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26th July to 8th August, 2010

Central Institute for Rural Electrification of Rural Electrification Corporation Ltd

(A Govt. of India)

Hyderabad, Andhra Pradesh, India

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CAPACITY BUILDING PROGRAM ON DISTRIBUTION SYSTEM LOSS REDUCTION

FOR

AFGHANISTAN POWER EXECUTIVES

CONCEPT AND PRINCIPLES OF DISTRIBUTION LOSSES; ENERGY ACCOUNTING & AUDIT

INTRODUCTION

- All Energy conversion, conveyance and utilization systems involve losses.
- These losses cannot be eliminated altogether.
- However, the developments and efforts have always been towards reducing losses to reasonable levels as determined by economic considerations and as possible with improvements in technology, materials, design of equipment, quality of construction, operation and maintenance techniques.

INTRODUCTION (Contd..)

•Reduction in the quantum of losses means improvement in efficiency, energy conservation and most important of all financial and economic benefits.

•The Transmission and Distribution (T&D) system, a complex network of lines operating at different voltages and sub-stations is an important and essential link between the power generating sources and widely spread and diverse categories of consumers

INTRODUCTION (Contd..)

- The optimum utilization of the generated power will not be possible without paying adequate attention to the transmission and distribution systems.
- While extensions to the transmission systems in many countries have been mostly made on the basis of load flow, short circuit, stability studies etc., the extensions in sub-transmission (66 kV & below) and distribution systems have been made from time to time to meet the immediate requirements, instead of planning them on a long term basis.

INTRODUCTION (Contd..)

- More often than not, the distribution systems in many countries had developed in an unplanned / haphazard manner.

- This, coupled with poor quality of equipment, bad construction and inadequate maintenance and also theft of energy, metering deficiencies, un metered power supply etc leads to a situation of high-energy losses and low standards of quality and reliability of supply in the systems.

Distribution Systems Development – Optimum Level of Losses

A good distribution system should ensure:

- Voltage conditions to be within the permissible limits.
- Minimum losses
- Reliability and security of supply
- Least system cost

Distribution Systems Development - Optimum Level of Losses (Contd..)

- At the distribution level, normally a voltage variation of -6% to +6% is permitted. These voltage variation limits become the guiding factor in the planning of distribution systems and the extension thereto.
- With the rising cost of electrical energy and depleting resources for power generation, the need for reduction of energy losses in the T&D system assumes greater importance.
- The higher the cost of energy, the lower the order of losses should be.

