Investigation into the Various Factors That Contributes to Losses in the Electric Power Distribution System

By

Jathullah Jaswal bin Jack

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

JATHULLAH JASWAL BIN JACK

ABSTRACT

For the Electricity and the electrical utilities that provide this facility to us have become a daily part of our life which we take for granted and in many cases are quite contemptuous about them. One should not forget the fact that electricity is a service and has to be managed very carefully at the generation, transmission and distribution stage to be cost effective.

In line with the new trends towards globalization, the energy industries through out the world have been undergoing drastic transformation; and opening up, liberalization and competition are becoming the new features of the energy markets. While electricity energy is becoming a commodity, new concepts have been developed in energy supply services, such as customers care, customer information systems, demand management systems, etc to make this sector face the tough realities of the modern world. Hence it is relevant to investigate into various factors that contribute to losses in the Electric Power Distribution System.

In this paper, the author focuses on Electric Power Distribution System concept besides doing investigation into the various factors that contributes to losses in the Distribution System.

It is significant for the reader to have an understanding and to get a brief view on what is the Electric Power Distribution is about before precede the report. Hence, the author put an overview and description regarding the topic at the literature review and theory section.

Furthermore of the paper, the author clarifies several factors that contribute to losses in the Electric Power Distribution System. Losses due to interruption causes were also identified besides summarize several technical measures that can be employed to optimize system losses. These were under the discussions section of the paper.

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ABBREVIATIONS AND NOMENCLATURES

AAAC	All Aluminum Alloy Conductor
DLFs	*See Distribution Loss Factors*
EHV	Extra-high Voltage
EPR	Ethylene-propylene Rubber
HV	High Voltage
HT	High tension
IEEE	Institute of Electrical and Electronics Engineering
kVAr	Reactive power
kW	Kilowatts
kWh	Kilowatt hours
LF	*See Load Factor*
LLF	*See Loss Load Factor*
LV	Low Voltage
LT	Low tension
MV	Medium Voltage
P.f	A ratio of the current drawn that produces real work to the total current drawn from the supplier such as the utility company
T&D	*See Transmission and Distribution*
XLPE	Cross-linked polyethylene

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The term Electrical Power Distribution System describes an arrangement of electrical equipment and components installed in a commercial, industrial, or other type of facility that provides the necessary electrical power to operate processes or to provide the desired service in a safe and reliable manner. The components usually include, but are not limited to, the following elements:

- Transformers
- Conductors (wire, cable, or bus duct)
- Switches
- Protective devices (fuses, circuit breakers, and relays with voltage and current sensing elements)
- Metering (either electro-mechanical or electronic)
- Line reactors, harmonic filters, and resistors
- Power factor correction capacitors
- Motors drive systems, power and lighting panels, heaters, lights, and other system loads.

These components are arranged to meet the needs of a facility. The continuity of production or building operation is only as reliable as its electrical distribution system. Selection of the best system or combination of systems depends upon a facility's needs. In general, system costs are increased with improved system reliability, and the maximum reliability per unit investment is achieved by using properly applied and well-designed components.

On the other hand, Distribution Loss Factors (DLFs) are used to adjust customers' metered consumption data to allow for electrical losses in the distributors' networks. They are applied only to the consumption of second tier customers in the National Electricity Market. The local retailer pays for all distribution losses that are not allocated to second tier customers.

1.2 PROBLEM STATEMENT

In this paper, focuses is more on the various factors that contribute to losses in the Electrical Power Distribution System. Technically, in engineering terms, power is the rate of delivery of energy and is proportional to the product of the voltage and current. It would be difficult to define the quality of this quantity in any meaningful manner. The power supply system can only control the quality of the voltage; it has no control over the currents that particular loads might draw.

Of course, there is always a close relationship between voltage and current in any practical power system. Although the generators may provide a near-perfect sine-wave voltage, the current passing through the impedance of the system can cause a variety of disturbances or losses to the voltage.

1.3 OBJECTIVES AND SCOPE OF STUDY

The main objective of the study is to understand certain knowledge besides investigating into various factors that contributes to losses in the Electric Power Distribution System.

i. To get better understanding on Electric Power Distribution System.
ii. To investigate into various factors that contributes to losses in the Electric Power Distribution System (EPDS).
iii. To segregate the various factors to its priority with a possible recommendation.
iv. To understand and apply the concepts of power factor correction in reducing losses upon EPDS.

1.3.1 The Relevancy of The Project

The aim of the project is to have a detailed study into the various factors contributing to losses in the Electric Power Distribution System. The study is in conjunction of the electrical energy supply authorities which are looking forward into the reduction of losses in the distribution system, as the losses in the primary and secondary of the distribution system vary up to 70 % of the total losses. The output of the study is the various factors of losses with possible recommendation in ensuring that the electrical energy that supplied to the consumers are at the most competitive price.

1.3.2 Feasibility of the Project within the scope and time frame

The project can be divided into two major component, which are the theoretical, and investigation section. The theoretical aspect of the project focuses on the understanding of how do Electric Power Distribution System works and its concepts. The next stage of the project is to familiarize with the various factors and its recommendation. The duration of the project is estimated to be a year whereby the first half of the year is concentrated on Electric Power Distribution System understanding.

CHAPTER 2

LITERATURE REVIEW & THEORY

2.1 DISTRIBUTION SYSTEMS OVERVIEW

Modern power grids are extremely complex and widespread. Surges in power lines can cause massive network failures and permanent damage to multimillion-dollar equipment in power generation plants. After electricity is produced at power plants it has to get to the customers that use the electricity. As generators spin, they produce electricity with a voltage of about 25,000 volts (a volt is a measurement of electromotive force in electricity, the electric force that pushes electrons around a circuit). The transmission and distribution system delivers electricity from the generating site (electric power plant) to residential, commercial, and industrial facilities.

The electricity first goes to a transformer at the power plant that boosts the voltage up to 400,000 volts for distribution through extra-high voltage (EHV) transmission lines. When electricity travels long distances it is better to have it at higher voltages since the electricity can be transferred more efficiently at high voltages. High voltage transmission lines carry electricity long distances to a substation. At transmission substations a reduction in voltage occurs for distribution to other points in the system through high voltage (HV) transmission lines. Further voltage reductions for commercial and residential customers take place at distribution substations, which connect to the primary distribution network.

Utility transmission and distribution systems (T&D) systems link electric generators with end users through a network of power lines and associated components. For instance, in the United States typically the transmission portion of the system is designated as operating at 69 kilovolts (kV) and above, while the distribution portion operates between 110 volts and 35 kV. A further distinction is often made between primary distribution (voltages between 2.4 and 35 kV) and secondary distribution (110 to 600 volt) systems. Industrial and commercial customers with large power demands often receive service directly from the primary distribution system.

2.1.1 Transformers

Transformers are a crucial link in the electric power distribution system. Utility transformers are high-voltage distribution transformers typically used by utilities to step down the voltage of electricity going into their customers' buildings. Distribution transformers are one of the most widely used elements in the electric distribution system. They convert electricity from the high voltage levels in utility transmission systems to voltages that can safely be used in businesses and homes. Distribution transformers are either mounted on an overhead pole or on a concrete pad. Most commercial and industrial buildings require several low-voltage transformers to decrease the voltage of electricity received from the utility to the levels used to power lights, computers, and other electric-operated equipment.

