cover and frame so shaped and retained together as to render dishonest and curious tampering with the internal mechanism as nearly impossible
- Means for fully protecting from malicious tampering the heads of all screws in the base which bind the damping magnets, etc., in place without rendering them inaccessible to those authorized to reach them. A single phase low voltage watt-hour meter where tampering often occurs is shown in Figure 4.2.

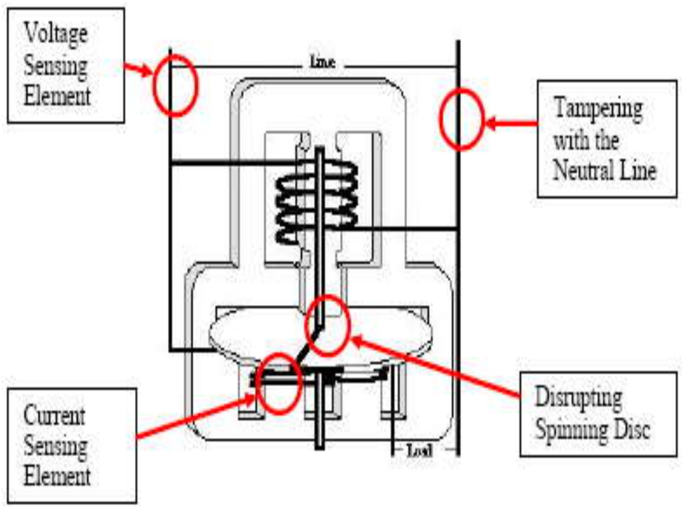

Figure 4.2 Parts of a Single-phase Watt-hour Meter.

4.6 TECHNIQUES OF ELECTRICITY THEFT

- **Direct connection to the power grid:** Since the meters and equipment in this section are in the 220 V system, where customers are mostly houses and small businesses, a direct connection to the power grid is much easier than the high-voltage system. Well, at least safer, a pair of rubber gloves could be all the necessary protection and a ladder and knife all the necessary tools, as opposed to climbing up HV lines. This is by far the most common method of electricity theft.
- **Using alternate neutral lines:** The single-phase system often has only one wire going into a house, the “hot” line. Neutral is usually grounded (electrically connected to the earth) and is sometimes provided by the foundation of the house to be more generic. So if

a person could manage to use a small transformer and use that as the "neutral", the meter that uses the very same neutral source would read the incoming voltage lower than it really is, resulting in a reduced unit count.

- **Phase-to-phase connection**: This is similar to using an alternate neutral line, except that the system voltage becomes the phase-to-phase voltage, at 240 or 380 volts.
- **Meter tampering/breaking seal**: This is basically the same thing that happens to the HV meters.
- **Other methods of electricity theft include:** Tapping off a nearby paying consumer, damage done to meter enclosures, and using magnets to slow down the spinning discs in the meter housing.

4.7 PREPAID ENERGY METERS

Indian power sector is facing serious problem of lean revenue collection as against energy supplied due to energy thefts and network losses. All the steps taken so far, regarding the improvement of the revenue collection did not yield satisfactory results. It is reported that the most faulty sub system is the metering and meter reading system. The traditional billing systems are discrete, inaccurate, costly, slow, and lack flexibility as well as reliability. Therefore, several attempts were made to automate the billing systems. Even though accurate and fast readings are obtained, bill payment is still performed based on the old billing procedure. They require an individual/agent to physically come and take down the readings and report to house hold/office the amount one has to pay.

Energy meters, the only direct revenue interface between utilities and the consumers, have undergone several advancements in the last decade. The conventional electro-mechanical meters are being replaced with electronic meters to improve accuracy in meter reading. Asian countries are currently looking to introduce prepaid electricity meters across their distribution network, buoyed up by the success of this novel methodology in South Africa. The existing inherent problems with the post-paid system and privatization of state held power distribution companies are the major driving factors for this market in Asia

Figure 4.3 Prepaid Meter

Over 40 countries have implemented prepaid meters in their markets. In United Kingdom the system, has been in use for well over 70 years with about 3.5 million consumers. The prepaid program in South Africa was started in 1992, since then they have installed over 6 million meters [24]. Other African counties such as Sudan, Madagascar are following the South African success. The concept has found ground in Argentina and New Zealand with few thousands of installations.

The prepaid meters in the market today are coming up with smart cards to hold information on units consumed or equivalent money value. When the card is inserted, the energy meter reads it, connects the supply to the consumer loads, and debits the value. The meters are equipped with light emitting diodes (LED) to inform consumers when 75 percent of the credit energy has been consumed. The consumer then recharges the prepaid card from a sales terminal or distribution point, and during this process any changes in the tariff can also be loaded in the smart card.

4.7.1 Benefits of Prepaid Meters

Improved operational efficiencies: The prepaid meters are likely to cut the cost of meter reading as no meter readers are required. In addition, they eliminate administrative hassles associated with disconnection and reconnection. Besides, going by South Africa's experience, prepaid meters could help control appropriation of electricity in a better way than conventional meters.

Reduced financial risks: Since the payment is up-front, it reduces the financial risk by improving the cash flows and necessitates an improved revenue management system.

Better customer service: The system eliminates billing delay, removes cost involved in disconnection/reconnection, enables controlled use of energy, and helps customers to save money through better energy management.

4.7.2 Market Drivers

Power sector reforms: The upcoming competitive and customer focused deregulated power distribution market will force the market participants to make the existing metering and billing process more competent. This is likely to drive the prepaid market.

Increasing non-technical losses: Metering errors, tampering with meters leading to low registration and calibration related frauds are some of the key components of non-technical losses. India reports greater than 10 percent of non-technical losses. It has been reported that prepaid meters control non-technical losses better than conventional ones.

Opportunities in the emerging electrifying markets: Most of the Asian countries do not have 100 percent electrification; hence new markets are being created by the increasing generating capacity. Prepaid systems can be more easily introduced in such new markets rather than the existing ones.

4.7.3 Market Restraints of Prepaid Meters

Consumer behaviour: Consumers have not had any major problems with the existing post-paid system, and hence it is likely to be difficult to convince them to change over to prepaid system.

Consumers might not appreciate the concept of "pay and use" as far as electricity is concerned because it might be perceived as an instrument to control common man's life style.

Initial investment: Utilities might be discouraged by the huge initial investment, which includes the cost of instrument, marketing campaign, establishing distribution channel, and other management costs.

Rapid technology changes: The rapid technology changes happening in the metering market are expected to delay the decision to go for prepaid system.

Uncertainty over the success: Prepaid system is not as proven a concept in all the markets as South Africa; hence there is bound to be uncertainty over its success, if implemented. The success of the system depends on the commitment by utilities and for this they need to get convinced on the real benefits of prepaid meters.

4.7.4 Recent Initiatives of Prepaid Meters

i. The Sabah Electricity State Board (SESB), Malaysia, has awarded a contract to a local manufacturer to supply 1,080 prepaid meters

ii. Countries such as Thailand, Bangladesh, Singapore, and Iran have been showing increased interest in adopting prepaid system

iii. In India, the State of West Bengal has decided to introduce the smart card operated prepaid energy meters in remote islands of Sunderbans. In Mumbai, pre-paid power is provided by the Brihanmumbai Electricity Supply and Transport (BEST) Undertaking. Tata Power plans to introduce pre-paid electricity in Delhi. Tata Steel is likely to install prepaid electricity meters at its employee township in Jamshedpur.

4.8 AN ON-LINE PRE-PAID ENERGY METER

Online prepaid energy meter is a device which can be interfaced with static electronic energy meter. This is a very good microcontroller based application [25]. This unit will accept the number of units recharged by the concerned department person, counts the number of units consumed by the customer and as soon as the customer exceeds the recharged amount, it will disconnect the power supply to the customer until the next recharge. Whenever the number of units in microcontroller becomes zero microcontroller sends a signal to “Contact Maker /Breaker circuit” which is nothing but the relay and this relay cuts off the power supply to the consumer until next recharge. The following figure 4.4 represents the block diagram of an online pre-paid energy meter:

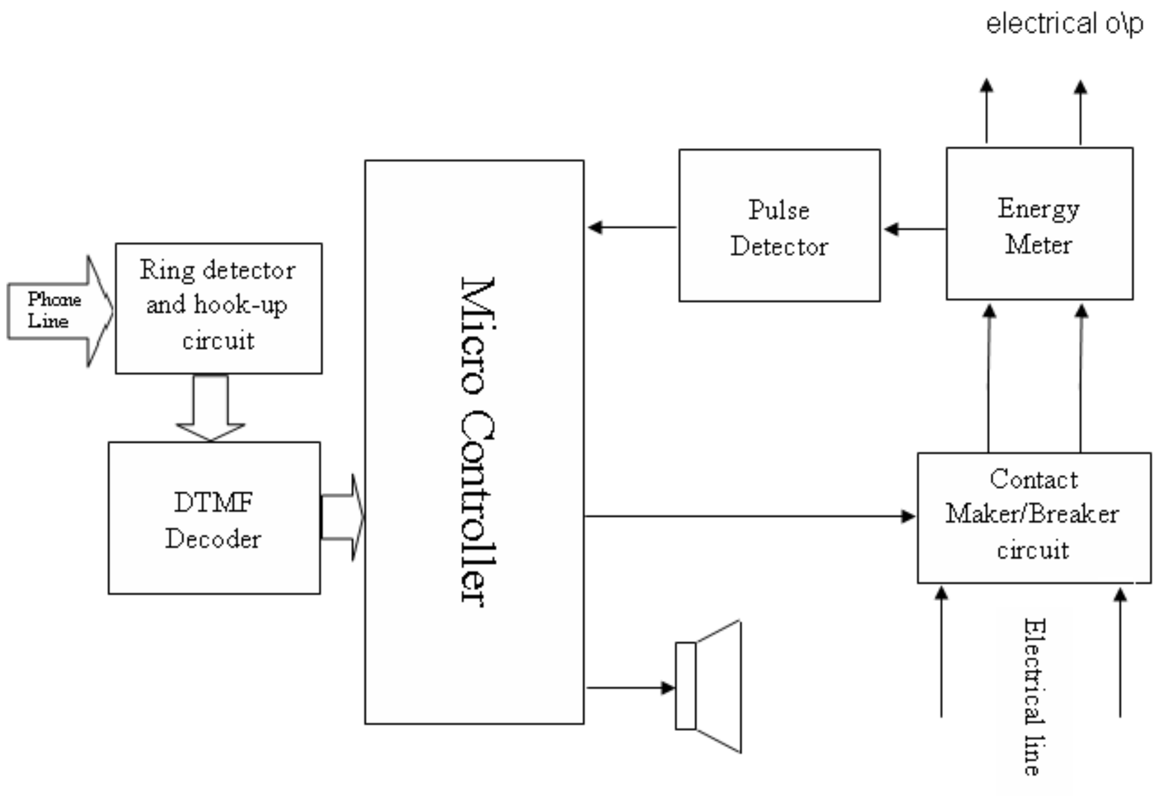

Figure 4.4 Block diagram of online prepaid energy meter

The consumers and the suppliers can be benefited by using the online prepaid energy meter in the following ways:

• This system is of great advantage for the electricity department as this unit can be utilized effectively for preventing power theft, non-payment of electricity bills etc

• The whole process of billing can be centralized

• Cost of manpower for billing / collection is reduced

4.9 SUGGESTIONS TO MINIMIZE NTL

Non-technical losses in distribution systems comprised about 2-3%, of the total system losses [23]. Total distribution system losses equals technical losses plus non-technical losses.