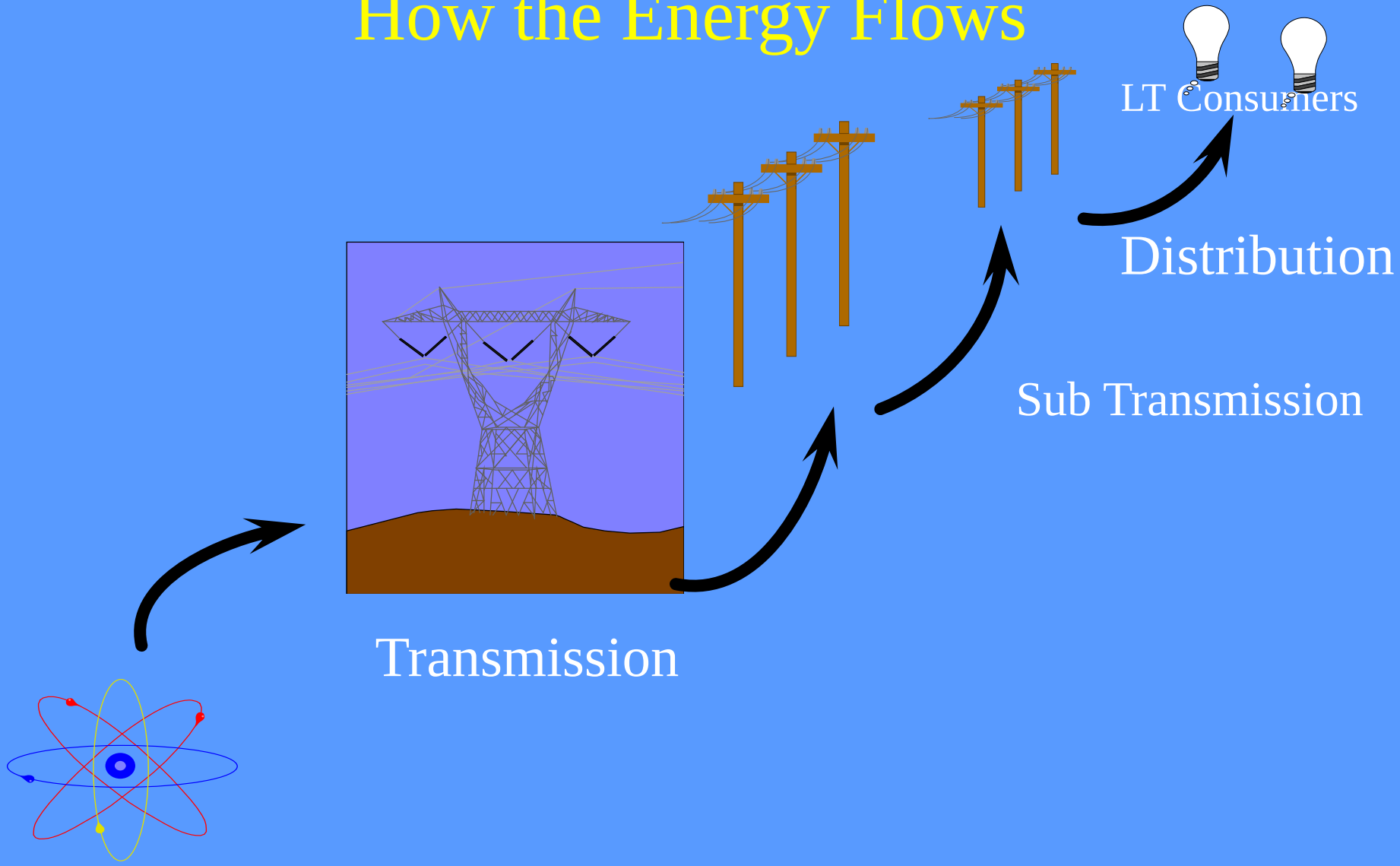
Key elements for successful Power Development

- Efficiency of electrical system in Generation, Transmission and Distribution of electricity
- Billing and recovery of costs for electricity delivered to/consumed by ultimate consumer
- Electrical energy accounting and auditing are the primary tools for controlling and lowering commercial and technical losses and improving financial performance of the utility