A transformer is almost never turned off. The expected life of a distribution transformer is 30 years to 40 years if operated at full load for 365 days each year. By connecting a transformer to a distribution system results in energy being used by the transformer due to the losses from primary magnetizing power. The amount of energy required depends on the supply voltage. Losses with no load on the transformer secondary increase or decrease as the voltage increases or decreases at a rate approximately equal to the voltage squared. These no-load losses are not affected by the amount of load being supplied by the transformer. So the no-load losses affect the electric bill by adding power to the kilowatt (kW) demand charge and electrical energy to the kilowatt hour (energy charge) portion of the electric bill. Transformer load losses are caused by the current flowing through the secondary coil wires. A distribution transformer peak load is usually coincident with the facility peak, so the peak loss can be used to determine the demand portion of the electric bill.

Temperature ratings of transformer insulation are based on the temperature rise, given in degrees C. Energy savings can be obtained over the estimated 30-year transformer life by using a lower temperature rise design and insulation. For example, an 80 degree C rise transformer will be more efficient than a 140 degree C rise unit since less heat is generated within the windings. Hence, the cooler transformer initially will cost more to purchase.

Transformers consist of two (2) primary components:

- a core made of magnetically permeable material; and
- a conductor, or winding, typically made of a low resistance material such as copper or aluminum.

The conductors are wound around a magnetic core to transform current from one voltage to another. Liquid insulation material or air surrounds the transformer core and conductors to cool and electrically insulate the transformer. Many different distribution transformer designs are available to utilities, depending on the loading patterns and needs of the end-user. Transformer engineers modify transformer design and vary material depending upon the needs of a particular utility (cost of energy, capacity, etc.).

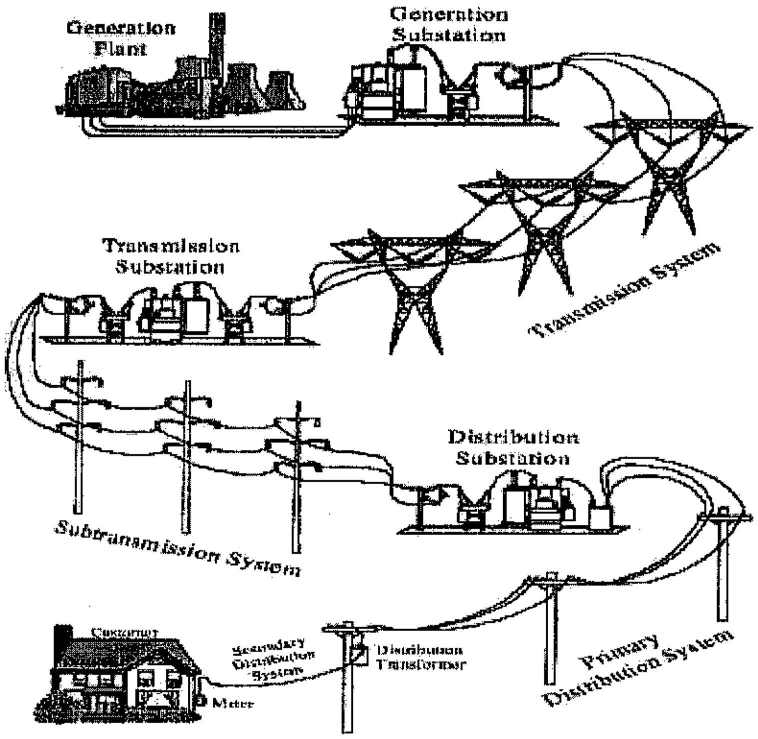

Figure 1: Electric Power Distribution System Diagram

Generation consists of generation plants and generation substations. Transmission consists of transmission lines, transmission switching stations and transmission substations and subtransmission systems. Distribution systems consist of distribution substations, primary distribution systems, distribution transformers and secondary distribution systems. A simplified drawing of an overall power system and its subsystems is shown as in figure 1 above.

2.1.2 Generation Subsystems

- ***Generation Plants*** produce electrical energy from another form of energy such as fossil fuels, nuclear fuels or hydropower. Typically, a prime mover turns an alternator that generates voltage between 11 kV and 30 kV.
- ***Generation Substations*** connect generation plants to transmission lines through a step-up transformer that increases voltage to transmission levels.

2.1.3 Transmission Subsystems

- **Transmission Systems** transport electricity over long distances from generation substations to transmission or distribution substations. Typical voltage levels include 69 kV, 115 kV, 138 kV, 161 kV, 230 kV, 345 kV, 500 kV, 765 kV and 1100 kV.
- **Transmission Switching Stations** serve as nodes in the transmission systems that allow transmission line connections to be reconfigured.
- **Transmission Substations** are transmission switching stations with transformers that step down voltage to subtransmission levels.
- **Subtransmission Systems** transport electricity from transmission substations to distribution substations. Typical voltage levels include 34.5 kV, 46 kV, 69 kV, 115 kV, 138 kV, 161 kV and 230 kV.

2.1.4 Distribution Subsystems

- **Distribution Substations** are nodes for terminating and reconfiguring subtransmission lines plus transformers that step down voltage to primary distribution levels.

- **Primary Distribution Systems** deliver electricity from distribution substations to substation transformers. Voltage range from 4.16 kV to 34.5 kV with the most common being 15-kV class (e.g., 12.47 kV, 13.8 kV).
- **Distribution Transformers** convert primary distribution voltages to utilization voltages. Typical sizes range from 5 kVA to 2500 kVA.
- **Secondary Distribution Systems** deliver electricity from distribution transformers to customer service entrances. Voltages are typically 120/240V single phase, 120/280V three phase or 277/480V three phase.

Electric power systems consist of many subsystems. Reliability depends upon generating enough electric power and delivering it to customers without any interruptions in supply voltage. A majority of interruptions in developed nations result from problems occurring between customer meters and distribution substations.

2.2 DISTRIBUTION SUBSTATIONS

Distribution systems begin at distribution substations. An elevation and corresponding one-line diagram of a simple distribution substation is shown in figure 2.1. The substation's source of power is a single overhead subtransmission line that enters from the left and terminates on a take-off (dead-end) structure. The line is connected to a disconnect switch, mounted on this same structure, capable of visibly isolating the substation from the subtransmission line. Electricity is routed from the switch across a voltage transformer through a current transformer to a circuit breaker. This breaker protects a power transformer that steps voltage down to distribution levels. High voltage components are said to be located on the "high side" or "primary side" of the substation.

The medium voltage side of the transformer is connected to a secondary breaker. If a transformer fault occurs, both the primary and secondary breaker will open to isolate the transformer from the rest of the system. The secondary breaker is connected to a secondary bus that provides power to four feeder breakers. These breakers are connected to cables that exit the substation in an underground ductbank called a "feeder get-away". Medium voltage components are said to be located on the "low side" or "secondary side" of the substation. Confusingly, substation secondary components supply power to primary distribution systems.

