CHAPTER-5

ANALYSIS OF NON-TECHNICAL LOSSES AND SOLUTION METHODOLOGY

5.1 INTRODUCTION

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].

In December 2011, over 300 million Indian citizens had no access to electricity. Over one third of India's rural population lacked electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. In 2010, blackouts and power shedding interrupted irrigation and manufacturing across the country [65].

Technical and non technical losses represent a significant proportion of electricity losses in both developing and developed countries. Technical and NTLs occur not only in developing countries, but also in developed countries. For example, in the United States, NTLs were estimated 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 [5]. It is apparent that 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 in 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.

5.2 MEASUREMENT OF NON TECHNICAL LOSSES 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:

CASE STUDY -I

In this work, a case study of 66 kV substations, Raj Nagar Extension was undertaken. Raj Nagar Extension is situated at a distance of about 7 km from district headquarters, Ghaziabad. It is a 66/11 kV substation. The main incoming lines of 66 kV are coming from Muradnagar. There are two step down transformers in the substation which step downs the 66 kV incoming voltage to 11 kV. There are total 8 outgoing 11 kV feeders from the substations details of which are as tabulated below in Tables 5.1(a) and 5.1(b). The readings have been taken from the 11 kV energy meters installed at substation. The readings of whole three month have been collected which
are shown in Table 5.2. The bus bar 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.

Table 5.1 (a) Detail of Transformer T1

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of Feeder</th>
<th>Type of Feeder</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>KW Sristi</td>
<td>Urban</td>
</tr>
<tr>
<td>2.</td>
<td>Classic Residency</td>
<td>Urban</td>
</tr>
<tr>
<td>3.</td>
<td>Quantum Residency</td>
<td>Rural</td>
</tr>
<tr>
<td>4.</td>
<td>Garhi</td>
<td>Rural</td>
</tr>
<tr>
<td>5.</td>
<td>Missal Garhi</td>
<td>Rural</td>
</tr>
</tbody>
</table>

Table 5.1 (b) : Detail of Transformer T2

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of Feeder</th>
<th>Type of Feeder</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>River Height</td>
<td>Urban</td>
</tr>
<tr>
<td>2.</td>
<td>Ajnara Grace</td>
<td>Urban</td>
</tr>
<tr>
<td>3.</td>
<td>Morta</td>
<td>Rural</td>
</tr>
</tbody>
</table>

For sake of simplicity, only one outgoing 11 kV feeder of Classic Residency has been considered for case study. Similar technique can be applied to any of the substation in Uttar Pradesh to calculate the losses. The losses have been calculated by the difference of the units supplied to Classic Residency and units which had been consumed or billed in that particular area. The U.P.P.C.L has proper record of all the incoming and outgoing units in the form of a log sheet. For this, it is decided to have 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 non technical losses because transmission and distribution losses are generally less in nature than non technical losses. Table 5.2 shows the detailed analysis of incoming and outgoing units from the main 66 kV substation.

Table 5.2 Incoming and Outgoing Feeders of Substation

<table>
<thead>
<tr>
<th>S.No</th>
<th>Name of Feeder</th>
<th>Reading as on 30-03-2011</th>
<th>Reading as on 30-12-2010</th>
<th>Difference of reading</th>
<th>Multiplying factor of meter</th>
<th>Total Units (kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Transformer- I</td>
<td>118452</td>
<td>114902</td>
<td>3550</td>
<td>1000</td>
<td>355000</td>
</tr>
<tr>
<td>2.</td>
<td>KW Sristi</td>
<td>10259.42</td>
<td>10058.48</td>
<td>200.94</td>
<td>1000</td>
<td>200940</td>
</tr>
<tr>
<td>3.</td>
<td>Classic Residency</td>
<td>36984</td>
<td>35433</td>
<td>1551</td>
<td>1000</td>
<td>155100</td>
</tr>
<tr>
<td>4.</td>
<td>Quantum Residency</td>
<td>2189.71</td>
<td>2089.71</td>
<td>100</td>
<td>1000</td>
<td>100000</td>
</tr>
<tr>
<td>5.</td>
<td>Garhi</td>
<td>5981.88</td>
<td>3881.88</td>
<td>2100</td>
<td>500</td>
<td>105000</td>
</tr>
<tr>
<td>6.</td>
<td>Missal Garhi</td>
<td>7812</td>
<td>6012</td>
<td>1800</td>
<td>1000</td>
<td>180000</td>
</tr>
<tr>
<td>7.</td>
<td>Transformer- II</td>
<td>132856</td>
<td>124427</td>
<td>8429</td>
<td>2</td>
<td>16858</td>
</tr>
<tr>
<td>8.</td>
<td>River Height</td>
<td>126245</td>
<td>117245</td>
<td>9000</td>
<td>2</td>
<td>18000</td>
</tr>
<tr>
<td>9.</td>
<td>Ajnara Grace</td>
<td>45428</td>
<td>44048</td>
<td>1380</td>
<td>2</td>
<td>2760</td>
</tr>
<tr>
<td>10.</td>
<td>Morta</td>
<td>30686</td>
<td>29286</td>
<td>1400</td>
<td>2</td>
<td>2800</td>
</tr>
</tbody>
</table>

Thus

Total outgoing supply from Transformer I

\[200940 + 1551000 + 100000 + 1050000 + 1800000 = 4701940 \text{ kWh}\]

Total outgoing supply from Transformer II

\[18000 + 2760 + 2800 = 23560 \text{ kWh}\]

Losses of Transformer-I = \[4701940 - 3550000 = 1151940 \text{ kWh}\]

Percentage losses = \[\frac{1151940}{3550000} = 32.44\%\]
Losses of Transformer-II = 23560 – 16858 = 6702 kWh
Percentage losses = 6702/16858 = 39.75%

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

5.3 DETAILED ANALYSIS OF CLASSIC RESIDENCY 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 5.3 Details of Billed Units