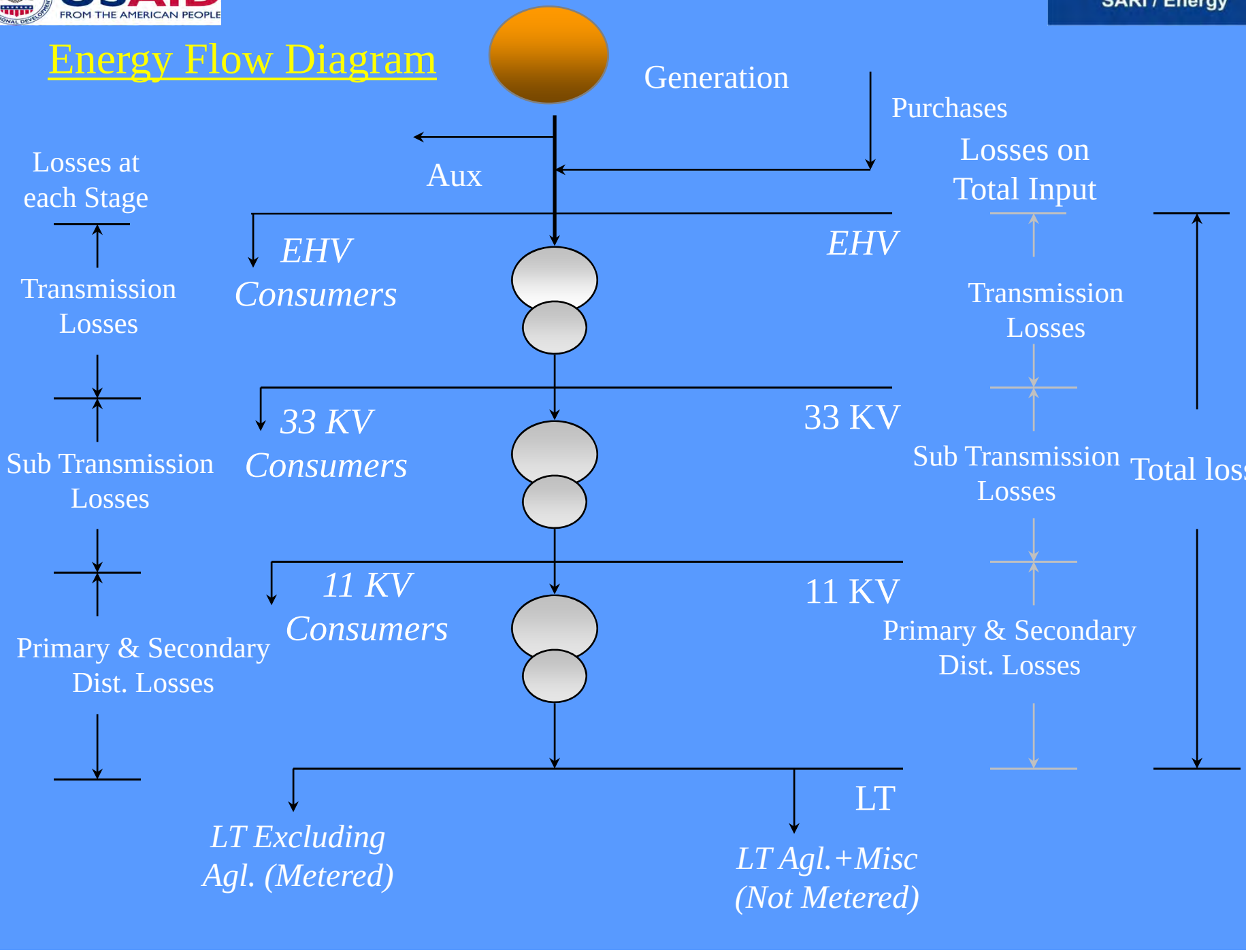
OVERVIEW OF POWER SYSTEM:

- Transmission : 132, 220 & 400 KV
- Sub – Transmission : 66 & 33 KV
- Primary Distribution : 11 KV & 6.6 KV
- Secondary Distribution : 400V

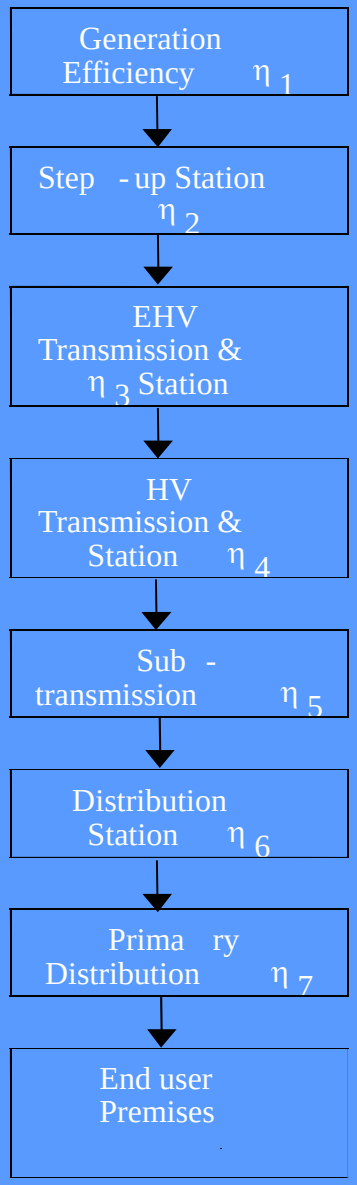
How the Energy Flows



Energy Flow Diagram



Levels of T & D



Efficiency ranges 28 - 35 % with respect to size of thermal plant, age of plant and capacity utilisation