By referring to the figure 2.1, an elevation and corresponding single-line diagram illustrates the basic components of a distribution substation. This substation has a single source, a single transformer and four feeders. This type of substations may cause reliability concerns due to its simple configuration. If any major component fails or is taken out of service, there will be no electrical path from the subtransmission source to the secondary bus and all feeders will become de-energized. Consequently, many distribution substations are designed with redundancy allowing a portion of feeders to remain energized if any major component fails or is taken out of service for maintenance.

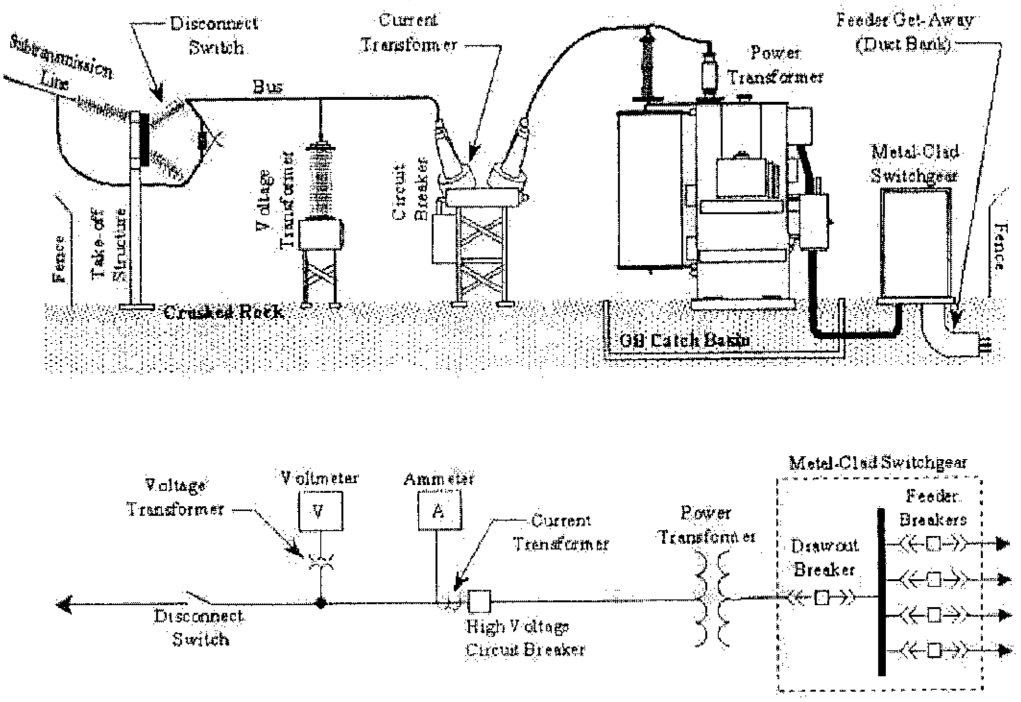

Figure 2.1: Basic components of a distribution substation.

Figure 2.2 shows a common substation layout to the left and a much more complicated (and reliable) substation to the right ("n.o." refers to normally open switch). The left substation is a typical design with two subtransmission lines and two transformers. It is sometimes referred to as an "H-station" or a "transmission loop-through" design. It is able to supply both secondary buses after the loss of either transmission line or either transformer. Faults, however, will generally cause one of both secondary buses to be de-energized until switching can be performed. The substation to the right further increases reliability by having an additional transmission line, an energized spare power transformer, primary ring-bus protection, motor-operated switches and a secondary transfer bus.

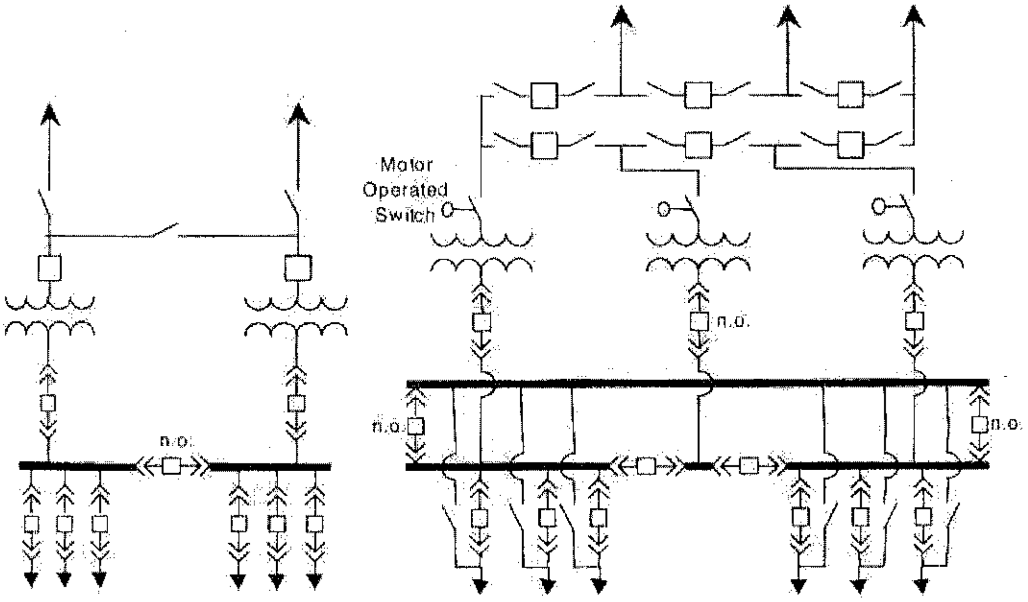

Figure 2.2: Typical design of substation

CHAPTER 3

METHODOLOGY / PROJECT WORK

In this part of the report it will be described about the methodology of the project. This will focus on the foundation of the Electric Power Distribution System, Distribution System Losses, Factors effecting Distribution System Losses etc. Several technical measures to optimize levels of system losses will be produced as a summing up of the data and factors that gathered.

3.1 PROCEDURE IDENTIFICATION

- Understand the idea and concepts given by supervisor and develop it for a detailed study and investigation.
- Expand the concepts and ideas into a new system that can improve the existing conventional one by doing literature studies through surveying the websites, reference books, journals, and site visit (TNB).
- Design the Gantt's chart so that the foundation of all works are guided to the proposed schedule and can be completed within the time frame
- All the main components of the project is divided into several parts as this project is to be carried out step by step and each step comprises own approach.
- Report finishing starting from the proposal until the final dissertation including the logbooks which will be submitted weekly to the supervisor. The other report is depends on the proposed plan in the Gantt's chart
- Preparing for the exhibition and the final oral presentation before handling in the final dissertation

3.2 LITERATURE REVIEW

The allocation of the project work has been mainly put on the aspect of the literature review and research during the preliminary of the project. Based on the literature review performed, all the data on how to carry out the project are been gathered. The main part of the project is the analysis of the theoretical framework and its development and data collection. Moreover, the literature review is based on the scope of the study of the given topic.