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Number of Consumers</th>
<th>Type of Consumers</th>
<th>Units Billed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>670</td>
<td>Domestic</td>
<td>594890</td>
</tr>
<tr>
<td>2.</td>
<td>74</td>
<td>Commercial</td>
<td>320400</td>
</tr>
<tr>
<td>3.</td>
<td>18</td>
<td>Small power</td>
<td>140240</td>
</tr>
</tbody>
</table>

Total units billed = (594890 + 320400 + 120240) kWh
= 1055530 kWh

Difference = (1051000 – 1055530) kWh = 495470 kWh

Percentage losses = 495470/1551000 = 31.945%

NTL are widely acknowledged by electricity distribution utilities worldwide and they are estimated to account for up to 30% revenue losses to utilities [25]. This has been nearly proved as above with the help of above case study. This result contains transmission, distribution and non technical losses. When someone is talking 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 it is well known that the energy billed and the input energy the difference between these two is T&D loss. Obviously the theft is included in this loss. When someone is talking 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 centre 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.

5.4 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 some shopkeepers has direct connected a wire in conductor and enjoying electricity without valid connection and a small mill with contracted load of 14.8 kW is running with a 63 kVA transformer inside its 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 consumer meter is burnt and the consumer is enjoying electricity with 63 kVA transformers 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:

- His meter is burnt
- He has a valid connection
- 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 anyone is arguing he says he has submitted the load enhancement application 5 days back, seems he knows in advance that his premises may be raided.
5.5 APPROACHES FOR REDUCTION OF NON TECHNICAL LOSSES

It is known that T&D losses also include 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. Worldwide 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 [6] which must be accomplished in order to reduce the non technical losses at utility and government level.

1. Approaches at the Utility Level

**Metering:** Adequate metering is essential to prevent electricity theft and non payment at the utility level.

**Organization of Commercial Functions:**

- Utilities should organize the functions of meter reading, billing and collection, customer accounting and follow up.
- These functions should be separated to avoid collusion and to enable greater control
- The practice of mailing checks or paying in cash at financial facilities instead of just giving cash to the meter man can reduce the non payment.
**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.

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.

5.6 **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 [5]. An illustration of the basic components of the watt-hour meter is shown in Figure 5.1 below.

![Image of a basic energy meter](image)

**Figure 5.1 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 5.2.

![Figure 5.2 Parts of a Single-phase Watt-hour Meter.](image)

### 5.7 TECHNIQUES OF ELECTRICITY THEFT

- **Direct connection from the pole**: Since the meters and equipment in this section are in the 220 V systems, where customers are mostly houses and small businesses, a direct connection from the pole 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.

- **Use of Remote**: Some Chinese remote is available in the market which slow down the meter speed

- **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.
**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.

**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.

### 5.8 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 [5].

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 [5-6].

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. 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 Figure 5.3 shows the Prepaid Energy Meter.

![Prepaid Energy Meter](image)

**Figure 5.3 Prepaid Energy Meters**

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. The prepaid energy meter can be recharged same as mobile recharge via coupons.

**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.

- **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.

- **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.

**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.

**Market Restraints of Prepaid Meters**

■ **Consumer behavior:** 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.

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

■ **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.

■ **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.

**Recent Initiatives of Prepaid Meters**

- The Sabah Electricity State Board (SESB), Malaysia, has awarded a contract to a local manufacturer to supply 1,080 prepaid meters and get 500 prepaid energy meter in other companies.
Countries such as Thailand, Bangladesh, Singapore, and Iran have been showing increased interest in adopting prepaid system

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.

5.9 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 [27]. 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 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
The following figure 5.4 represents the block diagram of an online pre-paid energy meter:

![Figure 5.4 Block diagram of online prepaid energy meter](image)

**Figure 5.4** Block diagram of online prepaid energy meter

### 5.10 SUGGESTIONS TO MINIMIZE NTL

Non technical losses in distribution systems comprised about 2-3%, of the total system losses. 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:

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

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

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

Statistical monitoring of energy consumption per sector, per class and geographical setup must be employed and statistical evaluation of meter readings must be done

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.

5.11 ANALYSIS OF LOSSES & 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 (for example high side or low side of the generator and transformer), 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 [28].
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% [29]. 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.

5.12 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 [30] expressed by the equations:

Hysteresis loss, \( P_H = K_h f B_m \)

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.

5.13 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**

\[
E_{\text{Loss}} = E_{\text{Delivered}} - E_{\text{Sold}}
\]

**Revenue Loss due to Technical losses**

\[
C_{\text{Com Loss}} = U_{\text{Elect Cost}} \times E_{\text{Loss}} + M_{\text{Maintenance Cost}}
\]

**Non-Technical Loss**

\[
C_{\text{NTL}} = C_{\text{Com Loss}} - C_{\text{Technical Loss}}
\]

where,

\[
U_{\text{Elect Cost}} = \text{Unit cost of electricity}
\]
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. 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.

The conductor size and line length will be chosen arbitrarily from the Table 5.4 shown below.