Step - up to 400 / 800 kV to enable EHV transmission.
Envisaged max. losses 0.5 % or efficiency of 99.5 %

EHV transmission and substations at 400 kV / 800 kV.
Envisaged maximum losses 1.0 % or efficiency of 99 %

HV transmission & Substations for 220 / 400 kV.
Envisaged maximum losses 2.5 % or efficiency of 97.5 %

Sub - transmission at 66 / 132 kV
Envisaged maximum losses 4 % or efficiency of 96 %

Step - down to a level of 11 / 33 kV.
Envisaged losses 0.5 % or efficiency of 99.5 %

Distribution is final link to end user at 11 / 33 kV.
Envisaged losses maximum 5 % of efficiency of 95 %

Cascade efficiency from Generation to end user

$$= \eta_1 \times \eta_2 \times \eta_3 \times \eta_4 \times \eta_5 \times \eta_6 \times \eta_7$$

The cascade efficiency in the T&D system from output of the power plant to the end use is 87% (i.e. 0.995 x 0.99 x 0.975 x 0.96 x 0.99.5 x 0.95 = 87%)

Energy Accounting & Audit

1. Energy Accounting to assess losses

2. Energy Auditing to identify measures for reduction of losses.

ENERGY ACCOUNTING AND AUDITING

- Idea is to treat one energy unit (KWH) as a unit of electrical money
- Similar to financial accounting and auditing which detects leakages, misappropriation, fraudulent transactions
- Energy made available at a unit and units utilized by consumers are to be checked
- Energy Accounting is not a one time exercise but is to be done on a continuous basis
- The financial turnaround of a utility can be achieved through a well developed energy accounting and audit system with accountability at all levels

NEED FOR ENERGY ACCOUNTING :

- Even 1 % reduction in T & D losses would provide substantial financial benefits to the utilities
- Reduction of technical losses involves large capital investment
- Reduction of commercial losses can be achieved at lesser cost and in a shorter time frame

ENERGY ACCOUNTING:

- How the energy has been consumed out of the total available over a period of time or specified period
- Highly data intensive
- Exercise to be carried out on a continuous basis
- Regular analysis and review of reporting from time to time is essential

STRATEGY

- Mechanism should be set for Energy Accounting System
- Responsibility and Accountability in the organization structure
- Metering System of requisite quality
- Regular reviewing of Metering System's health
- Management Information System(MIS) on energy account, billing and revenue collection

ACTIVITIES OF ENERGY ACCOUNTING:

- Installation of appropriate meters at high voltage (11KV and above) feeders
- Computerization of consumer data and billing
- Adoption of software for energy accounting and reporting
- Pinpointing of loss causing segments

Limitations in Accurate Accounting Of Losses

Billing:-

- Different Billing Cycles (HT, High Value, Monthly, Bi-monthly)
- Inaccuracies in consumption of Stuck up, Burnt Meters, Door Locks, etc.
- Energy assessed due to Pilferage, Revision of Bills - not apportioned to corresponding sales
- Difference in Reading dates of Consumer Meters and Sub-Station Meters
- Un-metered Agricultural Consumption

Limitations in Accurate Accounting Of Losses (Contd….)

Metering:-

- Location of Meters
  - Statutory Requirements
  - SS Yard or Control Room
  - Burden & Drop in Cable
- Reading Dates & Frequency
- Recording Mechanism

ENERGY AUDIT

- Enables analyzing the data in a meaningful manner to evolve measures for reducing leakages and losses

WHY ENERGY AUDIT?

- To Have Proper Accounting Of Energy
- To Reduce Leakages
- To Improve Finances
- Bring Reduction In Tariffs
- Achieve Consumers' Satisfaction
- All The Above Becomes More Important In Energy Shortage Situations

Objectives of Energy Audit:

- Review and up gradation of procedure for energy accounting
- Review of technical efficiency of system elements in Sub Transmission & Distribution (ST & D) system
- Analyzing the techniques for measuring energy received, energy billed and revenue collected
- Review of performance of equipment, meters, distribution transformers etc
- Audit the segregation of technical and non-technical losses
- Establishment of norms for checking the consumption of various categories of consumers and overall energy balance in a particular system.