3.3 DATA COLLECTION/GATHERING

Data collection is made from the literature review and research work. A few technicians, lecturers and engineers have been consulted regarding the project. Some beneficial information such as the fundamental concept on Electric Power Distribution System, several factors that contribute to losses in the Distribution System and etc have been obtained and analyzed. Other info gathered is the current measures taken in handling the system losses as well as interruption causes. Several journals and books are obtained from the laboratory technician other than from research centre in order to be used in the project. Further research has been done and it is focused on segregate the various factors that contributes to losses in the Electric Power Distribution System.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DISTRIBUTION SYSTEM LOSSES

4.1.1 Introduction

It has been established that 70% of the total losses are occurring in the primary and secondary distribution system, while transmission and subtransmission lines account for only 30% of the total losses. Distribution losses are 15.5% of generation capacity and the target level is 7.5%. Therefore the primary and secondary distribution system must be properly planned to ensure losses within the acceptability limits.

4.1.2 Power and energy losses

Power system losses may simply be defined as the difference in the amount of energy or power that is required to be delivered to a system to supply the customers' energy or power needs. The main reasons for minimizing the losses in a power system are as follows:

- **Power losses**, normally defined in units of kW or MW, create a need for the provision of additional capacity to be installed on the system over and above that required solely to satisfy the demand and

- **Energy losses**, which can be defined as the integrals of the power losses with respect to time and are normally stated in units of kWh or MWh, relate to the purchase of additional quantities of electricity in order to supply the energy losses. In addition to this purchase there may also be an environmental impact since the purchase of more electricity from thermal sources inevitably means the burning of more fuel and more emissions of waste gases.

Energy losses associated with the operation of a distribution system can also be classified as follows:

- **Technical losses** which are those losses associated with the passage of current through the system and comprise:

  i. ***Series losses*** which are proportional to the square of the current and to the resistance of the circuit element and
  ii. ***Shunt losses*** due to magnetizing losses in transformers and rotating machines as well as leakage currents in cables (for linear devices acting as resistors, these losses vary with the square of the voltage; in iron-cored devices such as transformers and rotating machines, the variation of shunt losses with voltage is non-linear due to saturation effects) and

- **Non-technical losses** which are those losses associated with unidentified and uncollected revenue, arising from such sources as illegal connections, meter tampering (i.e. electricity theft), metering errors and shortfalls in billing and revenue collection. For the purpose of report, only real power and energy losses (kWh, MWh) are considered and not reactive power losses (kVARh, MVARh).

4.2 LOAD FACTOR AND LOSS LOAD FACTOR

4.2.1 Series power losses

Series Power losses at peak demand can be related to average (technical) energy losses through consideration of load factors and loss load factors where:

- Load Factor (LF) is the ratio of the average demand over a period of time to the maximum demand within that period for a defined network and;
- Loss Load Factor (LLF) (sometimes also referred to as the loss factor) is the ratio of the average power losses to the losses at the time of peak load.

System load factor - Annual load durations, for example, it can be derived from average hourly loads to form an annual load-duration curve of the form as shown in Figure 3.

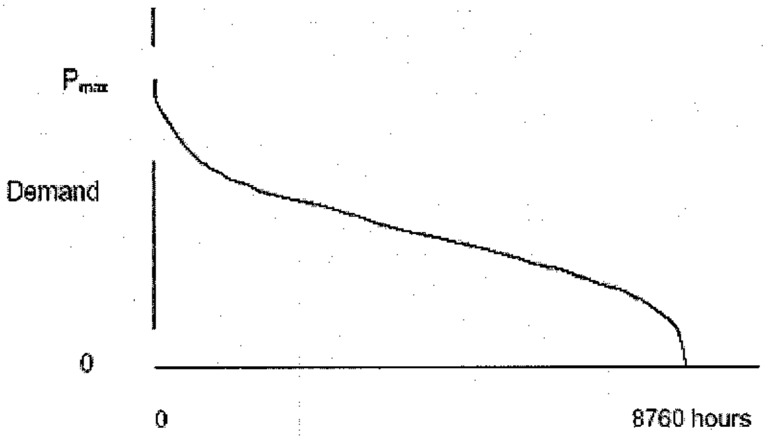

Figure 3: Annual Load Duration Curve

The system load factor LF is defined as the ratio of the average load, P_{ave} to the maximum load, P_{max} over a specified period, in this case a year, i.e. LF = P_{ave}/ P_{max}

- The area A_{Idc} under the annual load duration curve, when the ordinates are related to power demand, represents the annual energy supplied, from which
- $P_{ave} = P_{max}$ x A_{Idc}/(100% of time)
- and so LF = A_{Idc}/(100% of time x P_{max})

The area under the annual load duration curve therefore represents the system annual load factor.

Loss load factor - The loss load factor LLF is defined as the ratio of the average loss, L_{ave} to the maximum (i.e. peak-load) loss, L_{max} over a specified period. For this case i.e.

- LLF = L_{ave}/ L_{max}

Loss load factors, LLF are taken to be according to the generally accepted empirical formula

- LLF = k*(LF) + (1-k)*(LF)2

(where k is a constant, generally 0.1, 0.2 or 0.3 and determined by integrating the corresponding power loss duration curve).

Where demand recording exists such that half hourly (or time increment) load duration curves can be derived, it is relatively simple to calculate the load factor from:

- LF = sum of half hourly demands / (maximum demand * number of half hours).

A fairly accurate estimate of the corresponding LLF can simply be calculated from:

- LLF = sum of squares of half hourly demands / (square of maximum demand * number of half hours).

The value of LLF so obtained would be an improvement on that derived by using the empirical formula above, where the necessary data is available.

Average-loss and maximum loss factors - The average loss factor l_{ave} is defined as the ratio of the average loss, L_{ave} to the average load, P_{ave}, i.e.

- $l_{ave} = L_{ave} / P_{ave}$
  Then $LLF = L_{ave} / L_{max} = l_{ave} \times P_{ave} / (l_{max} \times P_{max}) = (l_{ave} / l_{max}) \times LF$
  And $l_{max} = (LF/LLF) \times l_{ave}$
  Since annual energy losses = L_{ave} x 100% time = EL,
- $L_{max} = LF/LLF \times L_{ave}/P_{ave} = LF/LLF \times EL/(P_{ave} \times 100\% \text{ time})$
  And peak power loss (%) = LF/LLF x average energy loss (%)

If LF and LLF are known, this relationship is useful if either peak loss is known (from load flow studies) or the average loss is known (from metering), hence enabling the unknown quantity to be derived. The concept of LLF has been applied by the Victorian Electricity Supply Industry (VESI) in determining DLFs.

4.2.2 Shunt power losses

Shunt power losses, mainly iron losses in transformers and to a lesser extent dielectric losses in cables, may be regarded as substantially fixed provided system voltages are kept reasonably constant. The total losses are therefore the sum of the series and shunt losses.

4.3 POWER FACTOR

4.3.1 Power Factor Concepts

The term power factor is defined as a ratio of the current drawn that produces real work to the total current drawn from the supplier such as the utility company. Like most aspects of modern electrical systems, power factor is a complex issue intertwined with utility rate structures, economic consideration and system capacities. In other word, Power factor is defined as the ratio of the actual power of an alternating current to the apparent power, or the ratio of the resistance to impedance.

