CHAPTER 1

INTRODUCTION

1.1 ELECTRICAL POWER SYSTEM

Electrical utility has three functional areas namely generation, transmission and distribution. Electricity is generated at the generating station by converting a primary source of energy to electrical energy. The power plants typically produce 50 cycles/second (Hertz), alternating-current (AC) electricity with voltages between 11kV and 33kV. At the power plant, the 3-phase voltage is stepped up to a higher voltage for transmission. High voltage (HV) and extra high voltage (EHV) transmission is the next stage from power plant to transmit AC power over long distances at voltages of 220 kV, 400 kV and 765 kV. The transmission of high voltage direct current is favored, where the transmission line lengths are over 1000 km to minimize losses in India. Sub-transmission network at 132 kV, 110 kV, 66 kV or 33 kV constitute the next link in the transmission network.

In the distribution network there are two main distribution network lines namely, primary distribution lines (33kV/22kV/11kV) and secondary distribution lines (415 volts line voltage). Primary distribution lines feed the HT consumers and distribution transformers. The distribution transformers feed the low voltage distribution networks which are the secondary distribution lines. Hence low voltage distribution network (LV network) is the last link connecting the consumers. The block diagram of electric power system is as shown in Figure 1.1. The industry doing all these or any of these business processes, Generation, Transmission and Distribution is termed as Electrical utility.
1.2 DISTRIBUTION SYSTEM

The power network, which generally concerns the common man, is the distribution network of 11 kV lines or feeders downstream of the 33 kV Substations. Each 11 kV feeder (High Tension Feeder) which emanates from the 33 kV Substation branches further into several subsidiary 11 kV feeders to carry power close to the load points (localities, industrial areas, villages, etc.). At these load points, a transformer further reduces the voltage from 11 kV to 415 V to provide the last mile connection through 415 V feeders (also called as Low Tension feeders) to individual customers, either at 240 V (as single phase supply) or at 415 V (as three phase supply).

1.2.1 Distribution Network Lines

The distribution network is divided into the following:-

i. Primary distribution lines: 33 kV/22 kV/11 kV.

ii. Secondary distribution lines: 415 V (voltage to neutral: 240 V)
Each of the primary distribution line leaves the sub-station as a three-phase circuit and supplies a number of distribution transformers. On the secondary side of the distribution transformer, the Secondary distribution lines are connected. The distribution transformers and secondary distribution lines are rated to maintain the voltage received by consumers within a prescribed tolerance over the full range of loading conditions. The secondary distribution network is termed as low voltage distribution network.

A feeder could be either an overhead line or an underground cable. In urban areas, owing to the density of customers, the length of an 11 kV feeder is generally up to 3 km. On the other hand, in rural areas, the feeder length is much longer (up to 20 km). A 415 V feeder should normally be restricted to about 0.5 - 1.0 km. Unduly long feeders lead to low voltage at the consumer end. For ideal condition the ratio of HT: LT should be 1:1. The Figure 1.2 shows the distribution system prevalent in India.

The main part of distribution system includes:-

i. Receiving Substation.
ii. Sub-transmission lines.
iii. Distribution substation located closer to the load centre.
iv. Secondary circuits on the LV side of the distribution transformer.
v. Service mains with metering arrangement.
1.2.2 Existing LV Network

The existing system in the distribution network is manually controlled. The typical distribution system of Indian scenario is as shown in Figure 1.3. The distribution transformers are located at convenient places in the load area. They may be located in specially constructed enclosures; Plinth mounted or pole mounted. The distribution transformers for a large multi storied building may be located within the building itself. At the distribution transformer, the voltage is stepped down to 415V and power is fed into the secondary distribution systems. The secondary distribution system consists of distributors (Pillar Boxes) which are laid along the road sides. The service connections to consumers are tapped off from the distributors.
Figure 1.3 Existing System of Low Voltage Distribution Network

The main feeders, distributors consist of overhead lines or cables or both. The distributors are 3 phase, 4 wire circuits, the neutral wire being necessary to supply the single phase loads. There are single phase and three phase services given by the electrical utility depending on the requirement of consumers. The service connections of consumer are known as service mains. The consumer receives power from the distribution system. There is no substitute for three phase service to run heavy industrial equipment. A ground connection is normally provided, connected to conductive cases and other safety equipment, to keep current away from equipment and people. The distribution voltages vary depending on customer need, equipment and availability. In industrial services, “delta” three phase services are commonly used. The “delta” service has no distributed neutral wire. For single phase
services the phase and neutral conductors from distribution transformer is connected. All schematic diagrams are represented in this thesis, with neutral run throughout LV network earthed at transformer end.

1.3 PERFORMANCE OF DISTRIBUTION SYSTEM

The Distribution system requires more attention as it is very difficult to standardize due to its complexity. As it involves consumers, power quality becomes paramount consideration in feeding the power supply. With a quality power there is need for uninterrupted supply of power. Supply and Demand has to match for uninterrupted supply of power to the consumers. Hence for better performance of the distribution system the requirements are quality power and reliable power at reasonable cost. To avoid shortage of power one important consideration is reduction of transmission and distribution losses. Transmission and distribution losses (T & D losses) in India have been consistently on the higher side between the ranges of 21–25%. Out of these losses, 19% is at the distribution level in which 14% is contributed by technical losses. This is due to inadequate investments for system improvement work.

1.3.1 Problems in Distribution Systems

The main issue in distribution systems or rather more appropriately the issue confronting the power sector as a whole, is the reduction of transmission and distribution (T & D) losses to acceptable minimum levels. The All-India T & D losses (www.powermin.nic.in) were about 15% till 1966-67. During the last few years, electrical utilities across the country have estimated the losses in the range of over 20% to 40% higher than the preceding years. T & D losses in developed countries are around 7-8% only. Taking into consideration the Indian conditions such as far-off rural areas, nature of loads and distribution system configuration the reasonable
permissible (technical) energy losses should be about 10%-15% in different states. While the losses in EHV network are about 4%-5%, bulk of the losses occurs in the T & D system.