TYPES OF LOSSES IN THE SYSTEM

Technical & Commercial Losses

1. **TECHNICAL LOSSES** are due to energy dissipated in the conductors and equipment used for Transmission, Transformation, Sub-transmission & Distribution of Power. These "Technical Losses" are inherent in the system and can be reduced to an optimum level.

2. **COMMERCIAL LOSSES** are caused by Pilferage, Defective Meters, Errors in meter reading and in estimating un-metered supply of energy.

Why Losses Occur (Technical)

- Every Component in System offers Impedance to Power Flow
- 3-5 Transformations before energy reaches the End Consumers, with every stage bringing in Losses
- Distances from Generation Points to Load Centres, Conductor Size, Load Mix, Load & Diversity Factors, Temperature, Power Factor, Over Loads, Under Voltages, etc. affect losses greatly

Other Causes Of Losses

- Tap Changers, Boosters, Phase Converters, Voltage Stabilizers, etc. make PF worse
- R&C (Restriction & Control), 9 Hrs. supply, 2/3 arrangements, etc.
- Under loaded Distribution Transformers (D.Trs) for Flats in cities
- Overload on D.Trs & Lines (Line designed for operation at 70%, if operated at 100%, Losses increase)
- Sub Station Capacitors not working (0.8 PF causes 60% increased Loss

Why Losses Occur (Commercial)

- Defective Meters
- Erroneous Meter Readings
- Billing Errors
- Accounting Errors
- Un-Accounted Services
- Pilferage

T & D Losses

Technical and Commercial losses together is termed as T&D Losses.

$$\text{T \& D Loss (\%)} = \frac{\text{Units Purchased} - \text{Units Billed}}{\text{Units Purchased}} \times 100$$

Distribution Systems Development – Optimum Level of Losses

The rising trend of energy losses indicates the absence of any upper limit of losses in the distribution system, which the planners can keep in view while planning and designing the distribution networks. According to a study carried out by Electric Power Research Institute (EPRI), USA, the losses in various elements of T&D system usually are of the order as indicated below:

TYPICAL NORMS

ZONE	SYSTEM ELEMENTS	POWER LOSS (%)
A	Step up transformer & EHV Transmission System	0.50% to 1.00%
B	Transformation to intermediate voltage level, transmission system and step-down to sub-transmission voltage level	1.50% to 3.00 %
C	Sub-transmission system and step-down to distribution voltage level	2.25% to 4.50%
D	Distribution lines and services connections	4.00% to 7.00%
TOTAL LOSSES		**8.25% to 15.50%**

The low investments on Transmission & Distribution lead to the neglect of distribution sector and funds are mostly used for giving new connections and immediate reinforcement needed thereof. Thus, distribution systems have to cater to the increased demand without commensurate augmentation and this in turn, contributes to increased losses besides poor quality and reliability of supply.

- These losses depend on pattern and nature of demand, load density and capability and configuration of system and equipment used
- Total losses beyond the above need further study
- Targets to be fixed for reduction of technical/non-technical losses
- Accomplish the same within the given time period

How To Conduct Energy Audit

- Identify Boundary Points
- Solve Border Disputes!
- Arrange Proper Meters
  - Accuracy Issues
  - Have Reading Mechanism & Procedures (Lay Down Rules)
- Arrive at Technical Losses
- Assess Un-Metered Energy In A Scientific Way
- Obtain Data
- Analyze
- Draw Conclusions

Problem Areas

- When Some Meters Don’t Work :
  - Have Check Meters at other ends
  - Assess for Change of Feedings
  - Apportion for the Constituent Parties Based On Transformer Capacity
- Assess for any other Reasons
- Arrive Area-wise Balance Sheets
- Compare with Previous Data
- Importance Of Check & Counter Checks

Types of Energy Audit

Direct Method: In this method, losses are found on the basis of difference of units sent out and received at the end of each element in the power system.