<table>
<thead>
<tr>
<th>Item</th>
<th>Conductor Size</th>
<th>A.C Resistance Ohm/cond./Km</th>
<th>Impedance Ohm/Cond./Km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20°C</td>
<td>50°C</td>
</tr>
<tr>
<td></td>
<td>mm² Dia. Of Str. mm/No. Of Str.</td>
<td>1.1371</td>
<td>1.2746</td>
</tr>
<tr>
<td>1.</td>
<td>25 2.14/7</td>
<td>1.1371</td>
<td>1.2746</td>
</tr>
<tr>
<td>2.</td>
<td>35 2.52/7</td>
<td>0.8200</td>
<td>0.9192</td>
</tr>
<tr>
<td>3.</td>
<td>50 3.02/7</td>
<td>0.5711</td>
<td>0.6401</td>
</tr>
</tbody>
</table>

Table 5.4 Sequence Impedance for 11 kV Transmission Line
<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>70</td>
<td>2.15/19</td>
<td>0.4211</td>
<td>0.4720</td>
<td>0.3664</td>
<td>0.620+j1.593</td>
<td>0.381</td>
</tr>
<tr>
<td>5.</td>
<td>95</td>
<td>2.52/19</td>
<td>0.3038</td>
<td>0.3405</td>
<td>0.3564</td>
<td>0.488+j1.583</td>
<td>0.371</td>
</tr>
<tr>
<td>6.</td>
<td>120</td>
<td>2.85/19</td>
<td>0.2376</td>
<td>0.2664</td>
<td>0.3486</td>
<td>0.414+j1.575</td>
<td>0.368</td>
</tr>
<tr>
<td>7.</td>
<td>185</td>
<td>2.52/37</td>
<td>0.1567</td>
<td>0.1757</td>
<td>0.3344</td>
<td>0.323+j1.561</td>
<td>0.349</td>
</tr>
</tbody>
</table>

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

\[ P_{\text{loss}} = P_{\text{source}} - P_{\text{load}} \]

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

Energy is power accumulated over time, or

\[ W_{\text{loss}} = Pt \]

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

\[ P_{1-\Phi} = V I \cos \theta \]

With \( P, V \) and \( I \) being the average power, rms voltage and rms current respectively. The term \( \cos \theta \) is the power factor of the element in question, while \( \theta \) 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 [6] (all variables are single phase, rms values and average power):

\[ P = V^2/R, \]

As \( V = IR \)
Therefore, \( P = I^2 R \)

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 5.5 represents the single line diagram of a two bus power system.

![Figure 5.5 A Two-Bus Power System](image)

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:
\[ I^* = \frac{S_{\text{load}}}{V_{\text{load}}} \]

and Power loss = \( VI^* \)

With \( S_{\text{load}}, V_{\text{load}}, I \) and \( R \) are the load apparent power, load voltage, current in the transmission line, transmission line resistance, respectively, while \( I^* \) is the complex conjugate of the current [31] 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.

5.14 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 it is known that total system losses are composed of technical and 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.

5.14.1 Load 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 Load 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 $\theta$ 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.

5.14.2 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

- **Active power**: It is represented by P having units of W
- **Reactive power**: It is represented by Q having units of VAr
- **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 (\( \theta \)).

\[ S = VI^* \]

Where I* = Complex conjugate of a number.
Thus,

\[ \text{Active power } P = S \cos \theta \]
\[ \text{Reactive power } Q = S \sin \theta \]

Hence the total power is given by the following relation:

\[ S = P + j Q \]

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 185 mm\(^2\) has been chosen & the line length has assumed to be 2 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.

**5.15 A PRACTICAL CASE STUDY**

Figure 5.6 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.
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 2 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: 22000 Volts, 100 Ampere, 2.2 MVA, 220 Ohms

Transmission Line Resistance = \(2 \text{ km} \times 0.1757 \text{ Ohms/cond./km} \times 3\) conductors

\[= 1.0542 \Omega\]

\[= 0.00479 \text{ p. u.}\]

Transmission Line Reactance = \(2 \text{ km} \times 0.3344 \text{ Ohms/cond./km} \times 3\) conductors

\[= 2.0064 \Omega\]

\[= 0.00912 \text{ p. u.}\]

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>
<thead>
<tr>
<th>Time</th>
<th>Industrial load (KVA)</th>
<th>Power factor of Load 1</th>
<th>Residential load (KVA)</th>
<th>Power factor of load 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
<td>0.92</td>
<td>30</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Table 5.5 Load Profiles for Industrial and Residential load
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>68</td>
<td>0.93</td>
<td>34</td>
<td>0.83</td>
</tr>
<tr>
<td>3</td>
<td>73</td>
<td>0.92</td>
<td>40</td>
<td>0.82</td>
</tr>
<tr>
<td>4</td>
<td>82</td>
<td>0.87</td>
<td>38</td>
<td>0.85</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
<td>0.88</td>
<td>25</td>
<td>0.86</td>
</tr>
<tr>
<td>6</td>
<td>106</td>
<td>0.91</td>
<td>40</td>
<td>0.80</td>
</tr>
<tr>
<td>7</td>
<td>120</td>
<td>0.87</td>
<td>80</td>
<td>0.82</td>
</tr>
<tr>
<td>8</td>
<td>148</td>
<td>0.85</td>
<td>70</td>
<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>200</td>
<td>0.77</td>
<td>110</td>
<td>0.79</td>
</tr>
<tr>
<td>10</td>
<td>230</td>
<td>0.80</td>
<td>62</td>
<td>0.85</td>
</tr>
<tr>
<td>11</td>
<td>245</td>
<td>0.70</td>
<td>52</td>
<td>0.85</td>
</tr>
<tr>
<td>12</td>
<td>265</td>
<td>0.78</td>
<td>55</td>
<td>0.82</td>
</tr>
<tr>
<td>13</td>
<td>275</td>
<td>0.80</td>
<td>30</td>
<td>0.80</td>
</tr>
<tr>
<td>14</td>
<td>300</td>
<td>0.87</td>
<td>57</td>
<td>0.85</td>
</tr>
<tr>
<td>15</td>
<td>320</td>
<td>0.78</td>
<td>48</td>
<td>0.88</td>
</tr>
<tr>
<td>16</td>
<td>320</td>
<td>0.82</td>
<td>59</td>
<td>0.84</td>
</tr>
<tr>
<td>17</td>
<td>250</td>
<td>0.84</td>
<td>90</td>
<td>0.78</td>
</tr>
<tr>
<td>18</td>
<td>175</td>
<td>0.83</td>
<td>110</td>
<td>0.78</td>
</tr>
<tr>
<td>19</td>
<td>145</td>
<td>0.87</td>
<td>140</td>
<td>0.77</td>
</tr>
<tr>
<td>20</td>
<td>88</td>
<td>0.92</td>
<td>150</td>
<td>0.72</td>
</tr>
<tr>
<td>21</td>
<td>87</td>
<td>0.92</td>
<td>170</td>
<td>0.79</td>
</tr>
<tr>
<td>22</td>
<td>72</td>
<td>0.90</td>
<td>82</td>
<td>0.80</td>
</tr>
<tr>
<td>23</td>
<td>62</td>
<td>0.92</td>
<td>73</td>
<td>0.84</td>
</tr>
<tr>
<td>24</td>
<td>59</td>
<td>0.92</td>
<td>65</td>
<td>0.92</td>
</tr>
</tbody>
</table>