Following are the non-technical strategies by which non-technical losses can be minimized or mitigated:

1. Upgrading of electricity meters to meet standard accuracy must be conducted to support reduction of non-technical losses thru statistical analysis

2. Integrated billing system and prepaid energy meters are the choices which need to be accomplished by the utilities in order to reduce the non technical loss reduction

3. Smart card technology can play an important role in minimizing the theft of energy.

4. Technical training to the operating personnel must be given plus enhancing employees loyalty will be there to eliminate pilferage in the distribution system

5. Statistical monitoring of energy consumption per sector, per class and geographical set-up must be employed and statistical evaluation of meter readings must be done

6. Statistical analysis of electricity meter readings must be done so that sample data from electricity meters can be analyzed statistically over time to estimate significant deviation from usual meter readings. This will help the operating personnel to keep track the energy usage of its consumers and will have a benchmark in case significant meter reading deviation especially at the totalizing meters is observed.

CHAPTER 5

STUDY OF VARIOUS LOSSES AND SOLUTION METHODOLOGY

Total system losses for a utility system can be calculated directly as the difference between production energy and electric sales. Losses obtained from metering differences are the most definitive method of determining energy losses. Errors are introduced into these values, however, because of meter reading billing cycles, meter placement (high side or low side of the generator transformer, for example), and accounting procedures, particularly for utilities which have other utilities' load within their service territory or which have loads within other utilities service territories. Energy diversion (stolen energy) may also result in the misrepresentation of losses calculated from the differences in the meters. Unmetered substation and company use will also be included in the metered difference and must be accounted for in the measured losses. After all non-technical losses are accounted for the remaining losses are the technical losses, those caused by current and voltage in lines and equipment [26].

T&D losses have been a concern for the Indian electricity sector since these have been very high when compared with other developed countries. The present T&D losses including unaccounted energy are about 30% [27]. As per MOP (Members of Parliament) this figure is optimistically low and there is need to reduce these losses through efficient management and the best operation & maintenance practices of the transmission and distribution.

5.1 ANALYSIS OF TECHNICAL LOSSES IN POWER SYSTEM

Technical losses result from equipment inefficiency, the inherent characteristics of the materials used in the lines and equipment, and the sizes of lines and equipment. The three major contributors are the current squared losses through a resistance, transformer excitation losses, and line and insulation corona or leakage losses.

In AC systems the copper losses are higher due to skin effect. Due to skin effect, the flux density at the centre of the conductor is great and current flow towards the surface of the conductor is greater. Therefore the skin effect increases the resistance and thus the power loss. The increase in resistance is proportional to the frequency of the AC signal. Transformer losses include copper losses due to the internal impedance of transformer coils and core loss. Power transformers are connected permanently to the power system, hence their no-load losses have to be considered. No-load losses are a function of the type of lamination, core material, insulation, voltage and frequency. The most predominant no-load losses are the core losses, made up of hysteresis and eddy current losses [28], expressed by the equations:

$$\text{Hysteresis loss, } P_H = K_h f B_m$$

$$\text{Eddy Current Loss, } P_E = K_e f^2 B_m{}^2$$

where ,

f = frequency,

B_m = flux density of the core material,

K_h, K_e = Hysteresis & Eddy current constant,

Dielectric losses are losses that result from the heating effect on the dielectric material between conductors. The heat produced is dissipated in the surrounding medium.

Induction and radiation losses are produced by the electromagnetic fields surrounding conductors. Induction losses occur when the electromagnetic field about a conductor links another line or metallic object and current is induced in the object. As a result, power is dissipated in the object and lost. Radiation losses occur because some magnetic lines of force about a conductor do not return to the conductor when the cycle alternates. These lines of force are projected into space as radiation and these results in power losses, that is, power is supplied by the source, but is not available to the load.

5.2 ANALYSIS OF NON-TECHNICAL LOSSES

NTLs, by contrast, relate mainly to power theft in one form or another. They are related to the customer management process and can include a number of means of consciously defrauding the utility concerned. By default, the electrical energy generated should equal the energy registered as consumed. However, in reality, the situation is different because losses occur as an integral result of energy transmission and distribution.

Energy Losses

$$E_{Loss} = E_{Delivered} - E_{Sold}$$

Revenue Loss due to technical losses

$$C_{Com\ Loss} = U_{Elect\ Cost} \times E_{Loss} + M_{Maintenance\ Cost}$$

Non-technical Loss

$$C_{NTL} = C_{Com\ Loss} - C_{Technical\ Loss}$$

where,

$U_{Elect\ Cost}$ = Unit cost of electricity

The information about the power sources and loads are needed to determine expected losses in the power system using load-flow analysis software. The actual losses are the difference between outgoing energy recorded by the source (e.g., at a substation) and energy consumed by the consumers, which is shown on the bills. The discrepancy between expected losses and actual losses would yield the extent of nontechnical losses in that system.

So firstly technical losses have been calculated using load flow studies. The various specifications of different parameters of transmission line, transmission line resistance and reactance values will be taken from 11KV transmission lines datasheet [9]. The conductor size and line length will be chosen arbitrarily from the Table 5.1 shown below:

Table 5.1 Sequence Impedance for 11 kV

Item	Conductor size		A.C. Resistance Ohm/Cond./Km		Impedance Ohm/Cond./ Km			
					Single Circuit		Double Circuit	
	mm^2	Dia of Str. mm/ No.of Str.	20^0C	50^0C	X1=X2	Ro+jXo	X1=X2	Ro+jXo
ALL ALUMINIUM CONDUCTOR								
1	25	2.14/7	1.137143	1.274624	0.401496	1.422624 + j1.628310	0.416624	1.570624 + j2.755995
2	35	2.52/7	0.820096	0.919246	0.391226	1.067246 + j1.618040	0.406354	1.215246 + j2.745725
3	50	3.02/7	0.571100	0.640146	0.379854	0.788146 + j1.606667	0.394982	0.936146 + j2.734352
4	70	2.15/19	0.421161	0.472079	0.366401	0.620079 + j1.593214	0.381529	0.766079 + j2.720099
5	95	2.52/19	0.303853	0.340589	0.356424	0.488589 + j1.583237	0.371552	0.636589 + j2.710922
6	120	2.85/19	0.237695	0.266432	0.348692	0.414432 + j1.575505	0.363820	0.562432 + j2.703190
7	185	2.52/37	0.156761	0.175713	0.334439	0.323713 + j1.561251	0.349567	0.471713 + j2.688937

The loads have been assumed to be balanced between all three phases, to avoid complex computing. This means that only the positive sequence impedance values need be used in calculations and negative and zero sequences can be ignored. The specifications provided about the loads should be as per the following:

- Power demands of the loads at various times of the day over 24 hours;
- Power factor values over the same time period;
- The averages of power demands and power factors.

Thus the incurred active & reactive power losses in transmission lines will be calculated. From the technical loss analysis above, the effects of an undetected load attached to one of the buses in the two-bus test system can be measured by adding extra demand values to one of the loads and evaluating the changed losses.

The average power loss in a transmission line can be expressed as

$$P_{loss} = P_{source} - P_{load}$$

Where P_{source} means the average power that the source is injecting into the transmission line at one end and P_{load} is the power consumed by the load at the other end of the transmission line.

Energy is power accumulated over time, or

$$W_{loss} = \qquad (\ )$$

Power, in a single-phase case, with sinusoidal current and voltage can be represented by

$$P_{1\text{-}\Phi} = V\, I \cos\theta$$

With P, V and I being the average power, rms voltage and rms current respectively. The term cos θ is the power factor of the element in question, while θ is the phase difference between the voltage and the current waveforms. From the above it can be summarized that the information needed to calculate the average power loss sampled at an instant of time in a transmission line or an arbitrary element in a power system has to be one of the following sets [23] (all variables are single phase, rms values and average power):

$$P=V^2/R,$$

As V=IR

Therefore, $P=I^2R$

Also $P= VI \cos\theta$

These sets of data and choices of calculations are the options for computing power losses using load-flow analysis. But in order to gain V or I both rms values, the voltage must be known at two ends of the element that is evaluated, at all times or as averages. This means the terminals that feed consumer loads must be appropriately monitored at all times using some of the more sophisticated meters that could store and compute average and instantaneous values that the load-flow analyst is interested in. The information about the power sources and loads are needed to determine expected losses in the power system using load-flow analysis software. The actual losses are the difference between outgoing energy recorded by the source (e.g., at a substation) and energy consumed by the consumers, which is shown on the bills. The discrepancy between expected losses and actual losses would yield the extent of nontechnical losses in that system. The following figure 5.1 represents the single line diagram of a two bus power system.

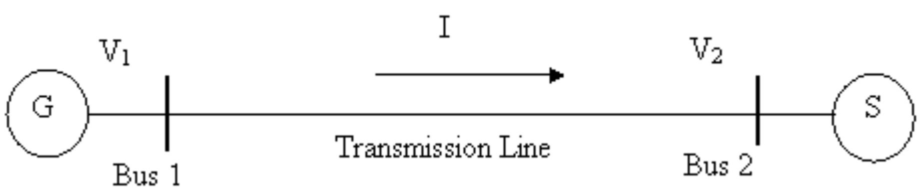

Figure 5.1 A Two-bus power system

For the simulations undertaken for this thesis, the voltage, current, power, and power factor of the generator have known values at the same time intervals, and, consequently, the current going through the transmission line. The loss in the transmission line is easily computed using the current and transmission line resistance values. Information of the load's power and power factor are unknown, but at this point the information at the generator is sufficient to determine what's happening to the transmission line using simple calculations:

$$I^* = S_{load} / V_{load}$$

and $$\text{Power loss} = VI^*$$

With S_{load}, V_{load}, I, and *R* are the load apparent power, load voltage, current in the transmission line, and transmission line resistance, respectively, while I* is the complex conjugate of the current [29] Any major calculations become unnecessary when current can be measured directly and the transmission line properties are known, which is never true for practical power systems.