1.3.2 Losses in Electrical Power Systems

Total power system losses comprise technical losses and non-technical losses, mostly distribution network losses being predominant. The distribution network losses can be defined just as the difference between the metered units of electricity entering the distribution network and those leaving the network paid for through electricity accounts, estimated or metered, in a well defined period of time.

There are two types of distribution losses namely commercial losses (non-technical) and technical losses. A non-technical loss is defined as, any consumed energy or service which is not billed because of defective meters or lack of manpower or improper tariff or ill intentioned and fraudulent manipulation to record low consumption. In other words they arise due to power theft, un-billed accounts and estimated customer accounts, errors due to the approximation of consumption by un-metered supplies and metering errors.

Technical losses are regarded as the electrical system losses which are caused by network impedance, current flows, length of lines and auxiliary supplies. The sources of technical losses may be directly driven by network configuration, network equipments and distribution network consumer loads. In effect, network investment is used for the work of system improvement and quality, by which distribution system is expanded and the quantum of distribution technical losses is decided. Technical losses and their reduction is the major concern for the electrical utility.
1.3.2.1 Technical Losses in Distribution Network

The major amount of losses in a power system is in the primary and secondary distribution lines; while transmission and sub-transmission lines account for only about 30% of the total losses. Therefore the primary and secondary distribution systems must be properly planned to ensure that the losses are within acceptable limits. Technical losses on distribution systems are primarily due to heat dissipation resulting from current passing through conductors and from magnetic losses in transformers. Technical losses occur during transmission and distribution. It involves the Substation, transformer, and line related losses. These include resistive losses of the primary feeders, the distribution transformer losses (resistive losses in windings and core losses), resistive losses in secondary network, resistive losses in service connection wires and losses due to nature of consumer loads.

The factors responsible for technical losses are as follows:

- The wide expansion of electricity distribution network without considering technical losses has lead to low voltage distribution over long distance both in urban and rural areas. The electrical utilities are doing this as it is less capital intensive than high voltage distribution. Low quality of equipment and inadequate maintenance also resulted in frequent breakdown leading to poor quality of supply to consumers.

- Inadequate size of conductors: As stated above, rural loads are usually scattered and generally fed by radial feeders. The conductor size of these feeders should be adequate.

- Too many transformation stages from transmission to low voltage supply resulting in high transformation losses.
Use of low efficiency distribution transformers with transformation losses of 2-3%. No load losses of distribution transformer are more than the permissible limits due to poor quality of stampings used in the core. Transformation losses in case of higher efficiency distribution transformers that use amorphous low-loss steal as core material are less than 1%.

Distribution transformers (DT) are not located at load center on the secondary distribution System. Consequently, the farthest consumers obtain an extremely low voltage even though a reasonably good voltage levels are maintained at the secondary of the transformers. This again leads to higher line losses. Therefore in order to reduce the voltage drop in the line to the farthest consumers, the distribution transformer should be located at the load center to keep voltage drop within permissible limits.

Over-rated distribution transformers and hence their Under-utilization studies on distribution feeders have revealed that often the rating of distribution transformer is much higher than the maximum kVA demand on the feeder. Over-rated transformers draw unnecessary high iron losses. In addition to these iron losses, it has additional detrimental effect of high capital cost locked up. From the above it is clear that the rating of distribution transformer should be judiciously selected to match the low voltage distribution network it is feeding.

Low voltage (less than rated voltage) appearing at transformers and consumers terminals: Whenever the voltage applied to induction motor varied from rated voltage, its performance is affected. A reduced voltage in case of induction motor results in higher currents drawn for the same output. For a voltage drop of 10%, the full load current drawn
by the induction motors increase by about 10% to 15%, the starting torque decreases by nearly 19% and the line losses in the secondary distribution line of low voltage distribution network increases. As the bulk load of rural areas and small scale industrial areas consists of induction motors, the line losses in the concerned distribution systems may even touch 20%. The above situation is corrected by operating an “on-load tap changing” in the power transformers situated at high voltage sub-stations 66/11 KV sub-stations and providing on the 11 KV feeders a combination of switched capacitors and automatic voltage regulators. Further, the “off-load tap changing” in distribution transformers is adjusted prior to the commencement of agricultural load season.

- **Lower Power Factor (PF):** In most LT distribution circuits, it is found that the PF ranges from 0.65 to 0.8. A low PF contributes towards high distribution losses. For a given load, if the PF is low, the current drawn in high. Consequently, the losses proportional to square of the current will be more. Thus, line losses owing to the poor PF can be reduced by improving the PF. This can be done by application of shunt capacitors.

- **Unbalance** is a serious power quality problem, mainly affecting low-voltage distribution systems. Improper load balancing in all three phases of distribution network is a major concern increasing the energy losses of low voltage distribution network. Low voltage loads are usually single-phase, e.g. personal computers or lighting systems, and the balance between phases is therefore difficult to guarantee. It results in overloading of low voltage distribution network and low voltage profiles for consumers.
Harmonic distortion: Harmonics are steady state disturbances, which inhibit the AC power system from retaining its inherently sinusoidal waveform. In real life situation, various devices like diodes, silicon controlled rectifiers, thyristors, voltage & current chopping saturated core reactors, induction & arc furnaces are deployed for various requirements and due to their varying impedance characteristics, these non linear devices cause distortion in voltage and current waveforms. Harmonics are characterized by their non-linearity and their presence on frequencies, which are integral multiples of the fundamental power line frequency, which is typically 50 Hz is of increasing concern in recent times.