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 5.7 shows the variation of industrial and residential loads during 24 hours.
As shown in table 5.5, 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 320 kVA for load 1 and 170 kVA for load 2. The average load demands (sum of peak values / no. of hours in a day) are 160.25 kVA and 70.75 kVA for load 1 and load 2, respectively. Load power factors are shown in Figure 5.8.
Transmission line resistance and reactance values are taken from 11 kV transmission lines datasheet. The conductor size and line length were chosen arbitrarily from the datasheet, with the maximum conductor size of 180 mm² 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 5.9(a) and Figure 5.9(b) describes the two types of losses i.e. active power losses & 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 [32]. 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.

**Figure 5.9 (a) Active Power Losses**

**Figure 5.9 (b) Reactive Power Losses**

### 5.15.1 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 [24]. 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. The extra load profile with negative power factor addition is shown in the table 5.6.

<table>
<thead>
<tr>
<th>Time (Hrs.)</th>
<th>NTL Load (KVA) Added at Bus 2</th>
<th>NTL Load Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.89</td>
<td>-0.0240</td>
</tr>
<tr>
<td>2</td>
<td>2.74</td>
<td>-0.0240</td>
</tr>
<tr>
<td>3</td>
<td>4.04</td>
<td>-0.0240</td>
</tr>
<tr>
<td>4</td>
<td>3.26</td>
<td>-0.0259</td>
</tr>
<tr>
<td>5</td>
<td>3.19</td>
<td>-0.0244</td>
</tr>
<tr>
<td>6</td>
<td>4.23</td>
<td>-0.0230</td>
</tr>
<tr>
<td>7</td>
<td>5.08</td>
<td>-0.0224</td>
</tr>
<tr>
<td>8</td>
<td>6.80</td>
<td>-0.0232</td>
</tr>
<tr>
<td>9</td>
<td>10.48</td>
<td>-0.0237</td>
</tr>
<tr>
<td>10</td>
<td>9.80</td>
<td>-0.0249</td>
</tr>
<tr>
<td>11</td>
<td>8.15</td>
<td>-0.0255</td>
</tr>
<tr>
<td>12</td>
<td>9.56</td>
<td>-0.0245</td>
</tr>
<tr>
<td>13</td>
<td>8.25</td>
<td>-0.0248</td>
</tr>
<tr>
<td>14</td>
<td>10.60</td>
<td>-0.0258</td>
</tr>
<tr>
<td>15</td>
<td>11.24</td>
<td>-0.0274</td>
</tr>
<tr>
<td>16</td>
<td>10.36</td>
<td>-0.0238</td>
</tr>
<tr>
<td>17</td>
<td>9.20</td>
<td>-0.0238</td>
</tr>
<tr>
<td>18</td>
<td>7.45</td>
<td>-0.0273</td>
</tr>
<tr>
<td>19</td>
<td>7.25</td>
<td>-0.0289</td>
</tr>
<tr>
<td>20</td>
<td>8.40</td>
<td>-0.0205</td>
</tr>
<tr>
<td>21</td>
<td>7.60</td>
<td>-0.0207</td>
</tr>
</tbody>
</table>
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 5.10 and Figure 5.11 respectively.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>3.25</td>
<td>-0.0260</td>
</tr>
<tr>
<td>23</td>
<td>4.16</td>
<td>-0.0242</td>
</tr>
<tr>
<td>24</td>
<td>3.20</td>
<td>-0.0275</td>
</tr>
</tbody>
</table>

Figure 5.10 NTL Addition

Figure 5.11 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 5.12 and 5.13 respectively.

**Figure 5.12** Active Losses With NTL

**Figure 5.13** Reactive 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 137.42 Watts (average of active power losses over 24 hours), while the power loss calculated using the average values of power and power factor is 110.20 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 720.06 watts maximum reactive power losses are while 886.7 Watts. This has been clearly shown with the help of figures 5.13.

5.15.2 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 5.14 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 5.14 Comparison of Active 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 5.16 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 5.17 & 5.18 respectively.
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 5.19 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.
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 [32]. 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 result is shown in table 5.7.

### Table 5.7 Net Result Summary

<table>
<thead>
<tr>
<th>Summary of losses</th>
<th>Calculations on each hour’s Average basis</th>
<th>Calculations on net average Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses without NTL (Watts)</td>
<td>137.42</td>
<td>110.24</td>
</tr>
<tr>
<td>Losses with NTL (Watts)</td>
<td>164.16</td>
<td>134.8</td>
</tr>
<tr>
<td>Increase in losses (Watts)</td>
<td>26.74</td>
<td>24.56</td>
</tr>
</tbody>
</table>

Figure 5.19 Total Increases 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 [32]. 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 result is shown in table 5.7.
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.

5.16 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 through 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 [33]. 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.

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% [29]. 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.

5.12 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 [30] expressed by the equations:

Hysteresis loss, \( P_H = K_h f B_m \)

Eddy Current Loss, \( P_E = K_e f B_m^2 \)

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.