Companies that generate and distribute electricity usually measure currents that enter and leave their facilities in order to measure the energy that is bought or sold. For areas outside the company's facilities, i.e., residential or business consumer areas, only peak power and accumulated energy are usually measured. However, the low voltage transmission systems (below 11 kV) are not as thoroughly measured because of the costs of the added metering. This is the reason power flow solutions are used to estimate the state of various points in the system.

5.3 SOLUTION METHODOLOGY FOR MEASUREMENT OF LOSSES

Increasing energy costs and environmentalists actions to protect the natural resources forces energy supply companies to conserve and reduce energy usage. Therefore the focal point of reducing energy is the reduction of electrical energy losses in distribution networks. The electrical energy losses can be divided into two main groups:

- Technical losses due to physical aspect
- Non-technical losses due to unauthorized line tapping or meter bypassing.

As we know that total system losses are composed of technical & non technical losses. Non technical losses are difficult to measure because of the presence of T & D losses in it and also it is not possible to segregate NTL from them. So, solution methodology for the measurement of technical losses using load flow has been developed. These losses when subtracted from the total losses will give the extent of NTL in the system.

5.3.1 Power Flow Problem Formulation

The solution to the power flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. A bus without any generators connected to it is called a Load Bus. With one exception, a bus with at least one generator connected to it is called a Generator Bus. The exception is one arbitrarily-selected bus that has a generator. This bus is referred to as the Slack Bus.

In the power flow problem, it is assumed that the real power and reactive power at each Load bus are known. For this reason, Load Buses are also known as PQ Buses. For Generator Buses, it is assumed that the real power generated and the voltage magnitude |V| is known. For the Slack Bus, it is assumed that the voltage magnitude |V| and voltage phase θ are known. Therefore, for each Load Bus, the voltage magnitude and angle are unknown and must be solved for; for each Generator Bus, the voltage angle must be solved for; there are no variables that must be solved for the Slack Bus. In a system with N buses and R generators, there are then 2(N − 1) − (R − 1) unknowns.

In order to solve for the $2(N-1)-(R-1)$ unknowns, there must be $2(N-1)-(R-1)$ equations that do not introduce any new unknown variables. The possible equations to use are power balance equations, which can be written for real and reactive power for each bus. Equations included are the real and reactive power balance equations for each Load Bus and the real power balance equation for each Generator Bus. Only the real power balance equation is written for a Generator Bus because the net reactive power injected is not assumed to be known and therefore including the reactive power balance equation would result in an additional unknown variable. For similar reasons, there are no equations written for the Slack Bus.

5.3.2 General equations used in program

In addition to the equations described in the Newton Raphson algorithm, some general equations are also used. Basically we have three types of powers in electrical system

(i) Active power: It is represented by P having units of W
(ii) Reactive power : It is represented by Q having units of VAr
(iii) Apparent power : It is represented by S having units of VA

$$S=\sqrt{P^2+Q^2}$$

So P & Q are determined from the above said Newton Raphson algorithm and hence S can be calculated. By Ohm's law, we know that

$$V=IZ,$$

$$Z = R + jX;$$

where,

j = imaginary part of the number

R=Resistance of element

X=Reactance of element

Z=Impedance of element

The real and reactive power, in turn, can be calculated using the apparent power and the angle representing the phase difference between the current and voltage, known as the power factor angle (θ).

$$S = VI^*$$

Where I^*= Complex conjugate of a number.

Thus,

$$\text{Active power} \quad P = S\cos\theta$$

$$\text{Reactive power} \quad Q = S\sin\theta$$

Hence the total power is given by the following relation:

$$S = P + jQ$$

Though all power systems that operate with more than 220 volts are three phase systems, the discussions and calculations here will treat the values as single-phase equivalents. In order to be able to do this, the three-phase system is assumed balanced, i.e., all three phases have exactly the same amount of power flowing through each of them. In reality, three-phase power systems are rarely, if ever, perfectly balanced. Also, the values of voltages and currents are all stated in root mean square (rms) values, while power values are average powers.

In the program, the resistance and reactance values are taken from 11 kV data sheet. A line conductor of 120 mm^2 has been chosen & the line length has assumed to be 3 km. Then Z_{bus} is formed and hence Y_{bus} can be calculated using following relation:

$$Y_{bus} = \frac{1}{Z_{bus}}$$

The values of voltages and currents are all stated in root mean square (rms) values, while power values are stated as average values.

5.4 A PRACTICAL CASE STUDY

Figure 5.2 represents a single-Line diagram of a Two-Bus, Two-Load power system with known load and known transmission line data. Each bus can be the slack bus.

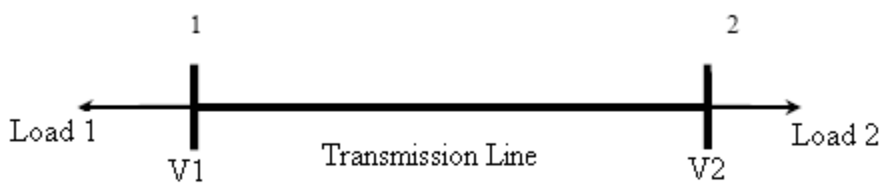

Figure 5.2 Load at both the buses

Two-bus subsystem has been shown with loads at both buses and one bus selected as a "slack bus" with constant voltage also known as reference bus (or node) in the system with known voltage and phase angle necessary for analysis of the system. This configuration is chosen for simplicity. The bus with constant voltage is presumed, as is the case with most systems, to be the one connected to the larger system that has a relatively infinite supply of electrical energy with constant source characteristics. Transformers are omitted from the simulation program for simplicity's sake. Consider the transmission line length to be 3 km. The following are the specifications of a simple two bus system which is needed to complete a load-flow calculation for power loss in the transmission line are given below:

Base Values: 11000 Volts, 100 Ampere, 1.1 MVA, 110 Ohms

Transmission Line Resistance = 3 km × 0.266432 Ohms/conductor/km ×3 conductors

= 2.3978 Ω

= 0.021799 p. u.

Transmission Line Reactance = 3 km × 0.348692 Ohms/cond./km × 3 conductors

= 3.1382 Ω

= 0.028529 p. u.

The following are the load profiles of a simple industrial load and a residential load. The load is shown in kVA with the power factor calculated for each hour.

Table 5.2 Load profiles for Industrial and Residential load

Time (Hrs.)	Industrial load (kVA)	Power factor of load 1	Residential load (kVA)	Power factor of load 2
1	65	0.92	32	0.82
2	70	0.92	30	0.82
3	88	0.92	50	0.82
4	87	0.87	38	0.87
5	92	0.90	25	0.85
6	102	0.91	42	0.77
7	120	0.87	83	0.72
8	150	0.82	75	0.74
9	230	0.77	100	0.79
10	235	0.77	62	0.83
11	255	0.77	50	0.85
12	265	0.77	57	0.81
13	275	0.77	30	0.80
14	300	0.77	60	0.85
15	300	0.77	45	0.88
16	300	0.82	59	0.79
17	250	0.82	90	0.75
18	175	0.82	100	0.71

19	135	0.87	130	0.73
20	90	0.90	150	0.70
21	85	0.91	175	0.79
22	70	0.92	82	0.80
23	65	0.91	73	0.84
24	60	0.91	65	0.91

A load profile of 24 hours has been shown for simplicity and the further calculations have been done with the help of Newton-Raphson method. Figure 5.3 shows the variation of the loads during 24 hours.

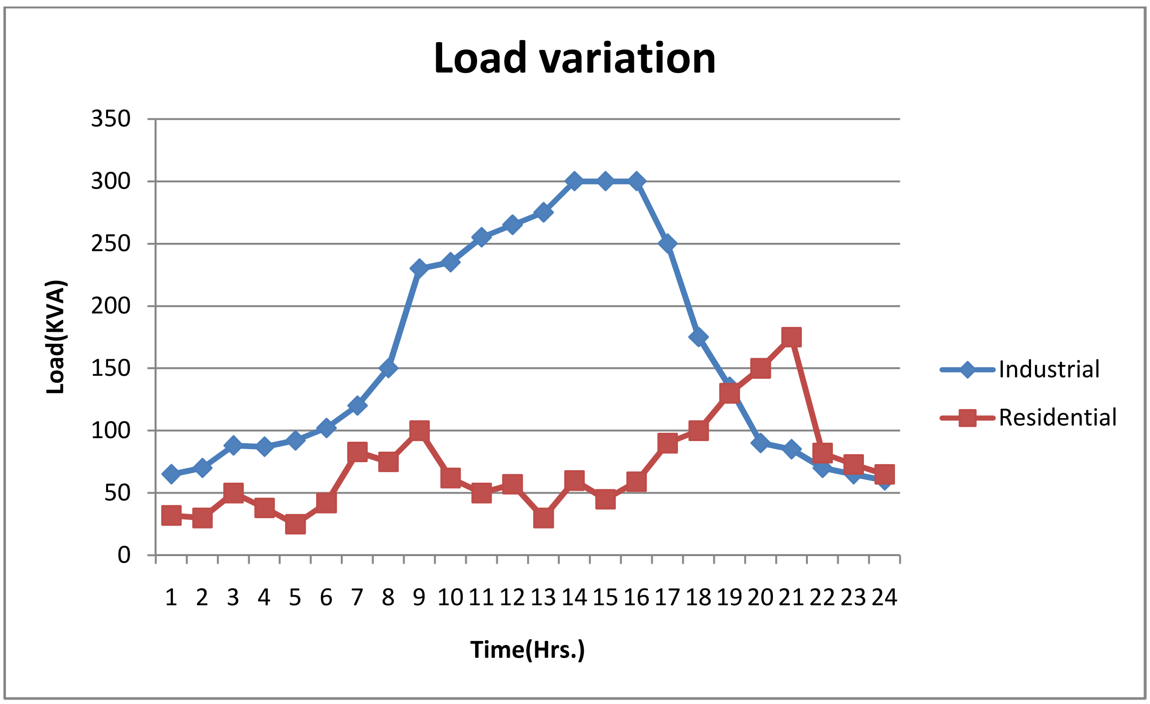

Figure 5.3 Load variations over 24 hours

As shown in table the industrial load has its peak demand during day times and the residential load demand is more during morning and evening hours. The load peaks are at 300 kVA for load1 and 175 kVA for load 2. The average load demands (sum of peak values / no. of hours in a day) are 161 kVA and 70.95 kVA for load 1 and load 2, respectively. Load power factors are shown in Figure 5.4 below.