Power factor ranges from 1.0, or unity, to zero. Incandescent lighting loads are resistive and result in a power factor of 1.0, or 100 percent. When loads draw reactive or harmonic currents in addition to the current that does real work, the power factor ratio becomes less than unity. Real work performed by motors, heaters, and lights is a result of the current in phase with the voltage. This real work is measured as active power in kW, and can be equated to hp, Btu, or lumens based on the efficiency of the device converting the electrical power to another form of power.

Electrical power, expressed in kW, is the capacity to do work. This is equivalent to power in a mechanical system in that force, or voltage, accompanied by displacement, or current flow, delivers power. No work is done, however, and no energy is expended unless power is applied over a period of time. When power is applied over a period of time, energy-expressed in kWh-is expended and work is performed.

Inductive loads such as motors, transformers, and lighting ballasts constitute a large portion of the load at most industrial facilities and to a lesser extent in commercial buildings. The inductance of these devices causes the current to lag behind the voltage. This lagging effect is caused by the magnetizing current required for operating these electro-mechanical devices. Without this magnetizing current, the devices would not work. Thus the lagging power factor effect is a fact of life that must be addressed.

Current not operating in phase with the voltage does not produce any real work which it can be shown mathematically, and therefore cannot be billed as kWh of electrical energy consumed. However, they do place an additional burden on the electrical system. These magnetizing amps cause heating to occur in PDS equipment and conductors upstream from the load. This current contributes to reactive power known as kilovolt amperes reactive (kvar). Because the utility company must invest in oversized equipment to serve low power factor loads, a penalty is commonly assessed on the electric bill to recover these equipment costs and the lost energy from the magnetizing current flowing through the equipment and conductors.

Capacitive components in an electrical system cause the current to lead the voltage. The leading current of a capacitor will counteract the lagging current required by an inductive device and cancel the effect of the lagging current. Since few capacitive components exist in typical electrical systems, capacitors or synchronous machines often are used to supply leading current to meet the kvar requirements of inductive loads. This reduces the kvar demand on the utility supply and the components in the PDS. Over-correction with too much capacitance can cause a leading power factor of less than unity. This situation is undesirable and can cause over voltage conditions to occur.

4.3.2 Power Factor Calculations

The power factor ratio measures the relative amounts of work-producing active power measured in kW vs. the total apparent power (kva). Power factor is defined as the cosine (cos) in the following equations:

Power factor = cos Power = Vrms Irms cos PF = kW / kva

Traditionally, power factor is based on the 60 Hz fundamental frequency. Harmonic currents drawn by adjustable speed drives, PCS, PLCs, and electronic office equipment are increasing in the modern facility. As a result, power factor must be viewed in reference to harmonic frequencies of the 60 Hz fundamental. Conventional power factor is now called displacement power factor to relate it to the displacement between the system current and voltage waveforms.

Distortion power factor, on the other hand, takes into account the harmonic currents that do not contribute to the real work produced by the load. Distortion power factor is defined as the ratio of the fundamental component of the line current to the total line current. The total power factor is thus a combination of both displacement and distortion power factors.

4.3.3 Power Factor Measurements

A facility can sometimes determine its power factor by examining its power bill or asking for the information from its utility representative. Power factor may be measured or calculated from other measurements such as kW, kva, or kvar measurements.

Measurement techniques that consider only the 60 Hz fundamental frequency determine the displacement power factor, which is simply the phase shift between current and voltage waveforms. Measurement techniques that include current and voltage root-mean-square (rms) values take into account the effects of harmonic currents to reflect both displacement and distortion power factors. Many solid-state power monitors are presently available to sample voltage and current waveforms and calculate the electrical parameters. These devices usually indicate both displacement and total power factor.

4.3.4 Cause and Disadvantages of Low Power Factor

Low power factor is caused by inductive loads (such as transformers, electric motors, and high intensity discharge lighting), which are a major portion of the power consumed in industrial complexes. Unlike resistive loads that create heat by consuming kilowatts, inductive loads require the current to create a magnetic field, and the magnetic field produces the desired work. The total or apparent power required by an inductive device is a composite of the following:

- Real power (measured in kilowatts, kW)
- Reactive power associated with components that alternately store energy and release it back to the line during each AC cycle (measured in kilovars, kVAR)

Reactive power required by inductive loads increases the amount of apparent power (measured in kilovolt amps, kVA) in the distribution system. The increase in reactive and apparent power is reflected by the increase of the angle between the two, causing the power factor to decrease.

Disadvantages of low power factor:

i. Increases the supply authorities cost since more current has to be transmitted, and this higher cost is directly billed to consumers being metered on maximum demand kVA systems.
ii. Causes overloaded generators, transformers and distribution lines within the plant, resulting in greater voltage drops and power losses. All of which represents waste, inefficiency and needless wear and tear on industrial electrical equipment.
iii. Reduces the load handling capability of the plants electrical system.

4.3.5 Power Factor Correction

Power factor correction is the process of installing reactive electronic components that bring the power factor of a branch or circuit closer to "unity power factor" or a power factor of 1.0. Unity power factor is obtained only when current and voltage are in phase. Loads that are inductive in nature require the installation of elements with capacitive terminal characteristics which have the primary function of improving power factor. It is used in the design of systems that are very sensitive to unusually high currents passing through the load. Generally, a power factor as close to a value of one as possible is the most desirable because most of the power generated from the power source to the load is useful or true power.

In an application, power factor correction is accomplished by the installation of capacitors to a normally inductive circuit. As a result, power factor is increased and the total current through the circuit is closer in phase with the applied voltage. In other word, the most practical and economical power factor improvement device is the capacitor. All inductive loads produce inductive reactive power (lagging by a phase angle of 90°). Capacitors, on the other hand, produce capacitive reactive power, which is the exact opposite of inductive reactive power. In this instance, the current peak occurs before the voltage peak, leading by a phase angle of 90°. By careful selection of capacitance required, it is possible to totally cancel out the inductive reactive power when placed in circuit together, but in practice it is seldom necessary to correct beyond 0.98 P.F. lagging since the additional savings to unity do not justify the cost of additional capacitors.

Capacitors can therefore be utilized to reduce the overall kVA and electrical costs. Improving Power Factor results in:

- Reduced kVA charges.
- Improved plant efficiency.
- Additional loads to be added to the system.
- Reduced overloading of cables, transformers, switchgear, etc.
- Improved voltage regulation due to reduced line voltage drops and improving the starting torque of motors.
- Reduced fuel requirements to generate power due to lower losses.

4.4 FACTORS EFFECTING DISTRIBUTION SYSTEM LOSSES

There are several factors contributing to the increase in the line losses in the primary and secondary distribution system. They are as follows:

i. Feeder length
ii. Inadequate size of conductor
iii. Location of distribution transformers
iv. Use of over rated distribution transformers
v. Low voltage
vi. Low power factor
vii. Poor workmanship in fittings

4.4.1 Feeder length

- In practice, 11 kV and 415 V lines in rural areas are hurriedly extended radially over long distances to feed loads scattered over large areas. This results in high line resistance, low voltage and high current and therefore leads to high I^2R losses in the line.