5.13 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**

\[ E_{\text{Loss}} = E_{\text{Delivered}} - E_{\text{Sold}} \]

**Revenue Loss due to Technical losses**

\[ C_{\text{Com Loss}} = U_{\text{Elect Cost}} \times E_{\text{Loss}} + M_{\text{Maintenance Cost}} \]

**Non-Technical Loss**

\[ C_{\text{NTL}} = C_{\text{Com Loss}} - C_{\text{Technical Loss}} \]

where,

\[ U_{\text{Elect Cost}} = \text{Unit cost of electricity} \]

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 non-technical 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. 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.
The conductor size and line length will be chosen arbitrarily from the Table 5.4 shown below.

Table 5.4 Sequence Impedance for 11 kV Transmission Line

<table>
<thead>
<tr>
<th>Item</th>
<th>Conductor Size</th>
<th>A.C Resistance Ohm/cond./Km</th>
<th>Impedance Ohm/Cond./Km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20° C</td>
<td>50° C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mm²</td>
<td>Dia. Str.</td>
</tr>
<tr>
<td>1.</td>
<td>25</td>
<td>2.14/7</td>
<td>1.1371</td>
</tr>
<tr>
<td>2.</td>
<td>35</td>
<td>2.52/7</td>
<td>0.8200</td>
</tr>
<tr>
<td>3.</td>
<td>50</td>
<td>3.02/7</td>
<td>0.5711</td>
</tr>
<tr>
<td>4.</td>
<td>70</td>
<td>2.15/19</td>
<td>0.4211</td>
</tr>
<tr>
<td>5.</td>
<td>95</td>
<td>2.52/19</td>
<td>0.3038</td>
</tr>
<tr>
<td>6.</td>
<td>120</td>
<td>2.85/19</td>
<td>0.2376</td>
</tr>
<tr>
<td>7.</td>
<td>185</td>
<td>2.52/37</td>
<td>0.1567</td>
</tr>
</tbody>
</table>

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

\[ P_{\text{loss}} = P_{\text{source}} - P_{\text{load}} \]

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

Energy is power accumulated over time, or

\[ W_{\text{loss}} = Pt \]
Power, in a single-phase case, with sinusoidal current and voltage can be represented by

\[ P_{1-\phi} = V I \cos \theta \]

With \( P \), \( V \) and \( I \) being the average power, rms voltage and rms current respectively. The term \( \cos \theta \) is the power factor of the element in question, while \( \theta \) 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 [6] (all variables are single phase, rms values and average power):

\[ P = \frac{V^2}{R}, \]

As \( V = IR \)

Therefore, \( P = I^2 R \)

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 5.5 represents the single line diagram of a two bus power system.

**Figure 5.5 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:

\[
I^* = \frac{S_{\text{load}}}{V_{\text{load}}}
\]

and Power loss = \(VI^*\)

With \(S_{\text{load}}, V_{\text{load}}, I\) and \(R\) are the load apparent power, load voltage, current in the transmission line, transmission line resistance, respectively, while \(I^*\) is the complex conjugate of the current [31] 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.

5.14 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 it is known that total system losses are composed of technical and 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.

5.14.1 Load 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 Load 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 \(\theta\) 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.

5.14.2 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

- **Active power**: It is represented by \(P\) having units of \(W\)
- **Reactive power**: It is represented by \(Q\) having units of \(\text{VAr}\)
- **Apparent power**: It is represented by \(S\) having units of \(\text{VA}\)

\[
S = \sqrt{P^2 + Q^2}
\]
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 (\( \theta \)).

\[ S = VI^* \]

Where \( I^* \) = Complex conjugate of a number.

Thus,

Active power \( P = S \cos \theta \)
Reactive power \( Q = S \sin \theta \)

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 185 mm² has been chosen & the line length has assumed to be 2 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.

5.15 A PRACTICAL CASE STUDY

Figure 5.6 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.

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 2 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: 22000 Volts, 100 Ampere, 2.2 MVA, 220 Ohms
Transmission Line Resistance = 2 km × 0.1757 Ohms/conductor/km × 3 conductors

= 1.0542 Ω
= 0.00479 p. u.

Transmission Line Reactance = 2 km × 0.3344 Ohms/cond./km × 3 conductors

= 2.0064 Ω
= 0.00912 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 5.5 Load Profiles for Industrial and Residential load

<table>
<thead>
<tr>
<th>Time</th>
<th>Industrial load (KVA)</th>
<th>Power factor of Load 1</th>
<th>Residential load (KVA)</th>
<th>Power factor of load 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
<td>0.92</td>
<td>30</td>
<td>0.84</td>
</tr>
<tr>
<td>2</td>
<td>68</td>
<td>0.93</td>
<td>34</td>
<td>0.83</td>
</tr>
<tr>
<td>3</td>
<td>73</td>
<td>0.92</td>
<td>40</td>
<td>0.82</td>
</tr>
<tr>
<td>4</td>
<td>82</td>
<td>0.87</td>
<td>38</td>
<td>0.85</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
<td>0.88</td>
<td>25</td>
<td>0.86</td>
</tr>
<tr>
<td>6</td>
<td>106</td>
<td>0.91</td>
<td>40</td>
<td>0.80</td>
</tr>
<tr>
<td>7</td>
<td>120</td>
<td>0.87</td>
<td>80</td>
<td>0.82</td>
</tr>
<tr>
<td>8</td>
<td>148</td>
<td>0.85</td>
<td>70</td>
<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>200</td>
<td>0.77</td>
<td>110</td>
<td>0.79</td>
</tr>
<tr>
<td>10</td>
<td>230</td>
<td>0.80</td>
<td>62</td>
<td>0.85</td>
</tr>
<tr>
<td>11</td>
<td>245</td>
<td>0.70</td>
<td>52</td>
<td>0.85</td>
</tr>
<tr>
<td>12</td>
<td>265</td>
<td>0.78</td>
<td>55</td>
<td>0.82</td>
</tr>
<tr>
<td>13</td>
<td>275</td>
<td>0.80</td>
<td>30</td>
<td>0.80</td>
</tr>
<tr>
<td>14</td>
<td>300</td>
<td>0.87</td>
<td>57</td>
<td>0.85</td>
</tr>
<tr>
<td>15</td>
<td>320</td>
<td>0.78</td>
<td>48</td>
<td>0.88</td>
</tr>
</tbody>
</table>
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 5.7 shows the variation of industrial and residential loads during 24 hours.