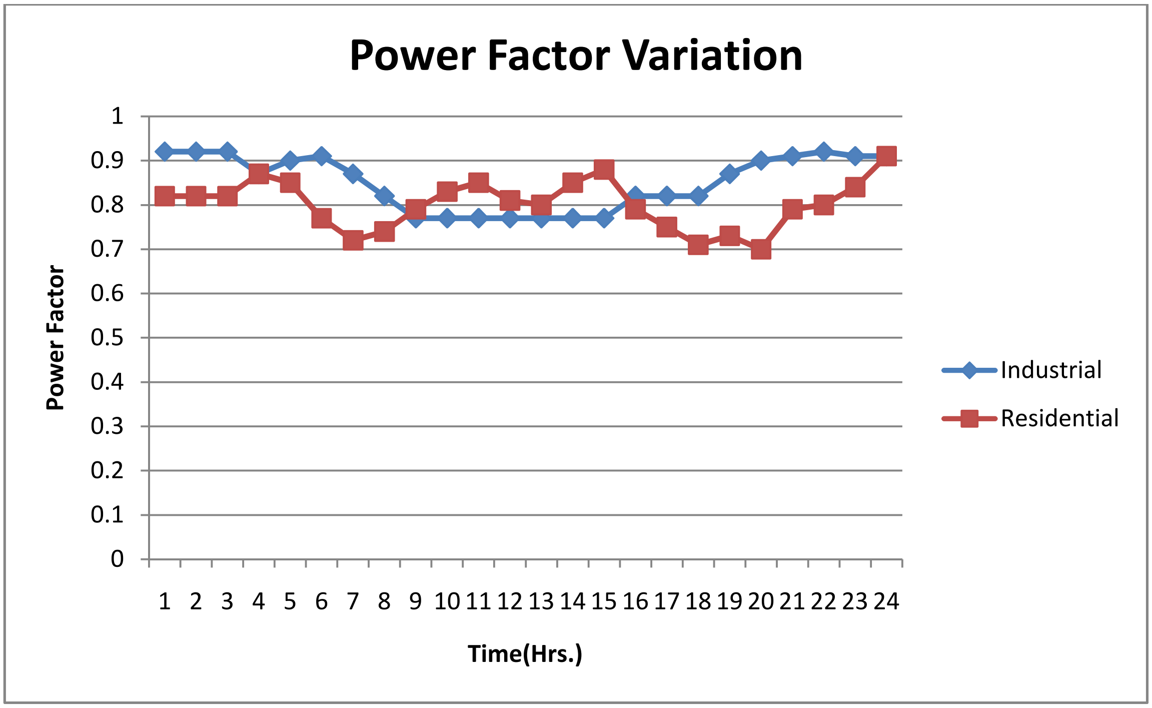

Figure 5.4 Variation of power factor over 24 hours

Transmission line resistance and reactance values are taken from 11KV transmission lines datasheet. The conductor size and line length were chosen arbitrarily from the datasheet, with the maximum conductor size of 120 mm^2 chosen to avoid overloading the line. Finally, the loads were assumed balanced between all three phases, to avoid complex computing. This means that only the positive sequence impedance values need to be used in calculations and negative and zero sequences can be ignored.

The Matlab simulator is used to calculate the transmission losses for the load demands and power factor for each hour, by using bus 1 as the slack bus. Figures 5.5(a) and Figure 5.5(b) describes the two types of losses i.e. active power losses & reactive power losses.

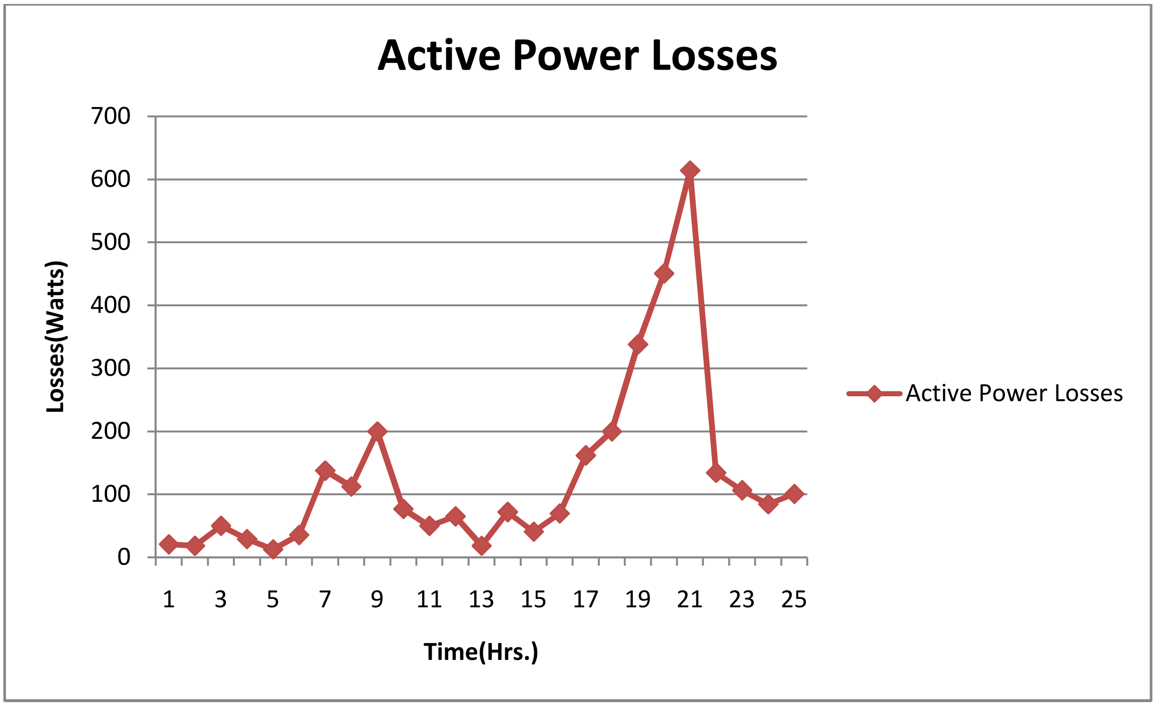

Figure 5.5(a) Active power losses

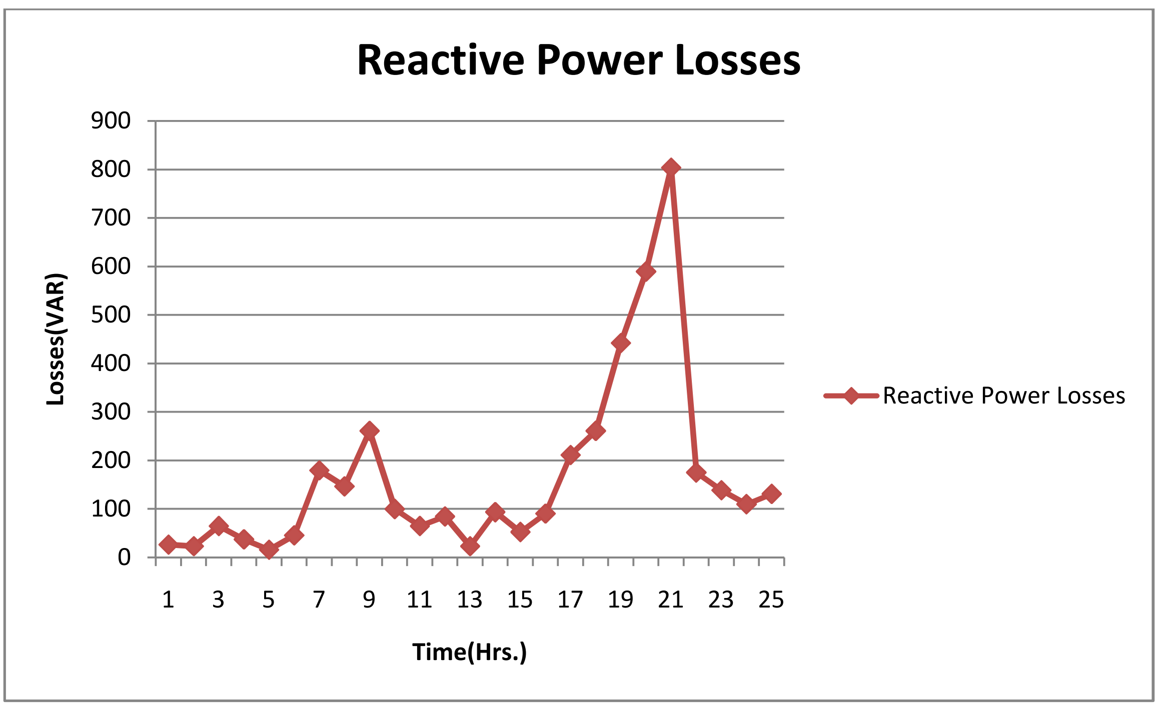

Figure 5.5(b) Reactive power losses

Transmission and distribution line sections that are most vulnerable to theft are the medium- and low-voltage lines that connect to most of the consumers. These lines are numerous and usually highly interconnected, which means that isolation of an area for calculation is difficult. The two-bus calculations above are done with one of the buses held constant, and there must always be a slack bus with constant known properties in order to run load flow analysis [30] In medium- and low- voltage subsystems, however, the bus voltages are often shifting along with consumer demand changes and even voltage levels at the incoming feeders sometimes fluctuate. At this point, it is getting clear that making calculations for expected losses accurately is nearly impossible in practice. The obstacle here is that meters installed and used by utilities are all old models that only record peak power and energy in kilowatt-hours. Even the industrial meters only record the worst-case power factor.

The average demand is not something difficult to find, but the problem for using this in load flow calculations is that the corresponding power factor must be found. Power factor, as mentioned earlier, is not a quantity that is recorded by most meters. The high-voltage or high-demand meters that record power factor exists mainly in utilities' installations or very large loads, while medium-sized loads often record only the worst-case power factor for the purpose of billing, which is not useful when it comes to finding the average power factor.

5.4.1 Addition of Non Technical Losses

As shown in the case study, non technical losses are not easy to calculate because it contains a major portion of transmission & distribution losses. Non-technical losses can also be viewed as undetected load of customers that the utilities don't know. When an undetected load is attached to the system, the actual losses increase while the losses expected by the utilities will remain the same. The increased losses will show on the utilities' accounts, and the costs will be passed along to the customers as transmission and distribution charges. From the various studies, it has been concluded that NTL constitutes 2-3% of the total system losses [21]. Thus calculations have been shown by adding 3% of the original kVA demand to one of the bus and the modified results have been shown using Matlab simulation. Hence the total increase in losses has been calculated. From the technical loss analysis above, the effects of an undetected load attached to one of the buses in the two-bus test system can be measured by adding 3% extra demand values to one of the loads and evaluating the changed losses.

Table 5.3 Extra load profile with negative power factor addition

Time (Hrs.)	NTL Load (KVA) added at Bus 2	NTL Load power factor
1	2.91	-0.0246
2	3.00	-0.0246
3	4.14	-0.0246
4	3.75	-0.0261
5	3.51	-0.0255
6	4.32	-0.0231
7	6.09	-0.0216
8	6.75	-0.0222
9	9.90	-0.0237
10	8.91	-0.0249
11	9.15	-0.0255
12	9.66	-0.0243
13	9.15	-0.0240
14	10.80	-0.0255
15	10.35	-0.0264
16	10.77	-0.0237
17	10.20	-0.0225
18	8.25	-0.0213
19	7.95	-0.0219
20	7.20	-0.0210
21	7.80	-0.0237
22	4.56	-0.0240
23	4.14	-0.0252
24	3.75	-0.0273

The power factor contributions chosen here are negative because the NTL load is assumed to be Inductive, i.e., motors or light fixtures. The extra load and negative power factor addition to second bus are shown in the Figures 5.6 and Figure 5.7 respectively.