4.4.2 Inadequate size of conductor

- As stated above, rural load are usually scattered and generally fed by radial feeders. The conductor size of the feeders must be adequate. The size of the conductor should be selected on the basis of km – kVA capacity of the stranded conductors. Losses in distribution feeder conductors are the result of current flow through electrical resistance of the conductors. The resistance a conductor offers to the flow of electricity is inversely proportional to its cross-sectional area – i.e., the larger the diameter of the conductor, the less resistance the current will encounter. Resistance is also a function of the type of material of which the conductor is made.

4.4.3 Location of distribution transformers

- Often the distribution transformers are not located centrally with respect to the customer. Consequently, the farthest customers obtain an extremely low voltage even though a reasonably good voltage level is maintained at the transformer secondary. This again leads to higher line losses.

4.4.4 Use of over rated distribution transformers

- Studies on 11 kV feeders have revealed that often the rating of distribution transformers is much higher than the maximum KVA demand on the LT feeder. Over rated transformer produces an unnecessarily high iron loss.

4.4.5 Low voltage

- Whenever the voltage applied to an induction motor deviates from rated voltage, its performance is adversely affected. A reduced voltage in case of an induction motor results in higher currents drawn for the same output, which leads to higher losses. This can be overcome by adjusting the tap changer at power transformer and at distribution transformer, if available.

4.4.6 Low Power Factor

- In most of the LT distribution systems, it is found that the power factor varies from as worse as 0.65 to 0.75. A low power factor contributes towards high distribution losses. For a given load, if the power factor is low, the current drawn is high, consequently the losses goes up significantly.

4.4.7 Poor Workmanship in fittings

- Bad workmanship contributes significantly towards increasing distribution losses, as joints are a source of power losses. So the number of joints should be kept to a minimum and at the same time care must be taken to avoid sparking and heating of contacts.

4.5 LOSSES DUE TO INTERRUPTION CAUSES

They are several interruption causes in the Electric Power Distribution System. These interruptions are caused by a wide range of phenomena including equipment failure, animals, trees, severe weather and human error. These causes are at the root of distribution reliability. Understanding and identifying these physical root causes is often the most cost effective way to address reliability problems. For discussion, the author only put emphasis on part of the interruptions caused by equipment failure.

Each piece of equipment on a distribution system has a probability of failing. When first installed, a piece of equipment can fail due to poor manufacturing, damage during shipping or improper installation. Whilst, healthy equipment can fail due to extreme currents, extreme voltages, mischievous animals, severe weather and etc. Sometimes equipment will fail spontaneously for reasons such as chronological age, thermal age, state of chemical decomposition, state of contamination and state of mechanical wear. The most common modes of failure for equipment that is most critical contributes to losses in distribution system are as follows:

i. Transformers
ii. Underground cable
iii. Overhead lines
iv. Circuit breakers

4.5.1 Transformers

- Transformers impact distribution system reliability in two related ways: failures and overloads. Catastrophic transformer failures can result in interruptions to thousands of customers. When this happens, other customers are often called upon to pick up the interrupted load. If there is not enough spare transformer capacity, a decision must be made whether or not to overload in-service transformers and accept the resulting loss-of-life. Understanding these issues requires a basic knowledge of transformer ratings and thermal aging.

4.5.2 Underground cable

- A major concern pertaining to underground cables is electrochemical and water treeing. Treeing occurs when moisture penetration in the presence of an electric field reduces the dielectric strength of cable insulation. When moisture invades extruded dielectrics such as cross-linked polyethylene (XLPE) or ethylene-propylene rubber (EPR), breakdown patterns resembling a tree reduce the voltage withstand capability of the cable. When insulation strength is degraded sufficiently, voltage transients caused by lightning or switching can result in dielectric breakdown.

4.5.3 Overhead lines

- Due to high exposure, most overhead line damage is caused by external factors such as vegetation, animals and severe weather. Bare conductor is able to withstand much higher temperatures than insulated conductors and damage due to high currents is less of a concern. High currents will cause lines to sag, reducing ground clearance and increasing the probability of phase conductors swinging into contact. Higher currents can cause conductors to anneal, reducing tensile strength and increasing the probability of break occurring. Fault currents, if not cleared fast enough, can cause conductors to fuse and burn down.

4.5.4 Circuit breakers

- Circuit breakers are complicated devices that can fail in many different ways. They can spontaneously fail due to an internal fault, spontaneously open when they should not, fail to open when they should, fail to close when they should, and so forth. Circuit breakers can fail to open or close due to faulty control wiring, uncharged actuators or simply being stuck.

4.6 BLACKOUT AND VOLTAGE COLLAPSE

4.6.1 Blackout

A blackout is a condition where a major portion or all of an electrical network is de-energized with much of the system tied together through closed breakers. Any area whose tie-lines to the high voltage grid cannot support reasonable contingencies is a candidate for a blackout. System separations are possible at all loading levels and all times in the year. Changing generation patterns, scheduled transmission outages, and rapid weather changes among other reasons can all lead to blackouts.

The system just prior to a blackout may not be dynamically unstable but in an overloaded condition. At such loadings, the collapse may come about due to damage to thermally overloaded facilities, or circuits contacting underlying facilities or vegetation. When an overloaded facility trips, other facilities will increase their loadings and may approach their thermal capabilities or relay trip settings.

4.6.2 Voltage Collapse

Voltage collapse is an event that occurs when an electric system does not have adequate reactive support to maintain voltage stability in which the sustained voltage level is controllable and within predetermined limits. Voltage Collapse may result in outage of system elements and may include interruption in service to customers.

Voltage collapse is the process by which voltage instability leads to the loss of voltage in a significant part of the system. This condition results from reactive losses significantly exceeding the reactive resources available to supply them. Circuits loaded above surge impedance loadings and reduced output of shunt capacitors as voltages decline can lead to accelerating voltage drops. Voltage collapse can look like both a steady-state problem with time to react and a problem where no effective operator intervention is possible.

4.7 MEASURES TO OPTIMISE LEVELS OF SYSTEM LOSSES

By replacing a conductor with one of a larger diameter or changing to a material that offers less resistance, power loss can be reduced when the same current is flowing through the conductor. Distribution feeder losses can be minimized by upgrading existing feeders with larger-size conductors, reconnection of customers, and sectionalizing feeders with switching. On single phase systems there is also a need to balance loading among the three phases. Segmenting shield wires can also eliminate losses associated with loop flows through this path.

Several issues associated with implementing action are listed as below:

- Requires accurate load information and estimates of type and number of consumer connected. Installation of demand metering on primary distribution feeders is a necessary data source.
- A modular standard approach to feeder design is essential. This necessitates use of computer software to optimize feeder sectionalizing
- Reconductoring existing lines is generally only cost-effective when a thermal capacity increase is needed, but existing load flow models or regional models for economic evaluation of conductor losses can be developed.
- Pole, tower and cross arm strength are a concern for existing lines. Most distribution facilities are built and designed to the size of the conductor on the line. A larger conductor adds greater windage, weight, and ice loading levels which may exceed the design capability of the tower equipment. Therefore, in many cases, increasing the line capacity requires a complete rebuild of the line besides of reconductoring.
- Environmental permitting can be extensive, especially where structure rebuilding is necessary. Environmental regulations are often unclear for this type of project. Lengthy permitting processes and costly conditions in permits may preclude consideration of or implementing a reconductoring project. Hence, examine ways to clarify and simplify environmental permitting, taking into account the advantages of using an existing transmission corridor and the fact that line losses would be reduced are considerable.