As shown in table 5.5, 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 320 kVA for load1 and 170 kVA for load 2. The average load demands (sum of peak values / no. of hours in a day) are 160.25 kVA and 70.75 kVA for load 1 and load 2, respectively. Load power factors are shown in Figure 5.8.
Transmission line resistance and reactance values are taken from 11 kV transmission lines datasheet. The conductor size and line length were chosen arbitrarily from the datasheet, with the maximum conductor size of 180 mm² 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 5.9(a) and Figure 5.9(b) describes the two types of losses i.e. active power losses & 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 [32]. 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.

Figure 5.9 (a) Active Power Losses
5.15.1 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 [24]. 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. The extra load profile with negative power factor addition is shown in the table 5.6.
Table 5.6 Extra Load Profile With Negative Power Factor Addition

<table>
<thead>
<tr>
<th>Time (Hrs.)</th>
<th>NTL Load (KVA)</th>
<th>NTL Load Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added at Bus 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.89</td>
<td>-0.0240</td>
</tr>
<tr>
<td>2</td>
<td>2.74</td>
<td>-0.0240</td>
</tr>
<tr>
<td>3</td>
<td>4.04</td>
<td>-0.0244</td>
</tr>
<tr>
<td>4</td>
<td>3.26</td>
<td>-0.0259</td>
</tr>
<tr>
<td>5</td>
<td>3.19</td>
<td>-0.0244</td>
</tr>
<tr>
<td>6</td>
<td>4.23</td>
<td>-0.0230</td>
</tr>
<tr>
<td>7</td>
<td>5.08</td>
<td>-0.0224</td>
</tr>
<tr>
<td>8</td>
<td>6.80</td>
<td>-0.0232</td>
</tr>
<tr>
<td>9</td>
<td>10.48</td>
<td>-0.0237</td>
</tr>
<tr>
<td>10</td>
<td>9.80</td>
<td>-0.0249</td>
</tr>
<tr>
<td>11</td>
<td>8.15</td>
<td>-0.0255</td>
</tr>
<tr>
<td>12</td>
<td>9.56</td>
<td>-0.0245</td>
</tr>
<tr>
<td>13</td>
<td>8.25</td>
<td>-0.0248</td>
</tr>
<tr>
<td>14</td>
<td>10.60</td>
<td>-0.0258</td>
</tr>
<tr>
<td>15</td>
<td>11.24</td>
<td>-0.0274</td>
</tr>
<tr>
<td>16</td>
<td>10.36</td>
<td>-0.0238</td>
</tr>
<tr>
<td>17</td>
<td>9.20</td>
<td>-0.0238</td>
</tr>
<tr>
<td>18</td>
<td>7.45</td>
<td>-0.0273</td>
</tr>
<tr>
<td>19</td>
<td>7.25</td>
<td>-0.0289</td>
</tr>
<tr>
<td>20</td>
<td>8.40</td>
<td>-0.0205</td>
</tr>
<tr>
<td>21</td>
<td>7.60</td>
<td>-0.0207</td>
</tr>
<tr>
<td>22</td>
<td>3.25</td>
<td>-0.0260</td>
</tr>
<tr>
<td>23</td>
<td>4.16</td>
<td>-0.0242</td>
</tr>
<tr>
<td>24</td>
<td>3.20</td>
<td>-0.0275</td>
</tr>
</tbody>
</table>

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 5.10 and Figure 5.11 respectively.
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 5.12 and 5.13 respectively.
In the case where bus 1 is used as the slack bus, the average power loss in the transmission line is around 137.42 Watts (average of active power losses over 24 hours), while the power loss calculated using the average values of power and power factor is 110.20 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 720.06 watts maximum reactive power losses are while 886.7 Watts. This has been clearly shown with the help of figures 5.13.

5.15.2 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 5.14 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.
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 5.16 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 5.17 & 5.18 respectively.
Figure 5.16 Per Unit Increase in Losses

Figure 5.17 Percentage Increase in Load

Figure 5.18 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 5.19 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 5.19 Total Increases in Losses](image)

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 [32]. 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 result is shown in table 5.7.
Table 5.7 Net Result Summary

<table>
<thead>
<tr>
<th>Summary of losses</th>
<th>Calculations on each hour’s Average basis</th>
<th>Calculations on net average Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses without NTL (Watts)</td>
<td>137.42</td>
<td>110.24</td>
</tr>
<tr>
<td>Losses with NTL (Watts)</td>
<td>164.16</td>
<td>134.8</td>
</tr>
<tr>
<td>Increase in losses (Watts)</td>
<td>26.74</td>
<td>24.56</td>
</tr>
<tr>
<td>% Increase in losses (Watts)</td>
<td>19.45</td>
<td>22.27</td>
</tr>
<tr>
<td>P.U Load Power at bus 2 without NTL (Watts)</td>
<td>0.056230</td>
<td>0.052716</td>
</tr>
<tr>
<td>P.U Load Power at bus 2 with NTL (Watts)</td>
<td>0.052024</td>
<td>0.054071</td>
</tr>
<tr>
<td>Increase in load (Watts)</td>
<td>3810.6</td>
<td>33802.8</td>
</tr>
<tr>
<td>% Increase in load (Watts)</td>
<td>9.3217</td>
<td>7.2136</td>
</tr>
<tr>
<td>Total increased losses(watts) (NTL Real Power plus increased transmission losses)</td>
<td>3863.4</td>
<td>3856.4</td>
</tr>
</tbody>
</table>

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.