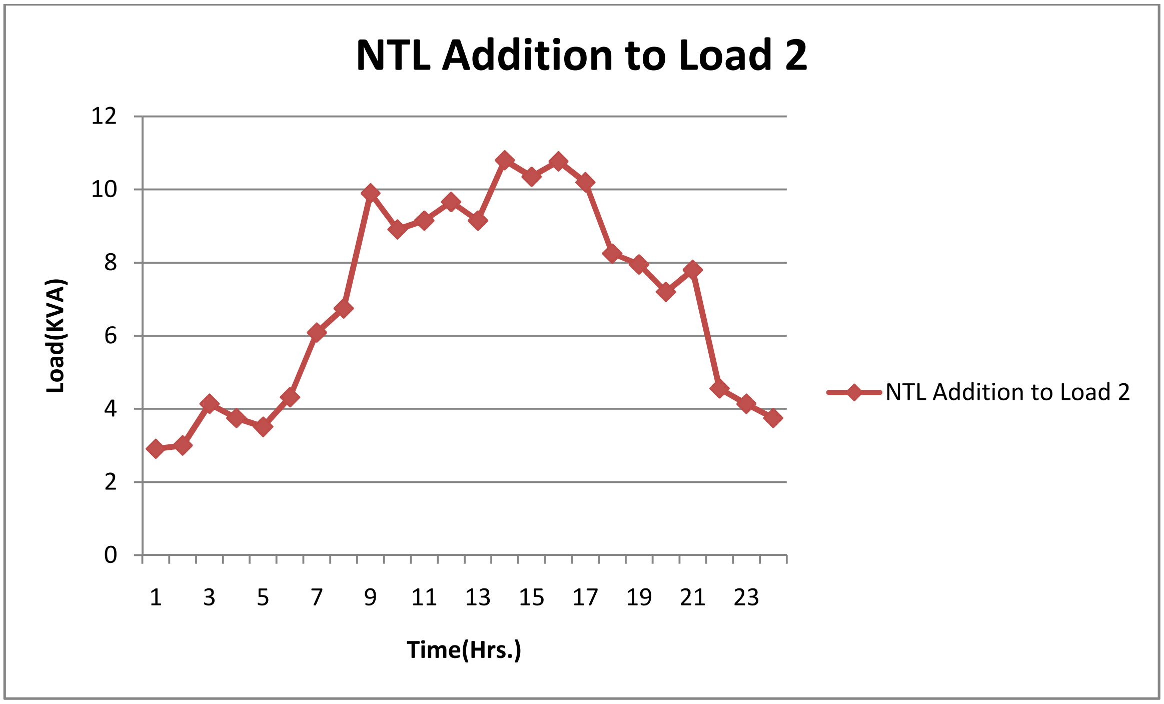

Figure 5.6 NTL addition

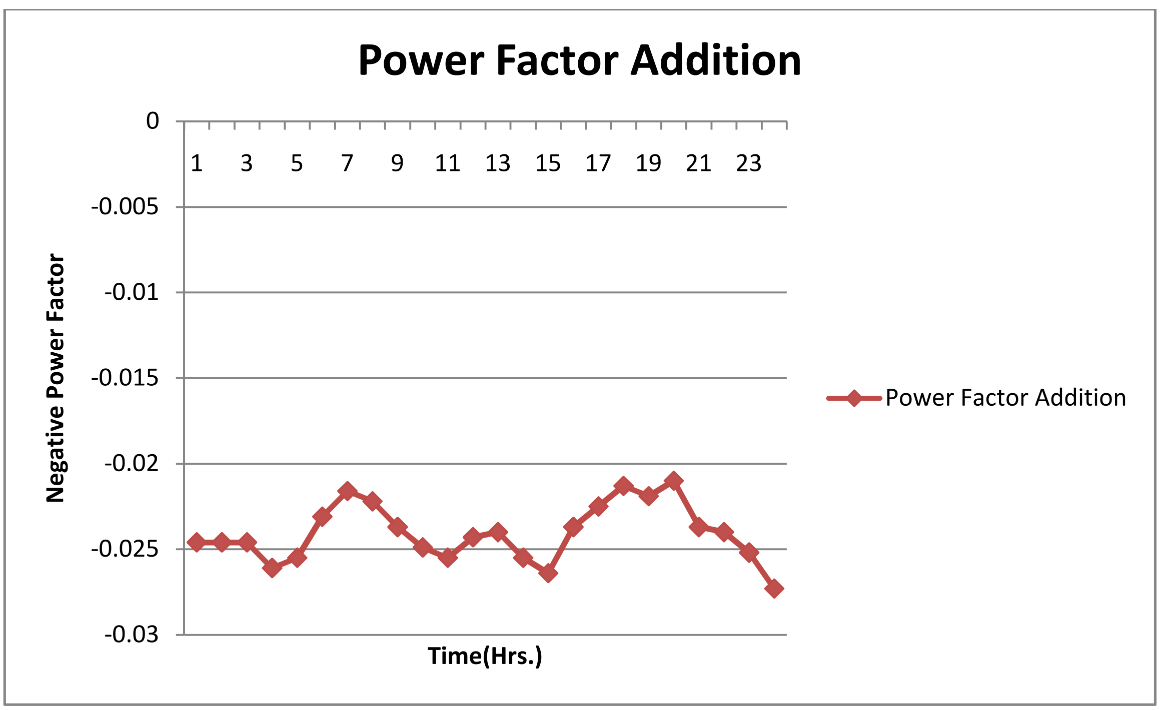

Figure 5.7 Power factor additions

The simulation is run with bus 1 as the slack bus. The NTL power factor contribution is negative at all times because the NTL load is assumed to be inductive. After the simulation was completed and evaluated, some notable results were evident. The Active & Reactive power losses along with NTL in transmission line are shown in Figures 5.8 and 5.9 respectively.

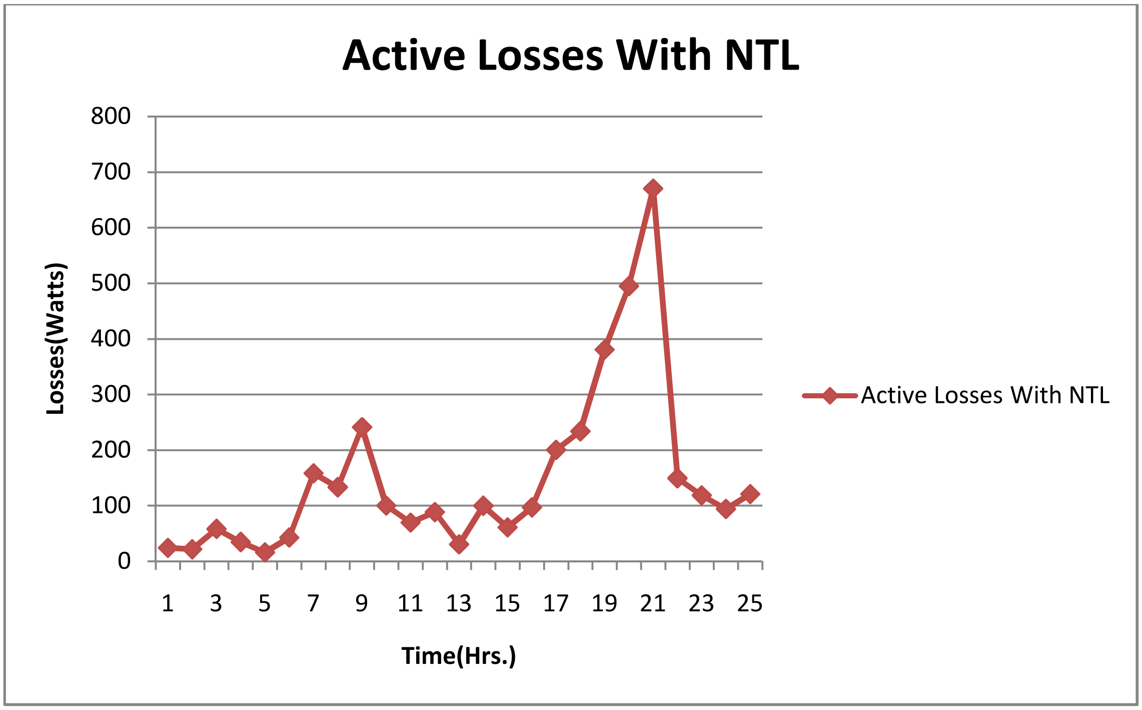

Figure 5.8 Active losses with NTL

In the case where bus 1 is used as the slack bus, the average power loss in the transmission line is around 128.72 Watts (Average of Active Power losses over 24 hours), while the power loss calculated using the average values of power and power factor is 100.23 Watts. The result is that the average of losses calculated using the sum of data from individual times is not equal to the losses calculated using the average values. The maximum active power losses occurred as shown in graph are 670.04 Watts maximum reactive power losses are while 876.9 Watts. This has been clearly shown with the help of figures.