Poor system operating conditions and practices: Bad workmanship contributes significantly towards increasing distribution losses. Efforts should, therefore, be made to have the best possible workmanship.

In this context the following points should be borne in mind:

i) Joints/contacts are a source of power loss. Therefore the number of joints should be kept to a minimum. Proper jointing techniques should be used to ensure firm connections.

ii) Connections to the transformer bushing-stem, drop out fuse, isolator, and switch etc. should be periodically inspected and proper pressure maintained to avoid sparking and heating of contacts.

iii) Replacement of deteriorated wires and services should also be made timely to avoid any cause of leaking and loss of power.

iv) There should not be delay in restoration of supply. Improper earthing at consumer end is another source of loss in low voltage distribution network.
1.3.2.2 Methodologies of Loss Calculation in Distribution Network

In any HT/LT network, if the line losses are reduced, then the consumer will naturally get a better voltage. As all the feeding/supply points such as a Substation, HT feeder, Distribution transformer are uniquely identified, the loss at that particular network can be found out very easily by adopting the following concept:

Loss in a 110/11 KV Substation =
Meter reading in 110 kV side of that Substation - Summation of Electrical energy recorded in all 11 kV feeders of that Substation.

Loss in a HT feeder of a Substation =
Meter reading in that HT feeder at the Substation end - Summation of Energy of all Distribution Transformers and HT consumers connected in that HT feeder.

Loss in a low voltage distribution network =
Meter reading in the LT side of the DT - Summation of all LT service consumption connected in that DT.

So, the line loss at the Substation, HT feeder, and low voltage distribution network can be easily found out and necessary rectification / improvement work are to be undertaken to reduce the line loss and improve the supply voltage.

1.4 ENERGY LOSS REDUCTION STRATEGY

Improvement of system and reduction of losses could be effectively achieved by conducting an energy audit. The term energy audit is commonly used to describe a broad spectrum of energy studies ranging from a quick walk-through of a distribution network to identify major problem areas, to a
comprehensive analysis of the implications of alternative methods sufficient to satisfy the technical and financial criteria of electrical utility. The energy audit is to be attempted starting with the areas known for excessive losses.

The aim of an energy audit is to:

- Assess the overall energy loss in a specified area (sub-station or distribution centre)
- Identify system elements causing excessive losses
- Identify and establish causes of excessive losses, whether it is due to technical or non-technical factors.
- Segregate technical and non-technical losses.
- Suggest various measures to reduce losses in cost-effective method and working out the pay back period, effectiveness, longevity and efficiency of each method.

1.5 DECISION PRIORITIES FOR REDUCTION OF TECHNICAL LOSSES

The measures for reducing technical losses in the system can be classified as short term, medium term and long term.

1.5.1 Short Term Measures

We call these measures as short term measures but the impact of these measures is greater than capital intensive medium and long-term measures. These measures have to be implemented continuously and consistently.
1.5.1.1 Consumer Reconfiguration for Balancing

The phase voltage and current unbalances in the low voltage distribution network are major factors leading to extra losses, interference in communication, equipment overloading and malfunctioning of the protective relay. It consequently results in the reduction of service quality and operation efficiency. Phase unbalance is also manifested in increased complex power unbalance, increased power loss, enhanced voltage drop, and increased neutral current. When a single phase consumer is affected service connection it has to be ensured every time that low voltage network is balanced after effecting the service connection. For effective and efficient implementation existing network should be balanced by consumer (node) reconfiguration.

1.5.1.2 Reactive Power Compensation

Provision of adequate reactive compensation in various distribution lines is required to improve the transmission capability as well as reduce system losses substantially. As loss is directly proportional to square of the current, there is 2% reduction in current by providing reactive compensation, this results in about 4% reduction in losses. LT motive power consumers cannot ensure the working of capacitors even if they are provided at the time of effecting of connections. It is because of lack of requisite knowledge and skills to decide the level of compensation and check the availability of capacitors. Thus while planning the distribution system; such practical problems can be taken care by the power utilities by providing the LT capacitors on distribution transformers. To overcome the seasonal changing load demand characteristics it would be worthwhile to provide minimum level of compensation at LT level to meet the average demand and dynamic capacitor allocation for demand above average demand.
1.5.1.3 Improving Standards and Practices

The usage of latest technologies such as identification of hot spots by thermo-vision infrared scanning and improvement in joints becomes essential. Training to upgrade knowledge and skills of personnel engaged in distribution at feeder level and consumer end is vital. Creating awareness with working personnel about earthing practices, effect of neutral current and reactive compensation constantly will drive the distribution network performance to achieve the desired results.

1.5.2 Medium and Long term measures

- Adoption of systematic and methodical approach to planning, design, construction, operation and maintenance of distribution system using computer aided tools.
- SCADA (Supervisory Control and Data Acquisition) – Implementation of SCADA for all Substations.
- Renovation, modernization and strengthening of 11 kV level Substations, Transformers/Transformer Centres. Re-conductoring of lines at 11kv level and below.
- Conversion of existing distribution network into High Voltage Distribution System (HVDS) that covers reduction of LT lines i.e. taking high voltage line up to the load Centre and supplying power through smaller capacity energy efficient distribution transformers so that each transformer supplies power to 10 to 15 households only; re-conductoring of over loaded sections.
- Geographic Information System (GIS) mapping and collecting pole-wise information and study of complete distribution system with automated mapping of all electrical components.
- Long term distribution system planning taking into consideration the projected load development during the next 15-20 years and re-conducting of overloaded lines.

- Adoption of distribution automation techniques for improving reliability and security of power supply, creation of authentic database and adoption of demand side management measures.