5.16 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 [33]. 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.

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% [29]. 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.

5.12 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 [30] expressed by the equations:

\[ \text{Hysteresis loss, } PH = KhfBm \]

\[ \text{Eddy Current Loss, } PE = Kef2Bm^2 \]

Where,

\( f = \text{frequency,} \)

\( Bm = \text{flux density of the core material,} \)

\( Kh, Ke = \text{Hysteresis & Eddy current constant} \)

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.

5.13 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

\[ \text{E Loss} = \text{E Delivered} - \text{E Sold} \]

Revenue Loss due to Technical losses

\[ \text{C Com Loss} = \text{U Elect Cost} \times \text{E Loss} + \text{M Maintenance Cost} \]

Non-Technical Loss

\[ \text{CNTL} = \text{C Com Loss} - \text{C Technical Loss} \]

where,

\[ \text{U Elect Cost} = \text{Unit cost of electricity} \]

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. 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.

The conductor size and line length will be chosen arbitrarily from the Table
5.4 shown below.

Table 5.4 Sequence Impedance for 11 kV Transmission Line

<table>
<thead>
<tr>
<th>Item</th>
<th>Conductor Size</th>
<th>A.C Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ohm/cond./Km</td>
<td>Impedance Ohm/Cond./Km</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single Circuit</td>
</tr>
<tr>
<td></td>
<td>mm²</td>
<td>Dia. Of Str. mm/No. Of Str.</td>
</tr>
<tr>
<td>1.</td>
<td>25</td>
<td>2.14/71.1371</td>
</tr>
<tr>
<td>2.</td>
<td>35</td>
<td>2.52/70.8200</td>
</tr>
<tr>
<td>3.</td>
<td>50</td>
<td>3.02/70.5711</td>
</tr>
<tr>
<td>4.</td>
<td>70</td>
<td>2.15/19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>95</td>
<td>2.52/19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>120</td>
<td>2.85/19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

\[ P_{\text{loss}} = P_{\text{source}} - P_{\text{load}} \]

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

Energy is power accumulated over time, or

\[ W_{\text{loss}} = Pt \]

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

\[ P = V I \cos \theta \]

With \( P \), \( V \) and \( I \) being the average power, rms voltage and rms current respectively. The term \( \cos \theta \) is the power factor of the element in question, while \( \theta \) 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 [6] (all variables are single phase, rms values and average power):

\[ P = \frac{V^2}{R}, \]

As \( V = IR \)

Therefore, \( P = I^2 R \)
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 5.5 represents the single line diagram of a two bus power system.

Figure 5.5 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:
\[ I^* = \frac{S \text{ load}}{V \text{ load}} \]

and Power loss = \[ VI^* \]

With \( S \) load, \( V \) load, \( I \) and \( R \) are the load apparent power, load voltage, current in the transmission line, transmission line resistance, respectively, while \( I^* \) is the complex conjugate of the current. 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.

5.14 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 it is known that total system losses are composed of technical and 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.

5.14.1 Load 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 Load 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 $\theta$ 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.

5.14.2 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

- **Active power**: It is represented by P having units of W
- **Reactive power**: It is represented by Q having units of VAr
- **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 (\( \theta \)).

\[ S = VI^* \]

Where \( I^* \) = Complex conjugate of a number.
Thus,

Active power $P = S \cos\theta$

Reactive power $Q = S \sin\theta$

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 185 mm² has been chosen & the line length has assumed to be 2 km. Then $Z$ bus is formed and hence $Y$ bus can be calculated using following relation:

$Y$ bus = $1/Z$bus

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

5.15 A PRACTICAL CASE STUDY

Figure 5.6 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 5.6 Load at Both Ends

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 2 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: 22000 Volts, 100 Ampere, 2.2 MVA, 220 Ohms

Transmission Line Resistance = 2 km × 0.1757 Ohms/conductor/km × 3 conductors

= 1.0542 Ω

= 0.00479 p. u.

Transmission Line Reactance = 2 km × 0.3344 Ohms/cond./km × 3 conductors

= 2.0064 Ω

= 0.00912 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 5.5 Load Profiles for Industrial and Residential load