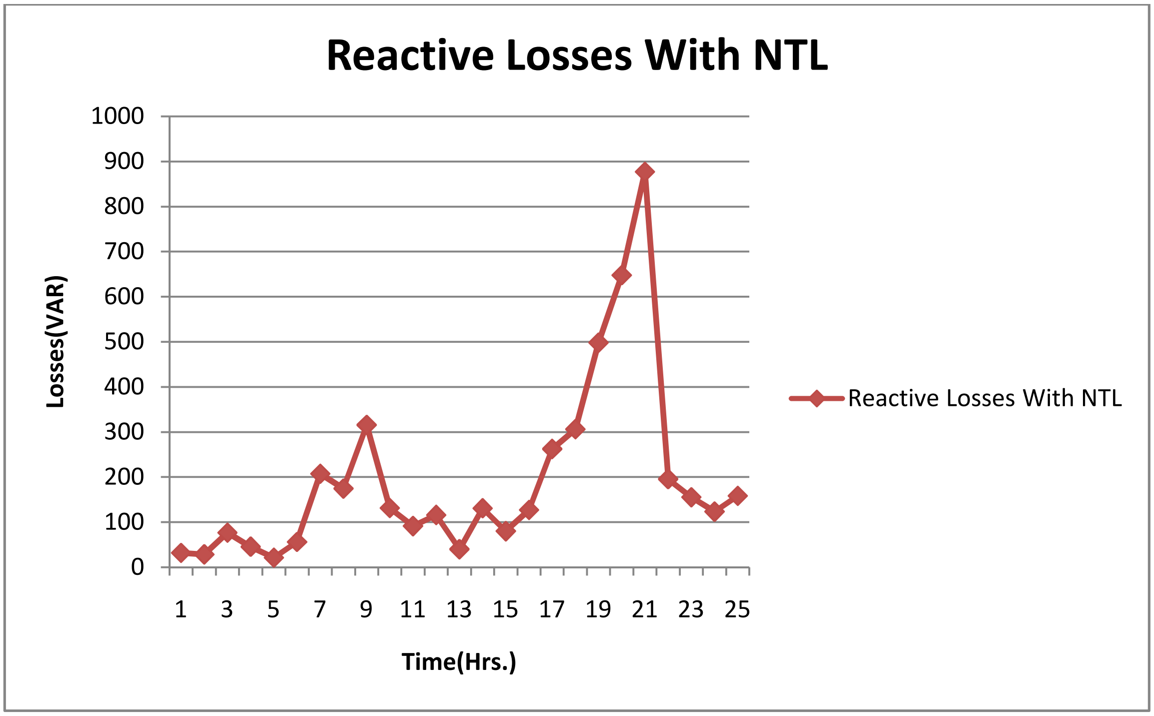

Figure 5.9 Reactive losses with NTL

5.5 COMPARISON OF LOSSES

With the addition of NTL to one of the load, the overall system losses will increase. This large increase is only due to small addition i.e. only 3% load. Mainly reactive power losses have higher range than active power losses. The two losses are compared with the help of waveform shown in Figure 5.6 below. The average demand for that same time period is the total energy consumption divided by the length of the time period, in seconds. This information is always available for metered loads, because it is what the utilities' revenues are based on.

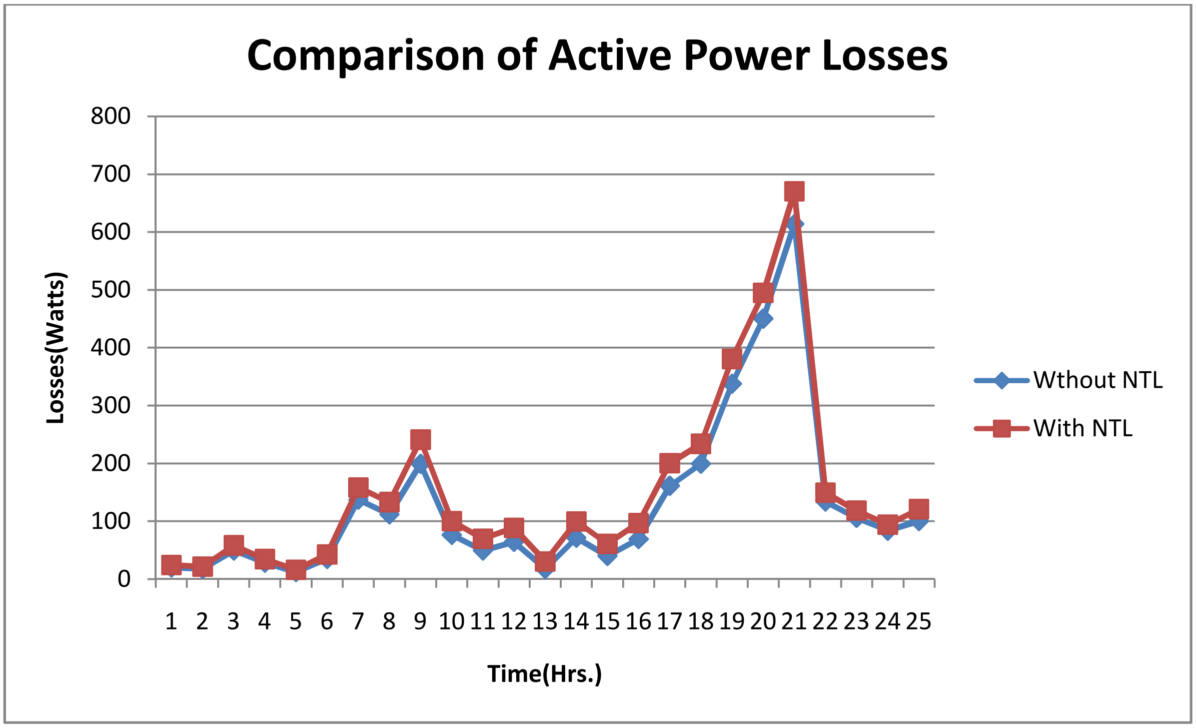

Figure 5.10 Comparison of Active power losses

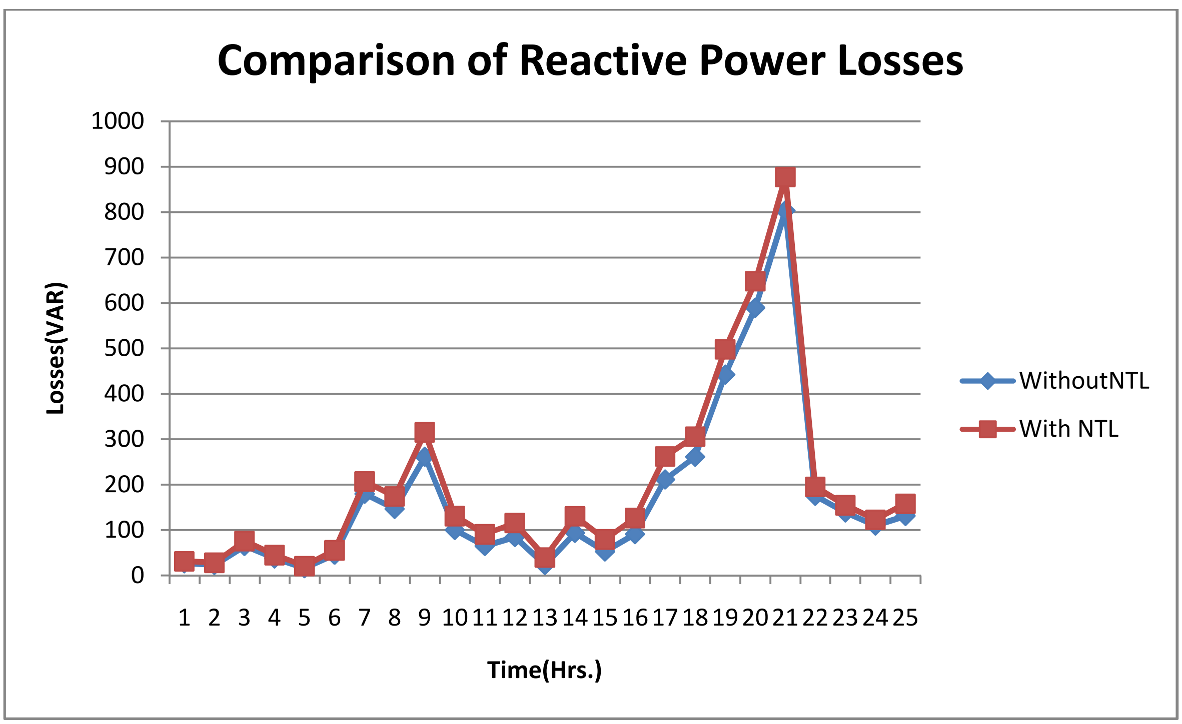

Figure 5.11 Comparison of Reactive power losses

The increase in load demand and the increase in transmission losses are not at the same levels. This is caused by the power factor contribution of the NTL load. Indeed, the losses increased at a greater rate than the loads. The average loss here is computed by averaging the overall loss increase for each hour. The Figure 5.12 shows the net per unit increase in losses at bus 2 where as percentage increase of load and losses due to NTL are also shown in Figures 5.13 & 5.14 respectively.