- In case of metered supplies, metering deficiencies in the form of non-functioning/defective meters have an impact on the correctness of energy consumption figures. The proportion of non-functioning, very old and defective meters should be identified and replaced wherever necessary.

- Introduce Remote Controlled Load Management Scheme (RCLM) that involves segregation and grouping of agricultural consumers and regulation of supply as per preannounced schedule in two or three groups with power supply during non-peaking hours. The benefits of the scheme would be reduction in technical losses on account of reduction in peak demand at 11 kV bus.

- Introduction of time-of-the-day tariff for bulk consumers that charge lower tariff for availing power during off-peak load period and higher tariff during peak load period.

### 1.6 PROBLEM STATEMENT

Among all the issues of distribution network the solution for the problem of unbalancing has been taken into consideration in this thesis.

The reason is that in India, North America, and South Africa and in most of the countries, the distribution system is unbalanced. In India distribution feeder is usually a three-phase, four wire system. The impact of unbalance on technical losses is more in India because of the existence of
more number of single phase loads in the LV network. If we compare the transmission network and distribution network the complexity of the distribution network is visible. There are a number of significant differences in the characteristics of typical distribution networks compared to typical transmission networks that are summarized in the Table 1.1 below.

**Table 1.1 Characteristics of Transmission and Distribution Networks**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Transmission</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topology</strong></td>
<td>Generally extensively meshed and must be analyzed as a whole</td>
<td>Generally many independent Substations each supplying several radial feeders. Can be analyzed as multiple independent islands</td>
</tr>
<tr>
<td><strong>Network Size</strong></td>
<td>A typical network size ranges from a few hundred busses to one or two thousand.</td>
<td>A typical network size ranges from 10,000 to 1,00,000 electrical nodes depending on feeder length and number of distribution transformers and consumers.</td>
</tr>
<tr>
<td><strong>Components</strong></td>
<td>Components line supports and transmission lines and switchyards are almost standardized and less complex</td>
<td>A distribution network typically comprises bus-bars, switches, feeders, distribution transformers, loads and therefore appears as a fairly complex network structure</td>
</tr>
<tr>
<td><strong>Dynamism and expandability</strong></td>
<td>Once the transmission network is setup for a city it requires re routing and re-strengthening after a long period</td>
<td>Distribution network is ever expanding and dynamic for further changes on day to day basis depending on consumer needs</td>
</tr>
<tr>
<td><strong>Phase unbalance</strong></td>
<td>The degree of unbalance is generally sufficiently small that it can be ignored and only positive sequence terms analyzed</td>
<td>The degree of unbalance may be quite large and each phase must be considered independently.</td>
</tr>
</tbody>
</table>
1.6.1 Reason for Energy Loss Due To Unbalance

In a three-phase four wire systems, when the current in the three-phases is same, the neutral current remains zero. Whenever an unbalance of current occurs in the system there exists a neutral current which causes energy loss. This is illustrated with a simple example.

Example to illustrate the amount of Energy saving obtained by balancing the load

Let the Resistance of the 3 phase wires = R Ohms
Resistance of the neutral wire = 2R
(Assuming area of neutral wire is $\frac{1}{2}$ of phase wire and power factor is 1)
Total Current = 50 A

Case-I: When the 3 phases are balanced

Current carried by each phase $I_{ph}$ = 50A
Neutral Current $I_N$ = 0 A (Assuming ideal Condition)
Line loss = Power Loss = $I^2R$ Watts
Energy Loss = Power Loss * Time
For time=1hour; Energy Loss = Power Loss * Time

Doing Calculation for 1 hour
Total Energy loss in phase wire $W_R$ = $50^2 \times R = 2.5 R$ kW
Here $W_R = W_Y = W_B$ (balanced condition)
Energy loss in the neutral wire $W_N$ = $0^2 \times 2R = 0$ Watts
Total Energy loss $W_{\text{tot1}} = W_R + W_Y + W_B + W_N$ \hspace{1cm} (1.1) \\
$= 2.5R + 2.5R + 2.5R + 0 = 7.5R$ kW

**Case-II: When there is an unbalance in Current**

Assuming $I_R = 20$ A, $I_Y = 70$ A, $I_B = 60$ A

Neutral current $I_N = \sqrt{I_R^2 + I_Y^2 + I_B^2} - (I_R * I_Y) - (I_Y * I_B) - (I_R * I_B)$ \hspace{1cm} (1.2) \\
$= 45.8$ A

Line loss in R phase $W_R = 20^2 * R$ watts \\
$= 0.400R$ Kw

Line loss in Y phase $W_Y = 70^2 * R$ watts \\
$= 4.9R$ kW

Line loss in B phase $W_B = 60^2 * R$ watts \\
$= 3.6R$ kW

Line loss in Neutral wire $W_N = 462 * 2R$ watts \\
$= 4.232R$ kW

Total Energy loss $W_{\text{tot2}} = W_R + W_Y + W_B$ Watts \hspace{1cm} (1.3) \\
$= 400R + 4900R + 3600R + 4232R$ watts \\
$= 13.132R$ kW

Total Energy savings with balance Condition $= W_{\text{tot2}} - W_{\text{tot1}}$ \hspace{1cm} (1.4) \\
$= 13.132R - 7.500R = 5.632R$ kW
Thus for a single distribution transformer, energy saving of 5.632R kW for one hour is obtained.