<table>
<thead>
<tr>
<th>Time</th>
<th>Industrial load (KVA)</th>
<th>Power factor of Load 1</th>
<th>Residential load (KVA)</th>
<th>Power factor of load 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>62</td>
<td>0.92</td>
<td>30</td>
<td>0.84</td>
</tr>
<tr>
<td>2</td>
<td>68</td>
<td>0.93</td>
<td>34</td>
<td>0.83</td>
</tr>
<tr>
<td>3</td>
<td>73</td>
<td>0.92</td>
<td>40</td>
<td>0.82</td>
</tr>
<tr>
<td>4</td>
<td>82</td>
<td>0.87</td>
<td>38</td>
<td>0.85</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
<td>0.88</td>
<td>25</td>
<td>0.86</td>
</tr>
<tr>
<td>6</td>
<td>106</td>
<td>0.91</td>
<td>40</td>
<td>0.80</td>
</tr>
<tr>
<td>7</td>
<td>120</td>
<td>0.87</td>
<td>80</td>
<td>0.82</td>
</tr>
<tr>
<td>8</td>
<td>148</td>
<td>0.85</td>
<td>70</td>
<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>200</td>
<td>0.77</td>
<td>110</td>
<td>0.79</td>
</tr>
<tr>
<td>10</td>
<td>230</td>
<td>0.80</td>
<td>62</td>
<td>0.85</td>
</tr>
<tr>
<td>11</td>
<td>245</td>
<td>0.70</td>
<td>52</td>
<td>0.85</td>
</tr>
<tr>
<td>12</td>
<td>265</td>
<td>0.78</td>
<td>55</td>
<td>0.82</td>
</tr>
<tr>
<td>13</td>
<td>275</td>
<td>0.80</td>
<td>30</td>
<td>0.80</td>
</tr>
<tr>
<td>14</td>
<td>300</td>
<td>0.87</td>
<td>57</td>
<td>0.85</td>
</tr>
<tr>
<td>15</td>
<td>320</td>
<td>0.78</td>
<td>48</td>
<td>0.88</td>
</tr>
<tr>
<td>16</td>
<td>320</td>
<td>0.82</td>
<td>59</td>
<td>0.84</td>
</tr>
<tr>
<td>17</td>
<td>250</td>
<td>0.84</td>
<td>90</td>
<td>0.78</td>
</tr>
<tr>
<td>18</td>
<td>175</td>
<td>0.83</td>
<td>110</td>
<td>0.78</td>
</tr>
<tr>
<td>19</td>
<td>145</td>
<td>0.87</td>
<td>140</td>
<td>0.77</td>
</tr>
<tr>
<td>20</td>
<td>88</td>
<td>0.92</td>
<td>150</td>
<td>0.72</td>
</tr>
<tr>
<td>21</td>
<td>87</td>
<td>0.92</td>
<td>170</td>
<td>0.79</td>
</tr>
<tr>
<td>22</td>
<td>72</td>
<td>0.90</td>
<td>82</td>
<td>0.80</td>
</tr>
<tr>
<td>23</td>
<td>62</td>
<td>0.92</td>
<td>73</td>
<td>0.84</td>
</tr>
<tr>
<td>24</td>
<td>59</td>
<td>0.92</td>
<td>65</td>
<td>0.92</td>
</tr>
</tbody>
</table>

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 5.7 shows the variation of industrial and residential loads during 24 hours.

Figure 5.7 Load Variations Over 24 Hours

As shown in table 5.5, 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 320 kVA for load1 and 170 kVA for load 2. The average load demands (sum of peak values / no. of hours in a day) are 160.25 kVA and 70.75 kVA for load 1 and load 2, respectively. Load power factors are shown in Figure 5.8.

Figure 5.8 Variation of Power Factor Over 24 Hours

Transmission line resistance and reactance values are taken from 11 kV transmission lines datasheet. The conductor size and line length were chosen arbitrarily from the datasheet, with the maximum conductor size of 180 mm2 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 5.9(a) and Figure 5.9(b) describes the two types of losses i.e. active power losses & 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 [32]. 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.

Figure 5.9 (a) Active Power Losses

Figure 5.9 (b) Reactive Power Losses

5.15.1 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 [24]. 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. The extra load profile with negative power factor addition is shown in the table 5.6.

Table 5.6 Extra Load Profile With Negative Power Factor Addition

<table>
<thead>
<tr>
<th>Time</th>
<th>NTL Load (KVA)</th>
<th>Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTL Load (Hrs.)</td>
<td>Added at Bus 2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.89</td>
<td>-0.0240</td>
</tr>
<tr>
<td>2</td>
<td>2.74</td>
<td>-0.0240</td>
</tr>
<tr>
<td>3</td>
<td>4.04</td>
<td>-0.0240</td>
</tr>
<tr>
<td>4</td>
<td>3.26</td>
<td>-0.0259</td>
</tr>
<tr>
<td>5</td>
<td>3.19</td>
<td>-0.0244</td>
</tr>
<tr>
<td>6</td>
<td>4.23</td>
<td>-0.0230</td>
</tr>
<tr>
<td>7</td>
<td>5.08</td>
<td>-0.0224</td>
</tr>
<tr>
<td>8</td>
<td>6.80</td>
<td>-0.0232</td>
</tr>
<tr>
<td>9</td>
<td>10.48</td>
<td>-0.0237</td>
</tr>
<tr>
<td>10</td>
<td>9.80</td>
<td>-0.0249</td>
</tr>
</tbody>
</table>
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 5.10 and Figure 5.11 respectively.

Figure 5.10 NTL Addition

Figure 5.11 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 5.12 and 5.13 respectively.

Figure 5.12 Active Losses With NTL

Figure 5.13 Reactive 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 137.42 Watts (average of active power losses over 24 hours), while the power loss calculated using the average values of power and power factor is 110.20 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 720.06 watts maximum reactive power losses are while 886.7 Watts. This has been clearly shown with the help of figures 5.13.

5.15.2 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 5.14 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.
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 5.16 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 5.17 & 5.18 respectively.

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 5.19 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 5.19 Total Increases 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 [32]. 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 result is shown in table 5.7.

Table 5.7 Net Result Summary

<table>
<thead>
<tr>
<th>Summary of losses</th>
<th>Calculations on each hour’s Average basis</th>
<th>Calculations on net average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Losses without NTL (Watts)</td>
<td>137.42 110.24</td>
<td></td>
</tr>
<tr>
<td>Losses with NTL (Watts)</td>
<td>164.16 134.8</td>
<td></td>
</tr>
<tr>
<td>Increase in losses (Watts)</td>
<td>26.74 24.56</td>
<td></td>
</tr>
<tr>
<td>% Increase in losses (Watts)</td>
<td>19.45 22.27</td>
<td></td>
</tr>
<tr>
<td>P.U Load Power at bus 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>without NTL (Watts)</td>
<td>0.056230 0.052716</td>
<td></td>
</tr>
<tr>
<td>P.U Load Power at bus 2 with NTL (Watts)</td>
<td>0.052024 0.054071</td>
<td></td>
</tr>
<tr>
<td>Increase in load (Watts)</td>
<td>3810.6 33802.8</td>
<td></td>
</tr>
</tbody>
</table>
% Increase in load (Watts) 9.3217 7.2136

Total increased losses(watts)

(NTL Real Power plus increased transmission losses) 3863.4 3856.4

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.

5.16 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 [33]. 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.