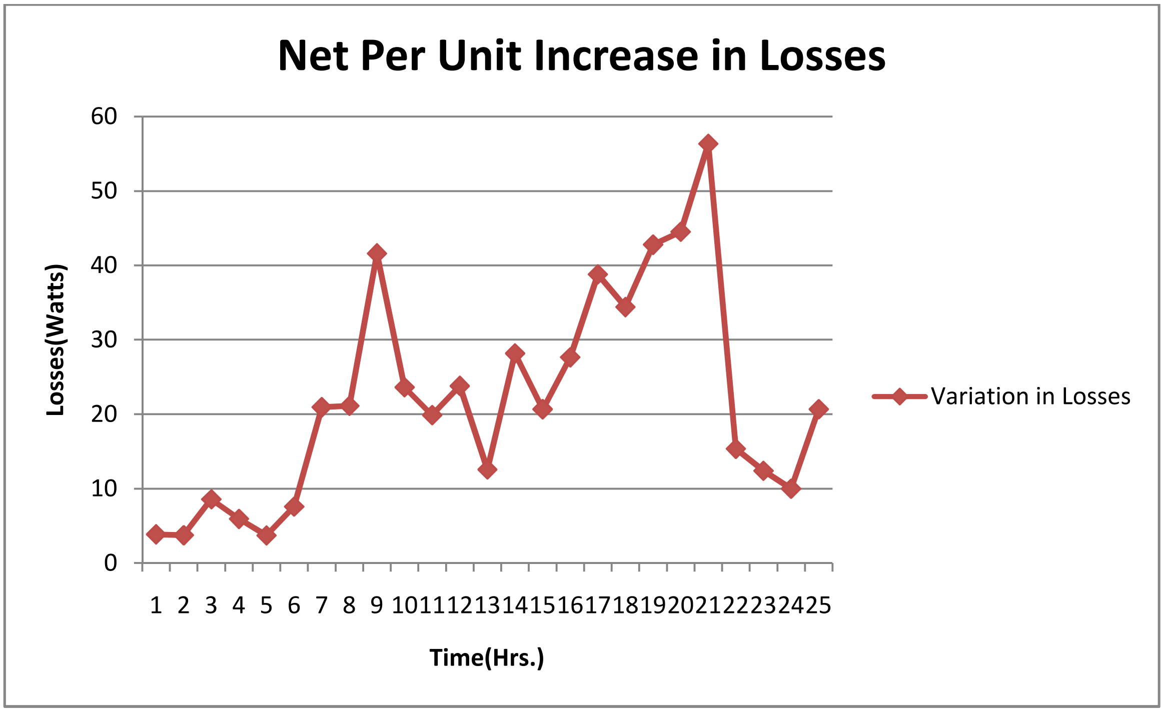

Figure 5.12 Per unit increase in losses

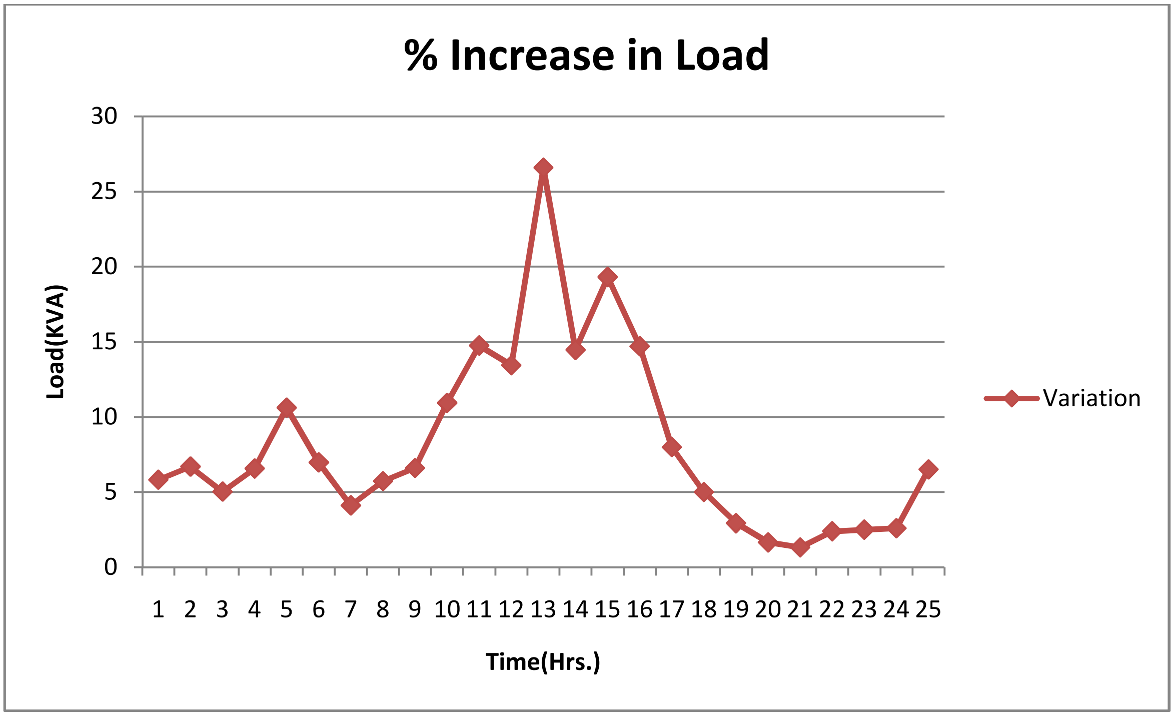

Figure 5.13 Percentage increase in load

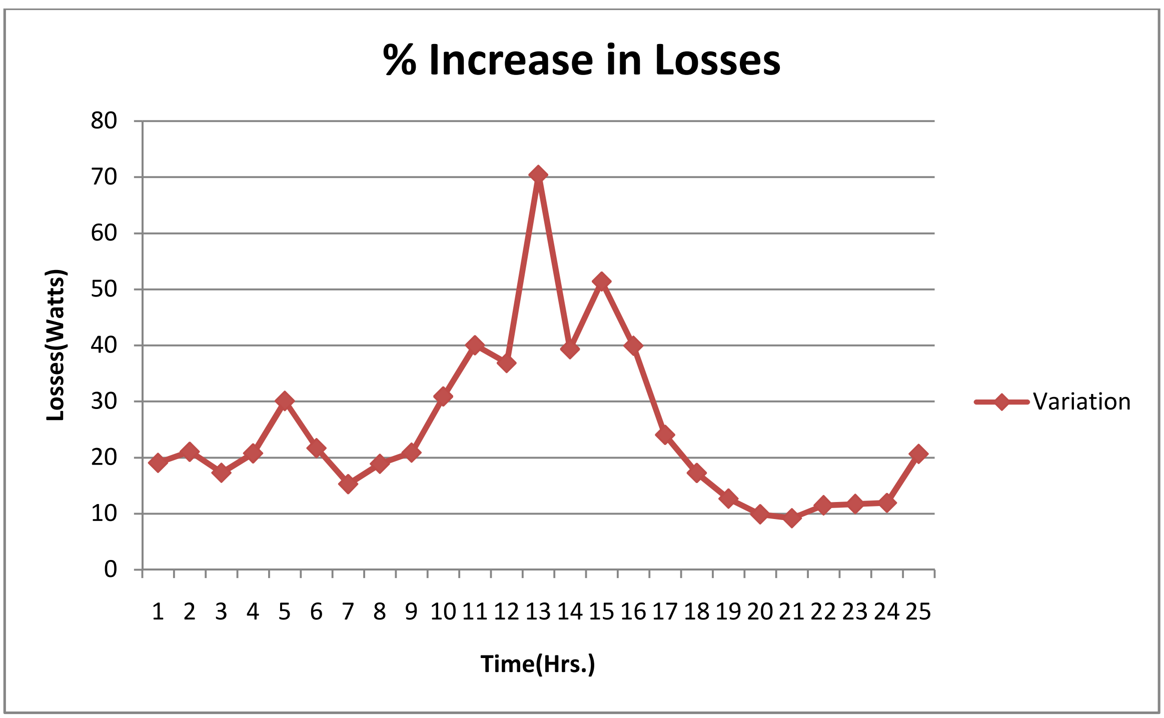

Figure 5.14 Percentage increase in losses

Even though the increase in transmission loss places a greater burden on the transmission equipment, the greater cause for concern would be the NTL load itself. The total power losses in the transmission line are shown in the Figure 5.15 which is sum of NTL active power and losses increase due to NTL. When the lines get overheated, serious consequences can follow, from loss of material strength to the weakening of insulation possibly dangerous if the lines are in a crowded area.

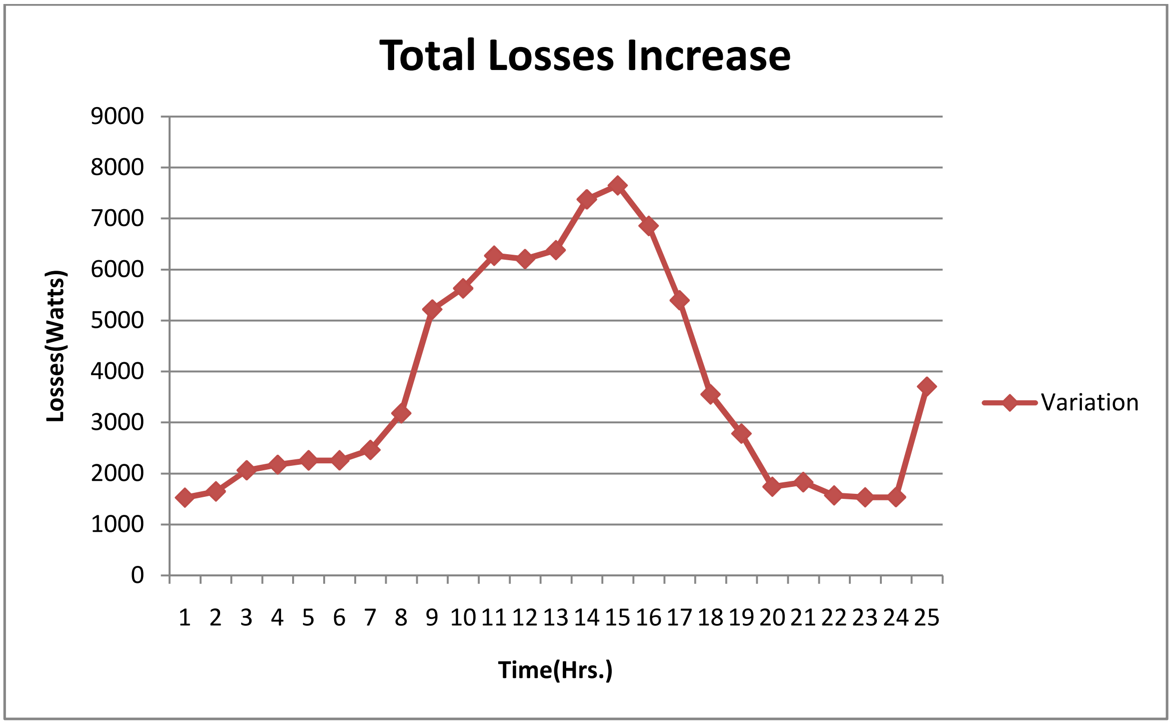

Figure 5.15 Total increase in losses

At this point, it is getting clear that making calculations for expected losses accurately is nearly impossible in practice. The way to obtain a fairly accurate value of average load demand is to utilize the information the utilities use to calculate the electric bills [30]. The calculation requires energy consumption accumulated up to the beginning of the time period and the consumption accumulated at the end of the time period. The accumulated consumption at the end of the period is subtracted by the accumulated consumption at the beginning of the period. The result is the total consumption during the time period in kilowatt-hours, and the portion of the bill for energy consumption is based on this number. The net summary of the simulation results is shown as follows:

Table 5.4 Net Results Summary

Summary of losses	Calculations on each hour's average basis	Calculations on net average basis
Losses without NTL,(Watts)	128.72	100.23
Losses with NTL,(Watts)	150.73	120.91
Increase in losses (Watts)	22.01	20.682
% Increase in losses (Watts)	17.099	20.635
P.U Load Power at bus 2 without NTL,(Watts)	0.050637	0 .051714
P.U Load Power at bus 2 with NTL,(Watts)	0.054011	0.055081
Increase in load (Watts)	3711.6	3704.7
% Increase in load (Watts)	8.2817	6.5126
Total increased losses(watts) (NTL Real Power plus increased transmission losses)	3733.6	3725.4

From the above results it has been cleared that reducing non-technical losses will ensure that the cost of electricity to the supplier will be reduced, as less electricity will be used from the power generating company. The cost of the electricity to the customer will therefore also reduce, as the customers will not have to pay for the non-technical losses in the electricity distribution network.

5.6 REDUCTION OF LOSSES IN SYSTEM

The degree of difficulty in reducing power losses will depend on the departure position which is characterized by the actual level of losses. In fact, technical losses level will strongly depend on the network characteristics. The degree of difficulty will also depend on the growth of the electricity demand that is expected to be a major driver of the rate of network development. In any case, the reduction of losses will demand an increase of the costs and/or of investment which should be compared with the benefits derived from that reduction.

It should also be noted that a reduction on non-technical losses does not lead to an energy efficiency improvement. However, it would lead to a higher degree of equity in the treatment of customers and shareholders. In fact, if non-technical losses are passed trough to customers on the corresponding tariffs, the existence of these losses will mean that some customers are paying for others. On the other hand, if non-technical losses are not passed trough in full to customers, the losses "retained" by the distribution operator are paid by shareholders instead. Reductions of non-technical losses may be possible provided significant additional investment and costs are secured: improved and more accurate metering, data management systems supporting it and more field inspectors.