They are several technical measures than can be employed to optimise system losses. The measures are as below:

- Low loss transformers (i.e. low fixed or magnetising loss) – particularly in the case of distribution transformers where transformers with different loss ranges are offered by manufacturers.
- Re-conductor overhead lines with larger cross-sectional area conductors; use of lower resistance conductors such as all aluminium alloy conductor (AAAC).
- Installation of cables having larger conductor sizes.
- Use of cables and capacitors with lower dielectric losses.
- The use of a higher sub-transmission system voltage further into the network, alternatively (and where possible) uprating of 11 kV networks to 22 kV working.
- Reactive power compensation - in practice the installation of (generally switched) shunt capacitor banks, either at substations or on the network (pole top capacitors).
- Tariffs with maximum demand and/or power factor clauses for medium and large customers thereby encouraging correction of power factor at source. (power factor limits are specified in the Electricity Distribution Code)
- Reconfiguration (normally open points) of HV feeders to reduce system losses, commensurate with other operational requirements.
- Balancing of load between phases on feeders.
- Load shifting – reduction of maximum demand through the off-peak tariffs.
- The use of energy efficient lighting (within zone substations).

CHAPTER 5

CONCLUSION

As the conclusion, the project is carried out to achieve its problem statement and most of its entire objective. If the project succeeds in other word come out with the identified various factors that contribute to losses in Electric Power Distribution System and its possible recommendation, thus it will enhance the electrical energy supply authorities and be a very beneficial of study material for further reference.

In addition, it should be remembered that the reduction in the transmission and distribution losses would make the electrical utilities more cost effective and this benefit can be passed on to the customer thus making the entire system more efficient. The cost of money saved would also mean that more money is available for investment, technology up gradation, Research and development and other customer related spending. One should remember the saying **"one unit of energy saved is one unit of energy generated"**.

Last but not least, optimistically, the project output is beneficial as planned.

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APPENDINCES

- **The Gantt Chart for the First Semester of 2 Semester FYP**

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■													
	-Propose Topic														
	-Topic assigned to students														
2	Preliminary Research Work		■	■											
	-Introduction														
	-Objective														
	-List of references/literature														
	-Project planning														
3	Submission of Preliminary Report			●											
4	Project Work				■	■	■	■							
	-Reference/Literature														
	-Practical/Laboratory Work														
5	Submission of Progress Report								●						
6	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
7	Submission of Interim Report Final Draft												●		
8	Oral Presentation													●	
9	Submission of Interim Report														●

● Suggested milestone
■ Process

- **The Gantt Chart for the Second Semester of 2 Semester FYP**

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue		■	■											
	-Practical/Laboratory Work														
2	Submission of Progress Report 1			●											
3	Project Work Continue				■	■	■	■							
	-Practical/Laboratory Work														
4	Submission of Progress Report 2								●						
5	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
6	Submission of Dissertation Final Draft												●		
7	Oral Presentation													●	
8	Submission of Project Dissertation														●

● Suggested milestone
■ Process

Electricity Distribution in Ulaanbaatar

2.1 The summary in this chapter was prepared by a team that consisted of staff from UBEDO and local and international consultants during 1997–97. Although this team focused its investigations on the capital, the national relevance of the study has not suffered unduly, because Ulaanbaatar consumes about 33 percent of the energy that is distributed annually by the national interconnected grid, and the characteristics of the power system in the capital are typical of those in Mongolia's other cities, including Darkhan.

2.2 Fieldwork, measurements, and discussions with the local counterpart led the team to the same broad conclusion that applied to the DHS, namely, that the increasing level of losses in the electricity distribution system can be attributed to both technical and non-technical causes. The study team focused on estimating the level of these losses, identifying their main sources, and drawing up a plan of action to reduce the losses to economic levels.

2.3 Preliminary estimates as well as measurements taken throughout the study indicate that total losses are increasing: they were 27 percent in 1995 and went up to 30 percent of the net energy supply in 2000. About 14 percent are estimated to be technical losses and 16 percent are estimated to be non-technical losses. This loss level means that about 300 GWh a year is supplied without receiving any payment for it. The main sources of technical and non-technical losses are as follows:

- Non-technical losses:

- Un-metered (but authorized) consumer supplies;
- power theft; and
- lack of transparent billing procedures for those apartment buildings that are metered as single units, the bills for which are being submitted to the building management. UBEDO customer relations and sales functions have not yet changed to match commercial practices and are fraught with problems that contribute to high non-technical losses.

- Technical losses:

- major problems were found to be in the low-voltage system, as opposed to the mid-voltage system. Overloaded transformers and excessively long and thin low-voltage lines (mostly in ger areas) are the highest priority for rehabilitation.

2.4 Following up on the work conducted by the study team, the GOM and the World Bank are preparing a loan to focus on the main problems identified in the study and to address simultaneously those institutiona l areas that must be reformed in order to put the sector on a commercial footing.

2.5 The next section summarizes the study team's fieldwork, conducted during the 1996–97 period. The figures have been updated to year 2000.

Background

2.6 The Ulaanbaatar supply system operates at voltages of:

- 110 kV for transmission,
- 35 kV for subtransmission and some distribution lines, especially in rural areas,
- 6 and 10 kV for primary (medium- voltage) distribution in the urban areas, and
- 400 V for three-phase low-voltage consumer supplies.

2.7 The 6-kV feeders emanate primarily from Power Stations 2 and 3, in which generators operate at 6 kV and are directly connected to distribution busbars. But a few 6-kV feeders originate in substations not belonging to Power Stations 2 and 3. Some of the physical characteristics of the supply network in Ulaanbaatar City itself (not the entire UBEDO supply area) are shown below:

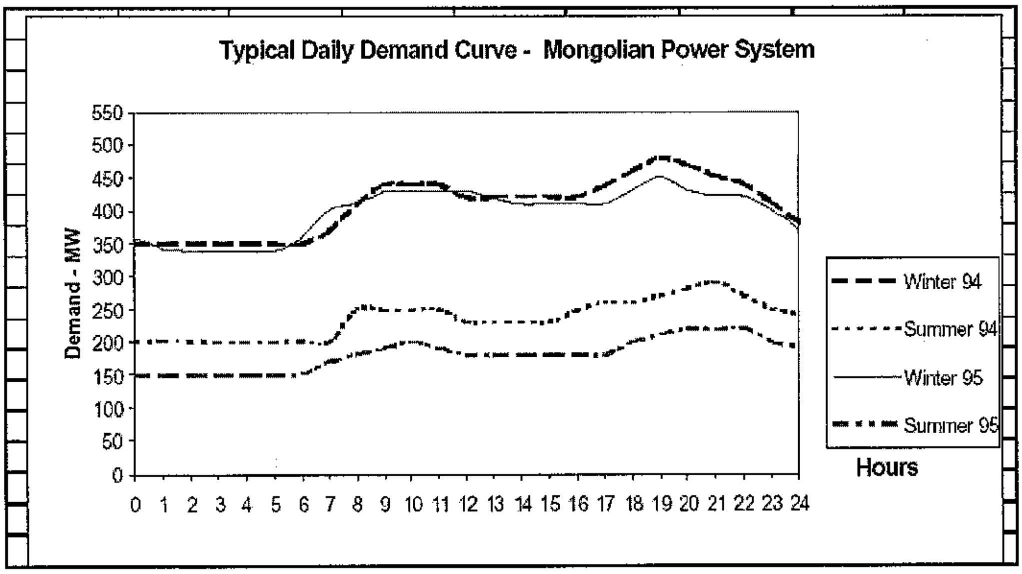
Table 2.1: Ulaanbaatar City Power Supply System