Considering Aluminium Conductor Steel Reinforced Conductor (ACSR) of size 7/3.35 for LV network

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance, R</td>
<td>0.587 Ohms</td>
</tr>
<tr>
<td>Cost per kWh</td>
<td>3.2</td>
</tr>
<tr>
<td>Ratio of peak load to average load on an average</td>
<td>2.3</td>
</tr>
<tr>
<td>Energy saving per day</td>
<td>34.5 units</td>
</tr>
<tr>
<td>Cost saving per day</td>
<td>₹110.4</td>
</tr>
</tbody>
</table>

In the state of Tamil Nadu, India (www.tneb.in) alone there are approximately 1,92,000 transformers. If energy saving aggregate for all distribution transformers are approximated as 24 units per day, for 1, 92,000 Transformers energy saving will be 1, 92,000*24 = 46, 08,000

Total cost saving over the state per day = 46, 08,000*3.20 
= ₹14.75 millions

The square is the heart of the I²R problem and the problem is exponential as the amperage increases. Amperage only has to go down a little to reap huge rewards. Once the current in three phases are balanced the neutral current decreases and hence energy losses decreases.

### 1.6.2 Motivation for the Research

To establish the relevance of the problem of unbalance and its remedy, the existence of single phase consumers in typical state of India have been analyzed and results are as shown in Table 1.2 and Figure 1.4.
Table 1.2 Total Number of Consumers in Different Regions.

<table>
<thead>
<tr>
<th>Region No</th>
<th>1 Phase</th>
<th>3 Phase</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>9,41,438</td>
<td>3,74,632</td>
<td>13,16,070</td>
</tr>
<tr>
<td>Region 2</td>
<td>18,30,432</td>
<td>3,74,632</td>
<td>22,05,064</td>
</tr>
<tr>
<td>Region 3</td>
<td>22,63,972</td>
<td>4,77,291</td>
<td>27,41,263</td>
</tr>
<tr>
<td>Region 4</td>
<td>25,74,429</td>
<td>2,65,075</td>
<td>28,39,504</td>
</tr>
<tr>
<td>Region 5</td>
<td>26,41,774</td>
<td>1,61,241</td>
<td>28,03,015</td>
</tr>
<tr>
<td>Region 6</td>
<td>31,42,119</td>
<td>2,86,412</td>
<td>34,28,531</td>
</tr>
<tr>
<td>Region 7</td>
<td>21,67,344</td>
<td>3,43,284</td>
<td>25,10,628</td>
</tr>
<tr>
<td>Region 8</td>
<td>16,94,252</td>
<td>1,88,213</td>
<td>18,82,465</td>
</tr>
<tr>
<td>Region 9</td>
<td>18,02,741</td>
<td>3,93,412</td>
<td>21,96,153</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,90,58,501</strong></td>
<td><strong>28,64,192</strong></td>
<td><strong>2,19,22,693</strong></td>
</tr>
</tbody>
</table>

Figure 1.4 Total Number of Consumers in Different Regions

To further augment the results, the study on consumption pattern of consumers in a typical city of India has been studied for five months in the year 2007. They have been segregated with reference to single phase and three phase consumers. The results are as shown in Table 1.3 and Figure 1.5. It has been verified that the single phase consumption is more than three phase consumption.
Table 1.3 Total Consumption pattern of Consumers of typical City

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Single Phase Consumption (MWh)</td>
<td>131466</td>
<td>128619</td>
<td>129333</td>
<td>145375</td>
<td>149708</td>
</tr>
<tr>
<td>Three Phase Consumption (MWh)</td>
<td>110007</td>
<td>116345</td>
<td>112253</td>
<td>114622</td>
<td>120514</td>
</tr>
<tr>
<td>Total (MWh)</td>
<td>241473</td>
<td>244964</td>
<td>241586</td>
<td>259997</td>
<td>270222</td>
</tr>
</tbody>
</table>

Figure 1.5 Consumption pattern of typical city

1.7 LITERATURE SURVEY

Various papers and work carried out by different authors on loss evaluation of distribution network, distribution network planning, reasons for technical losses, feeder reconfiguration, voltage unbalance, current unbalance, reactive compensation with capacitors installation and distribution automation concepts are reviewed. They are categorized under:

- Loss evaluation techniques of distribution network.
- Loss reduction methodologies for optimization of distribution network in this literature survey.
1.7.1 Loss Evaluation Techniques of Distribution Network

Jasmon and Lee (1991) suggested load flow techniques in planning and daily operation of power systems. The performance of three load flow techniques second-order Newton-Raphson method, fast decoupled load flow method and Distflow method are presented with voltage stability analysis. These techniques described are suitable for balanced three phase loads.

Daniel Karisson and David (1994) described an approach for experimental determination of aggregate dynamic loads in power systems. The authors state that the models of dynamical analysis of power systems typically have a consistency problem. The modeling involves more mathematical equations, linear and non-linear functions than physical modeling.

Balda et al (1997) evaluates neutral current flow due to non-linear loads and linear load unbalances in distribution network. The analysis of measurements focuses on the magnitudes of the triplen-harmonic currents and voltages relative to their corresponding phase rms values in order to separate the impact on the neutral conductors of non linear loads and linear load unbalances.

Oliveira et al (2001) presented novel approach for the computation of technical (energy and demand) loses in distribution systems classified into 8 segments namely Sub transmission network, Distribution Substation, Medium voltage networks, Distribution transformers, Low voltage networks, Customer connections, Energy meters and others (connectors, insulators) and tested in Brazil utility company. There is substantial low voltage distribution network losses present in the system as per their statistics.
Voltage unbalance in low voltage distribution networks have been extensively studied by Paulo Vinicious et al (2001). This work considers voltage unbalance measurements carried out in a Brazilian distribution company. The statistics and results validate that main cause of voltage unbalance is current unbalance due to distribution of single-phase loads in the distribution network.

Ajay Kumar Saxena et al (2003) have developed a loss management model using Multi-Criteria Futuristic decision making methodology to identify the priorities for loss management. The paper has identified technical losses and non-technical losses with decision priority weights depending on their impact on the distribution system. In grouping technical losses the order of grouping is as follows:

- Conductor loss
- Iron loss in the transformer
- Auxiliary loss
- Unbalanced load loss
- Loss due to low power factor
- Loss due to overloaded lines
- Corona loss.