It should be noticed that the potential for further reductions of non-technical losses may be limited given the levels of efficiency already attained. Technical losses are essentially associated with energy and environmental efficiency [31]. This type of losses is mainly driven by investment in network assets. Reducing these losses requires fundamental changes in the design and in the topology of the networks as well as using more efficient technologies such as low loss transformers or higher cross section conductors.

CHAPTER 6

CONCLUSIONS AND SCOPE OF FUTURE WORK

6.1 CONCLUSIONS

The measurement of NTL and its effects on electrical power systems as a whole using existing analytical tools would be possible only if information about the NTL loads themselves is available to the analyst. Accurately estimating losses in distribution systems is becoming increasingly important, as regulatory thinking shifts from input-based to output-based methods. Also private companies become more involved in the distribution segment of the electricity industry. Thus this need is particularly important in developing countries, where total losses are generally high, especially prior to the incorporation of the private sector. The problem is that it is precisely in these situations where needed data for accurately estimating the total losses and particularly their breakdown into technical and nontechnical components are generally lacking. The information would have to include either the NTL load's power consumption profile comparable to the legitimate loads being analyzed at the same time, as well as the NTL power factor, or power factor contribution at same time.

NTLs experienced by electricity utilities have an impact on a number of areas, including financial and economic outcomes and political stability. Financial impacts are the most critical for many utilities for they involve a reduction in profits, a shortage of funds for investment in improving the power system and its capacity, and the necessity for implementing means to cope with the losses. More general economic impacts flow from power utilities that are experiencing increasing losses being associated with corruption and forms of internal political interventions. The current methods of dealing with NTLs impose high operational costs and require extensive use of human resources. Several alternative efforts have been made in other countries to minimize such problems. Most concentrate on onsite technical inspections, which have the similar limitation of high operational costs, as well as taking up much human resource time.

In my work, I have taken a two bus system with one bus as slack bus and load is on another bus. The load profiles of simple industrial area and residential area has been taken. Then a small percentage of NTL has been added to one of the load and the increased load and losses have been shown with the help of Newton-Raphson load flow method and Matlab. The power factor contributions chosen here are negative because the NTL load is assumed to be inductive. All the simulation results have been shown in the form of bar diagrams clearly. The readings of one full day have been taken. Then a case study of one small village has been carried out to determine the extent of non technical losses in that area. The total units supplied and total units billed have been thoroughly measured for one full month. Then their difference is used to determine the extent of non technical losses in that area.

Thus it has been concluded that it is nearly impossible to find the exact amount of non technical losses in a system because we know the energy billed and we know the input energy the difference between these two is T&D loss obviously the theft is included in this loss but there is no way to segregate theft from the T&D losses. Thus following are some of the techniques which must be accomplished by system authorities to minimize non technical losses:

- Methods to reduce non technical losses primarily based on detection by utility companies' meter reading employees and statistical analysis of customer information
- Facilitating time-varying calculations of system losses
- The utility must decide whether the costs of accurately measuring NTL be worth the returns in the form of recovering the NTL costs that were not recovered by the processes already in place
- Reducing the economic and social turbulences and political and economic situations in the local areas.

6.2 SCOPE OF FUTURE WORK

The main scope of future work is by the use of newer technologies to increase measurement capabilities, on the current measures favored by the utilities compared with other possible measures. Non-technical losses (NTL) in all forms are very real and significant problems for utilities companies. So following improvements can be made to the system in order to reduce the non technical losses:

- The system can be made more user friendly by using smart card technology.
- Further work can also be done in reading the consumed energy from energy meter wirelessly using Bluetooth technology.
- Integrated billing systems must be accomplished in order to reduce non technical losses.
- Remote monitoring systems & prepaid energy meters are the choices which can be adopted by the utilities.

These solutions are somewhat not cost effective. Meters that can perform the required duties, which includes somehow sending data to the computing facility, would be much more expensive than the regular kind of meters currently in use. The possible use of newer metering technologies on an experimental basis is the technique which must be accomplished. For example, some meter manufacturers have developed meters that could be read remotely by the utilities staff. Such meters could be fitted with diagnostics equipment to detect meter tampering.

In the end, it has been concluded that utilities will have to concentrate on non-technical loss reduction prior to reducing technical losses. Reducing these losses ensure that the cost of electricity to customers will be reduced and in turn the efficiency of the distribution network will be improved.

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APPENDIX A

ALGORITHM USED IN PROGRAM

1. The impedance value of the transmission line has been taken from 11 kV datasheet as shown in Table 5.1. A conductor diameter of 120 mm^2 has been taken.
2. **Loads for Two Bus System**: A two bus system is considered and each bus is assumed to be taken as load bus. At bus1 industrial load is taken and at bus 2 residential load is assumed. Data for kVA demand and power factor for 24 hours is taken for both loads to calculate hourly losses. Average of load demand for both loads is taken to calculate average losses.
3. **Calculation of Active and Reactive Power:** Active and reactive power demand at both buses is calculated using the given data. Also the power angle is calculated in both degree and radian value.

$$P = \text{kVA demand} \times \text{power factor}$$

$$Q = \text{kVA} \times \sin(\cos^{-1}(pf))$$

Using the above data load power for both buses is stored in matrix form.

4. **Load Flow Studies:** load flow studies using Newton-Raphson method has done to calculate the final value of voltage at both buses so as to calculate the losses. The following steps are done for load flow studies.
5. **Formation of Y_{bus} matrix:** Y_{bus} is formed using the given data for the impedance of both loads and the transmission line connecting the loads. Y bus is assembled using equation

$$Y_{bus} = A^T YA.$$

6. **Initial Values for voltage and load angle at each bus:** initial values are assumed at each bus of the system. Initial voltage is taken as 1 p.u. and load angle is taken as 0. Bus 1 is assumed to be slack bus and bus 2 is taken as load bus.

7. **Calculation of Total Power at load bus:** The initial values of voltages and loads are used to calculate P2 and Q2 at load bus 2 as bus 1 is assumed as slack bus.

$$P2 = \sum_{j=1}^{n} Vi\, Vj\, Cos\,(\delta i - \delta j - \gamma ij) + \text{load Power of bus 2.}$$

$$Q2 = \sum_{j=1}^{n} Vi\, Vj\, Cos\,(\delta i - \delta j - \gamma ij)$$

where n is number of buses and i =2.

8. **Formation of Jacobian Matrix:** Jacobian matrix is formed using P2 and Q2 using the following relations.

$$[J] = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} \end{bmatrix}$$

where,

a) $\frac{\partial P}{\partial \delta}$ is an $n \times n$ matrix where the elements are calculated as follows:

$$\frac{\partial Pi}{\partial \delta i} = \sum_{\substack{j=1 \\ j=i}}^{n} \text{Vi Vj Yij sin } (\delta i - \delta j - \gamma ij) \qquad \text{for diagonal elements, and}$$

$$\frac{\partial Pi}{\partial \delta k} = |Vi|\ |Vk|\ |Yik| \sin (\delta i - \delta k - \gamma ik) \qquad \text{for } i \neq k$$

b) $\frac{\partial P}{\partial V}$ is an $n \times n$ matrix where the elements are calculated as follows:

$$\frac{\partial Pi}{\partial Vi} = |Vi|\ |Yij|\ \cos \gamma ij + \sum_{j=1}^{n} \text{Vi Yij Cos } (\delta i - \delta j - \gamma ij) \qquad \text{for diagonal elements,}$$

and

$$\frac{\partial Pi}{\partial Vk} = |Vi|\ |Yik| \text{ Cos } (\delta i - \delta k - \gamma ik) \qquad \text{for } i \neq k$$

c) $\left[\frac{\partial Q}{\partial \delta}\right]$ is an $n \times n$ matrix where the elements are calculated as follows:

$$\frac{\partial Qi}{\partial \delta i} = \sum_{\substack{j=1 \\ j=i}}^{n} \text{Vi Vj Yij Cos } (\delta i - \delta j - \gamma ij) \qquad \text{for diagonal elements,}$$

and

$$\frac{\partial Qi}{\partial \delta k} = |Vi|\ |Vk|\ |Yik| \text{ Cos } (\delta i - \delta k - \gamma ik) \qquad \text{for } i \neq k$$

d) $\left[\frac{\partial Q}{\partial V}\right]$ is an $n \times n$ matrix where the elements are calculated as follows:

$$\frac{\partial Qi}{\partial Vi} = \text{-Vi Yij } \sin \gamma ij + \sum_{j=1}^{n} \text{Vj Yij Sin } (\delta i - \delta j - \gamma ij) \qquad \text{for diagonal}$$

elements, and

$$\frac{\partial Qi}{\partial Vk} = |Vi|\ |Yik| \sin(\delta i - \delta k - \gamma ik) \qquad \text{for } i \neq k$$

9. **Calculation of change in voltage n load angle due to change in load:** The variations vectors ΔV and $\Delta\ \delta$ are computed by using the following equation:

$$\begin{bmatrix} \Delta V \\ \Delta\delta \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

This change in voltage and load angle at bus 2 is added to initial values and new value of voltage n load angle is calculated at bus 2.

$V_2^1 = V_2^0 + \Delta V$

and

$\delta_2^1 = \delta_2^0 + \Delta\delta$

Similarly iterations are done and the value of voltage and load angle is updated at each step until $\Delta Q <$ tolerance.

10. **Calculation of losses:** After iterations final value of voltage and load angle is used to calculate active and reactive power losses using the relation

$$\text{Ploss} = \text{Re}\left[\sum_{i=1}^{n} \bar{V} i\left(\sum_{i=1}^{n} \bar{V}\, \text{Yij}\right)^*\right] = \sum_{i=1}^{n} \sum_{j=1}^{n} \text{ViVjYijCos}(\delta i - \delta j - \gamma ij)$$

$$\text{Qloss} = \text{Imag}\left[\sum_{i=1}^{n} \bar{V} i\left(\sum_{i=1}^{n} \bar{V}\, \text{Yij}\right)^*\right] = \sum_{i=1}^{n} \sum_{j=1}^{n} \text{ViVjYijSin}(\delta i - \delta j - \gamma ij)$$

11. Losses are calculated both in Watts and Per Unit (p.u.) system. Equation given above yields the sum of average power losses throughout the power system. However, equation above is

sufficient for calculating the losses because the test power system used is a two-bus system with only one transmission line and no transformers. Even the losses are calculated from the average value of data.

12. **Data for Non Technical Losses:** An inductive load is taken as NTL load and its additional VA demand is added to load 2. The power factor is also added to bus 2.

13. Repeat Steps No. 3 to 11 with added demand

14. **Calculation of increase in losses and load demand due to NTL**: The increase in losses due to NTL is calculated both in p.u. and Watts. The increase in losses is calculated by taking the difference between the losses without NTL and with NTL. Also the increase in load demand is calculated in p.u. and Watts. All calculations are done both for average data of loads and hourly data for both loads. These values are used to make bar graphs.

15. The results have been shown in Chapter 5.