SUBSTATIONS		LINE LENGTHS	
Voltage kV	No.	Voltage kV	Length km
220	1	220	285.8
110	13	110	207
35	50	35	753
6/10	549 pole-mounted	6/10	3908 overhead
6/10	590 indoor	6/10	678 underground
		0.4	965 overhead
		0.4	514 underground

2.8 The loads in Ulaanbaatar City are roughly divided into three areas. In and around the city center is a densely concentrated area in which consumers are predominantly industrial and commercial. Surrounding this central area and extending into the suburbs, the loads are primarily residential. Out in the suburbs themselves, residential dwellings are often grouped into communities consisting of 60 or more small houses and tent-like structures. These communities, generally referred to as the gerdistricts,[3] are characterized by dense population and relatively low consumption, averaging about 180 kWh/month per house during the winter, when space heating is required.

2.9 Major industrial loads include municipal water pumping from deep wells, pumping installations for the central DHS, the abattoir, bakeries, wool processing factories, and carpet factories. As a result of the severe winters in Ulaanbaatar, the system must cope with a high peak in electricity consumption during half of the year, when electric space and water heaters are used and when additional energy is needed to pump water into the central DHS. The figure below shows the seasonal differences for two consecutive years.

Figure 2.1



2.10 Very few substations, including those within the power stations, are equipped with meters that can directly indicate the power factor or even the reactive power demand. Measurements on a number of feeders showed that many of these operate at very low power factors (less than 75 percent). UBEDO itself has not installed any capacitors, but there is power factor correction equipment in a number of consumer owned substations.

2.11 Electricity demand in the Ulaanbaatar area has grown from 570 GWh in 1998 to 604 GWh in year 2000, while energy purchases by UBEDO—to satisfy that demand—have grown from 810 GWh in 1998 to 911 GWh in year 2000. Thus overall losses have grown from 29.6 percent to 33.7 percent in 2000, a compounded annual loss rate of 13 percent.

Transmission and Distribution Losses

Non-technical Losses

2.12 Non-technical losses account for about 16 percent of the energy annually supplied to the UBEDO transmission and distribution systems. By international standards, this is a very high level. Non-technical losses, which represent energy supplied to consumers for which no bills have been issued, are the result of errors or inadequacies in the metering, meter reading, or billing systems of the utility. Common contributors to non-technical losses are:

- *Un-metered supplies to registered consumers.* Only about one-third of UBEDO's residential consumers are provided with company-installed meters. A very large percentage of the residential consumption is therefore estimated, at a time when annual residential growth in the ger districts in year 2000 was 8.5 percent.

- *Power theft.* Unauthorized connections to UBEDO's system are a major contributor to non-technical losses. In the ger districts it is not difficult to find examples of illegal diversion of power. The problem is more pronounced in winter, when many householders are unable or unwilling to purchase coal for space heating. These households connect directly to UBEDO's system in order to run poor-quality resistance heaters. Power theft is also a factor in technical losses, since the illegal connections are most easily made to the lowest phase of the utility's low- voltage feeders. As a result, this phase becomes too heavily loaded and the resulting imbalance between phase currents increases the technical losses in the system.

- *Faulty meter installations.* This category includes wiring defects, mismatch of instrument transformers, and tilted meters, etc.

- *Metering defects.* Meters may be incorrectly calibrated, or may lose accuracy with age, or may suffer from deliberate tampering with the mechanism.

- *Meter-reading errors.* Many apartment buildings are equipped with only a single UBEDO meter and the bills are submitted to the building management companies. These companies resort to sub-metering the individual apartments, but the meters concerned are not owned by UBEDO and are not read by its personnel. In many cases, the management companies dispute the readings of the single official meter and pay instead for what they claim is the actual total consumption, based on summing the readings of the individual meters. UBEDO is not allowed to check this procedure and has so far (reluctantly) accepted the position of the management companies. It is difficult to find other examples in the world of a utility that allows the customer to decide what his or her consumption has been, despite the existence of an official meter.

2.13 The study team concluded that each of the above five factors contributes to some extent to the high level of UBEDO's non-technical losses, but decided that the following three factors most urgently require attention: (i) un-metered but authorized consumer supplies, (ii) power theft, and (iii) regularization of billing and payment procedures for single- meter apartment buildings.

Technical Losses

2.14 During the next few years, work should focus on the following five priority areas in order to reduce technical losses to economically acceptable levels:

- *Overloaded low-voltage distribution transformers.* Routine checks showed a large number of such units to be highly overloaded, some up to more than 230 percent of their rated capacity. In general, a transformer that operates frequently at or above its rated capacity should be replaced in order to ensure system reliability and to keep losses at an acceptable level. Preliminary estimates indicate the need to purchase and install about 200 MVA low-voltage distribution transformers.

- *Overloaded medium-voltage distribution transformers.* Based on the loadflow analysis performed during its fieldwork, the team recommends the reinforcement of seven medium- voltage distribution transformers.

- *Voltage upgrading of 6-kV feeders.* An evaluation of the economics of upgrading those 6-kV substations and feeders that are too heavily loaded indicates that upgrading to 10 kV would produce a marked benefit. Since it is not possible to tackle all of the 6-kV substations and transformers on emanating feeders within one simultaneous exercise, the team recommends starting with substation Dornod 1 and the transformers on its 12 feeders.

- *Reconductoring low-voltage feeders.* Calculations have made it clear that the low-voltage feeders produce the highest share of the total conductor losses. A very large number of these low-voltage feeders are of the 25-mm2 bare aluminum steel conductor type, but the poles, insulators, and related hardware will support 35-mm2 conductors without modification. An evaluation of the economics in upgrading 40 km of low-voltage feeders from 25 mm2 to 35 mm2 showed a favorable benefit.

- *Capacitor installation for power factor improvement.* Measurements, presented in the main report, have shown that many medium-voltage feeders operate at very low power factors. Sample calculations of the economics of capacitor installation for loss reduction in these feeders show a good benefit.

Table 2.2: Ulaanbaatar City Power Supply System

GWh	1997	1998	1999	2000
Energy purchases	796	810	867	911
Energy sales	559	570	603	604
Losses: %	29.8	29.6	30.4	30.7

Source: EA's statistics, December 2000.