There is correlation between conductor loss and unbalanced load; increase in unbalance in three phases of distribution network increases the conductor loss. The correlation weights are not assigned and discussed in the paper.

A statistically based loss calculation and costing methodology has been developed for radial distribution networks. However, the errors in empirical energy loss calculations with stochastic loads are large.

Ochoa et al (2005) studied distribution system losses that consider load unbalance and the effect of explicitly representing with neutral wire. A general power flow algorithm for three-phase four-wire radial distribution networks, based on the current summation backward-forward technique is applied. Loss analysis results obtained from three-phase four-wire medium and low voltage test feeders with unbalanced load scenarios are presented and discussed.

Alessandro Ferrero (2008) analyzed in depth the proliferation of non-linear and time-variant loads in causing a number of disturbances on the electric network. The paper gives a survey of power-quality problems and some indications about the present trends of the research work in this field. Several indices have been proposed to detect the deviations from the reference ideal conditions of power quality measurements.

Math H.J. Bollen et al (2007) proposed two methods for classification of underlying causes of power quality disturbances. According to them, an expert system is suitable when one has limited amount of data and sufficient power system knowledge. Statistical methods are suitable for large data analysis. Power quality disturbances include sustained under voltage due to overload in any of the phases.

Salahedin Zandi Poryan (2009) evaluated model for estimating and determining the power and energy losses of distribution companies. Practical measuring of losses at sample medium voltage network has been presented. Though the method is mostly mathematical the analysis of low voltage distribution network model study was not found.
Michal Kolcun and Jerzy Szkutnik (2009) depicted the methodology for optimization of energy distribution network based on the criterion of minimum costs of energy distribution. They have come out with optimization formulas for optimum level of load, optimal number of station supplying the network, etc and tested with Polish energy network. In the existing system of large distribution network of countries with more population such formula may not yield any feasible solution for optimization.

Mohammed and Mustafa (2010) have designed a program under Visual Basic to calculate and evaluate electrical energy losses in electrical power systems and tested it in Kirkuk electric distribution network. Their findings clearly states that as power loss in transmission /distribution line is proportional to resistance and square of current (i.e. $P_{\text{loss}} = I^2R$) the major part of loss is taking place only in distribution network and accounts for 80-90% of T & D losses. It can be reduced by capacitor reactive compensation and phase balancing of distribution network.

Loss analysis of three-phase unbalanced load of low voltage distribution network has been presented by Yang Guang and He Tao (2010). Analysis has been done on Pudong power supply company, China. The influences of three phase unbalanced load to circuit loss have been thoroughly studied in this paper. The long term continuous real time monitoring of distribution transformer’s parameters such as voltage, current, active power, reactive power and power factor have been advocated by authors for the optimization of low voltage distribution network.

Carlos Leon (2011) presents an integrated expert system (IES) for the analysis and classification of all available useful information of the consumers for finding out non-technical losses. The proposed solution uses all the available consumer information like consumption reports, information on
the measuring equipment and inspector’s documentation. Such databases can be used as well for evaluating technical losses.

Chin Kim Gan et al (2011) presented a method with a statistical approach for assessing general LV distribution network design strategies based on a large set of realistic test networks and optimal economic circuit design. This work is done on UK networks where “balance feeder” is feasible. In developing country scenario starting from low voltage distribution network up to feeders there is unbalance impact of consumer loads.

1.7.2 Loss Reduction Methodologies for Optimization of Distribution Network

There are various techniques suggested and implemented for loss reduction of distribution network. They are grouped and discussed under different categories as follows.

1.7.2.1 Loss Reduction by Unique Techniques

The use of active power line conditioner (APLC) has been suggested by Banaei et al (2005) for loss reduction in the parallel paths of sensitive loads and also parallel transformers too. The proposal could not be used for general load conditions of Indian scenario and most of the developing countries due to scalability issue.

Ali Nourai and et al (2008) presented the significance of shifting load from the peak to the off-peak period on reduction of transmission and distribution losses. Though the benefits of load leveling is well known from the viewpoints of demand response and deferral of capacity upgrade this paper has quantified and saved T & D losses and stated that the ratio of T&D
losses to peak load is 6% to 8%. It also indicates that, by balancing the loads the peak load loss can still be reduced on load leveling.

Apart from distribution network power quality issues, no load losses of distribution transformer are the one of the major concerns. Bertrand Jarry et al (2009) advocated amorphous sheet core transformers to be experimented in European Regional Development Fund (ERDF) network for reduction of no-load losses of distribution transformer.

Lutfu Saribilut et al (2011) proposed dynamic control of unified power flow controller under unbalanced network conditions. The simulation results are presented as case studies in typical power transmission systems. The proposed technology was not tested in distribution networks where the impact of unbalance loads was the most.

1.7.2.2 Loss Reduction using Harmonic Filters

Bhim Singh and Vishal Verma (2007) presented a topology of an improved Hybrid Filter System (IHF) with self supporting DC bus to eliminate harmonics in supply current and voltage at the point of common coupling. The system has been modeled and simulation results obtained in a three phase balanced model system. The results have to be proved for practical unbalanced distribution system.

Harmonics injected into the distribution system has to be filtered by proper design and implementation of filters. Gianfranco Chicco et al (2011) made a thorough study of injection of harmonics in distribution network due to unbalance and non-linear loads. This paper provides a direct quantification of the extent to which non-triplen harmonics are present in the zero-sequence current components and triplen harmonics are present in the positive and negative sequence components. Joy Mazumdar et al (2006) proposed artificial
neural network based method for measurement of harmonics injected into power system network by consumer loads.

1.7.2.3 Loss Reduction by Reactive Compensation using Capacitors

Fuzzy–based multi-objective approach for capacitor placement in the distribution network has been presented by Rada sanu and Barladeanu (2001) and tested in 20kV network and results are satisfactory.

Carlos et al (2009) in their paper modeled the problem of locating and sizing capacitors for reactive compensation in the distribution network as a multi-objective programming problem. Two objective functions, minimization of system losses and minimization of capacitor installation costs are considered in the model. The algorithm has been tested in Portuguese distribution network and the work is found satisfactory in the primary distribution network.

Abdelaziz et al (2010) have proposed two methods for improving voltage profile of distribution network. In the first method fuzzy expert system is used for capacitor allocation and second method illustrated the voltage regulator in distribution network. Both solutions are confined to primary distribution network.

Yongjun Zhang et al (2008) made a thorough study on reactive power optimization with integrated approach on medium voltage and low voltage distribution networks. According to them the low voltage compensation is cheap in price and good in effect, therefore should be combined with primary distribution network reactive compensation. The authors have simulated the algorithms and proved that such approach have great potential for energy saving in China.
For optimizing distribution network both reconfiguration loads and reactive compensation are important factors. Zhang Dong et al (2010) have suggested a joint optimization algorithm for loss minimum optimization in primary distribution networks.

### 1.7.2.4 Loss Reduction by Distributed Generation

Jieton Zhang et al (2009) suggested active management (AM) as an effective method to network enforcement for the connection and operation of DG unit. The main barrier for reaching higher levels of DG in distribution networks is the voltage rise effect. Hence AM exercise control over distribution network. The authors have validated the result on hypothetical distribution network by simulation. Similar studies have been undertaken by Joon-Ho Choi and Jae-chul Kim (2000), Stefania Conti (2009) and Paulo Moises Costa and Manuel A.Matos (2009). Paulo et al (2009) also quantified avoided losses on LV networks as a result of microgeneration.

Electrical systems are evolving from centralized generator plants connected to the transmission network to a decentralized smaller generation units connected directly to the distribution networks near consumption packets. Calderaro et al (2005) proposed a reconfiguration methodology based on genetic algorithm that aims at achieving the maximum DG penetration while observing thermal and voltage constraints. The proposed technology showed its effectiveness on a well known 33-bus system on simulation results.

Degroote et al (2010) presented a fast harmonic simulation model that can be applied to study the influence of DG unit on the total losses and elucidate the importance of harmonic losses in proportion to the total losses. When small single phase DG units are used the losses in neutral conductor become higher. The losses per phase decrease most when the DG unit is
connected to the most loaded phase. The combined network has to be studied and it needs lot of research work in this area for optimal solution.

1.7.2.5 Loss Reduction by Reconfiguration of Primary Distribution Line

Although there are many research papers discussing the reconfiguration algorithms for loss minimization of distribution systems hardly any work related to loss reduction in developing countries scenario is reported. Very little work has been done on secondary distribution network, low voltage distribution network where the impact of unbalance is predominant.

Two types of switches are used in primary distribution systems, they are closed switches (sectionalizing switches) and open switches (tie switches). These two types of switches are designed for both protection and configuration management and by altering the open/closed status of switches loss reduction and optimization of primary distribution network can be achieved. There are many researchers proposing algorithms on primary distribution network. They have either simulated their methodology or tested in practical distribution network and proved with results. Each technique has its own merits and demerits. Going into each method in depth is beyond the scope of this thesis since this thesis presents methods of loss reduction in low voltage distribution network, i.e. secondary distribution network. However an exhaustive list is presented with little briefing.


1.7.2.6 Loss Reduction by Reconfiguration of LV Network

The low voltage distribution networks have been referred as a secondary distribution network in most of the literatures. As contrast to primary distribution network where the reconfiguration is switching on and off of tie-break switches and sectionalizing switches, in LV network it is configuring single phase consumers between three phases of LV network. Most of the reconfiguration methodologies suggested is associated with automation of LV network up to consumer end. These methods are suitable for scenarios where per capita consumption is high and automation is available up to feeder end. They are not cost-effective methods for developing countries with inherent low per-capita consumption, more number of consumers, lengthy low voltage (LT) distribution lines and more distribution transformers covering more radial distances.

Clinard N Kay (1984) discusses challenges in distribution automation up to consumer end. His work has been experimented by Carolina Power & light company, North Carolinna, US. According to him functions and application areas like remote metering of certain consumers that are not economical or justifiable should be excluded from the distribution automation project.
Anil et al (1991) presented the operation of pilot distribution automation systems experimented in Kansas city power & light and Midwest Energy, Kansas city, U.S.A total of 1,00,000 residential participants are assumed. The result shows that benefit/cost ratio is best for centralized air-conditioned consumers followed by other consumers and scenario is high per capita consumption justifying the capital investment of automation.

Ault et al (2005) presented UK research activities on advanced distribution automation. The paper emphasis active network management with focus on distributed generation. Chan (1989) has presented work on integrated load management, Distribution automation with SCADA system for old Dominion Electric cooperative, Virginia, US. Again scenario is high per capita consumption.

Simard et al (2006) described different studies made to formulate a vision and development program for distribution automation. His work mainly concentrates on network monitoring of medium voltage network, real time monitoring of major equipment and assessing and tracking the level of quality of supply to consumers. Distribution automation upto consumer end is not highlighted. It is a review paper on Hydro-Quebec utility, Quebec, east-central Canada.

Nara et al (2007) has presented a method to include 3-phase power flow in distribution automation system for Japan scenario. According to him most distribution feeders are automated and automation with DG technology should emerge as additional Distribution automation function.

Willy M.Siti et al (2011) discussed distribution network phase load balancing reconfiguration algorithms in Distribution Network with load connections done via switching matrix with triacs and hence is a costly alternative for developing countries.
1.8 OBJECTIVE OF THE THESIS

The main objective of the thesis is reduction of energy losses in distribution in low-voltage distribution network and node reconfiguration cost-effectively. For optimizing the LV network, the critical and inherent issue of low voltage distribution network, the unbalancing of current in each phase is considered. Balancing the phase currents in every segment of the low voltage distribution network and reducing the neutral line current is a very difficult task for the distribution engineers considering that they do not have control over power utilization by the consumers. These tasks involve changing the service connection phases (load distribution points) often to achieve phase balance after many field measurements and judgments analysis.

The techniques presented should meet the developing countries scenario where minimum research work has been done on low voltage distribution network.

The detailed analysis of distribution transformers with different types of loading patterns leads to very interesting findings. Such data are not available in scientific way for analysis across the country, India. Therefore, utmost care has been taken to collect the data from different places like metro, urban and rural populated regions. There are at least data from 100 transformers analyzed before presenting the inferences. Out of 100 transformers, 9 transformers have been presented in this work. The proposed techniques in this thesis takes into consideration both online and offline methodologies for loss reduction.

Main objectives of this thesis are given below.

- Development of Distribution Simulation Package (DSP) for load analysis of LV network using LabVIEW. This DSP forms the backbone for off-line analysis.
- Implementation of On-line Monitoring System for LV network. Pilot study is undertaken in one urban transformer of typical city of India with Salzer as industrial partners. Line loss study is performed in the LV network by providing remote meters to distribution transformer and all connected consumers.

- Fuzzy-logic based expert system is developed to balance the LV network which is an off-line method. Three numbers distribution transformers are considered for study and line-loss analysis is performed.

- Pole-wise load balancing is performed by heuristically resulting in reduction of neutral current in all sections of LV network.

- Cost-benefit analysis of the proposed methods is performed.

### 1.9 SCOPE OF THESIS WORK

This thesis work presented will be very much beneficial to the Indian scenario and for developing countries. The case study of typical distribution system in the city of India is presented in the Table 1.4.

<table>
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<th>Table 1.4 Salient features of Region Distribution Network</th>
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<td><strong>Salient Features of Distribution network of a Region</strong></td>
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From the Table the following inferences are made.

- HT:LT ratio very low causing more energy loss
- Total number of single phase consumers is more than total number of three phase consumes.
- Consumption of single phase consumers are also more than the consumption of three phase consumers.
- Consumer density per transformer is also high.
- Feeders both primary and secondary are radial in nature.
- There are non-linear loads present in the form of information technology related consumer industries causing harmonics.
- DG penetration as such is very complex and demands more research work for protection in low voltage distribution network. The works in this area for secondary distribution network is yet to make a start.
- Distribution automation up to consumer end is not an economically viable solution for millions of consumer in each state of India or China or developing countries.

The analysis has been done extensively on many low voltage distribution networks in different parts of the country to study different scenarios. Considering the above inferences the scope and effectiveness of this thesis for electrical utilities is very much significant and beneficial both technically and financially. In a nutshell, needed optimization can be achieved in LV network without much capital expenditure.
1.10 ORGANISATION OF THE THESIS WORK

Chapter 1 is the overview of the whole project. It introduces the topic, aims and the contents of the thesis. It discusses the Electrical power system and distribution system in detail. The components of distribution system such as distribution transformers, distribution lines, service lines of consumers are explained with present state of technical losses in the distribution system. Literature survey has been performed extensively covering all possibilities of loss reduction methods proposed across the globe for different scenarios. It discusses the methods available with the present system proposed. The objective of the thesis is the optimization of low voltage distribution network by reconfiguring consumers reducing energy losses, improving load profile of distribution transformer in cost effective way. There are three methodologies studied and their merits and demerits analyzed in subsequent chapters.

In chapter 2 load balancing on phases is performed using a technique in the form of remote metering by providing meters with modem to individual consumers. To get the secondary distribution to operate at its optimal performance, a technique in the form of remote and automated technology is needed. This research contributes to such a technology at the low voltage side of the distribution network. The main demerit of this system is the high cost solution which is suitable for LV network with high per-capita consumption consumers.

Chapter 3 presents a development of distribution simulation package and forms the basis for subsequent off-line methods developed. There are many low voltage distribution networks studied, analyzed and results obtained using this package. Many hypotheses were derived based on which conclusions are drawn for off-line methods discussed in chapter 4 and chapter 5.
Chapter 4 discusses the off-line method making use of low voltage side distribution album with connected consumers and their consumption. The method uses fuzzy logic based expert system as a tool for load balancing. The effect of load reconfiguration on loss reduction is studied practically in one number urban distribution transformer (Urban DT1). CYMDIST simulation software is used to study two additional transformers (Urban DT2 and Urban DT3). Reduction of energy losses have been observed and noted.

Chapter 5 presents a heuristic technique, which is off-line method developed successfully for solving the combinatory optimization problem making use of low voltage side distribution album with connected consumers and their consumption. There is a very good practical implication with this method. The approach has been tested with the same two distribution transformers (Urban DT2 and Urban DT3) discussed in chapter 4 and gives fruitful results.

Chapter 6 is the conclusion of the entire investigation where the problem statement and aim of the work are correlated with the obtained results. Ideas about future development, improvement and work are stated, suggestions for system performance optimization of the proposed technology are given. The research has demonstrated the effectiveness and practical reliability and its contribution in achieving optimal performance is presented with the comparisons. The cost effectiveness and suitability of the work for low voltage distribution network scenario is highlighted and possibility of energy saving in terms of few millions of rupees per month is explained.