Advantages: It is straightforward and simple.

Disadvantages: It requires:

- metering of very high class of accuracy
- simultaneous reading of meters.
- High accuracy class Current & Potential Transformers
- Nil reading error .

Types of Energy Audits(Contd)

Indirect Method: The losses are determined by simulation of the network. With the advent of powerful mini and micro computers at affordable prices and good models for simulation of Transmission & Distribution networks, this is more popular and practical.

Advantages: It highlights losses in each element.

Disadvantages: It requires power factor, load factor and hourly load data for simulation.

Constraints in Conducting Energy Audit

- Absence of Proper Metering at Input & Output Points of Power Flow
- Change in Power Flows due to System Requirements & Operational Exigencies
- Difficulty in Taking Readings Simultaneously at all Points
- Inaccuracies due to poor Voltages, Low Frequency & Low Power Factor
- Power Flows and Revenue Accounts are not Co-terminus
- Inherent Errors in Meters, Current & Potential Transformers.
- Higher Current Transformer ratios for substation meters

Action for Energy Audit

District Wise Energy Audit: Provides the losses in each District network consisting of 132 KV, 33 KV, 11 KV, and LT systems. The losses comprise Technical and Commercial losses.

220 KV, 132 KV and 33 KV Lines Energy Audit: Provides the losses in each 220 KV, 132 KV, and 33 KV lines. These losses can be taken as Technical losses, as theft of power is very remote at these voltage levels.

11 KV Energy Audit: Provides the losses in each 11 KV feeder, consists of technical and commercial losses.

Distribution Transformer Energy Audit: Provides the losses in the LT network under each distribution transformer. The losses comprise Technical and Commercial Losses.

Planning for Energy Audit

1. Gauging of Agricultural Consumption
2. Calculation of System Losses
3. Calculation of Energy Losses in the Various Elements of Power System:
   - Losses in EHT Feeders And Connected Equipment:
   - 33 KV Feeder wise And Connected Equipment Losses
   - 11 KV Feeder wise And Connected Equipment Losses
   - Low Voltage Network Losses

Gauging Agricultural Consumption

1. Agricultural consumption is often disputed as it is based on the estimates and also as it varies widely with cropping pattern, depth of ground water, acreage, season etc.
2. Estimate agricultural consumption by fixing meters at 10 agricultural services per a Revenue Unit (Mandal) and selecting the wells with different cropping, acreage, water depths etc.
3. At least 5% sampling to be made to get meaningful results.
4. Estimation of agricultural consumption based on sample metering at ten pilot services in each Mandal has revealed that the energy consumed in this sector is of the order of 7835 MU for 1996-97.

Calculation of System Losses

1. Identify Import/Export points and provide meters at such points.
2. Monthly figures of total energy sold under each category in the district are collected and the agricultural consumption is assessed (as discussed).
3. The difference between total input energy and total energy sold gives T&D Loss.

Calculation of Energy Losses in the Various Elements of Power System

1. Losses In Extra High Tension (EHT) Feeders And Connected Equipment:

- Energy meters should be provided at sending and receiving ends.
- The meter readings at both ends should be taken on the same day of every month, precisely at a fixed time.
- The net energy sent out on 33 KV feeders emanating from each Extra High Voltage (EHV) sub station are to be arrived at.

Calculation of Energy Losses in the Various Elements of Power System (cont'd)

- Also arrive at the energy exported to other sub stations and areas normally fed by other areas.
- Arrive at the total energy sent out from all the EHV sub-stations (1).
- Obtain total energy handled by the identified EHT and H.T. feeders from the various generating stations/switching stations/sub-stations(2).
- Arrive at the EHT line and connected equipment losses (2-1)

Calculation of Energy Losses in the Various Elements of Power System (Contd)

2. 33 KV Feeder wise And Connected Equipment Losses:

- Meters shall be provided for all 33 KV feeders emanating from EHV substation (1).
- Provide meter on Low Voltage side of each power transformer immediately to assess the demand and energy handled by substation.
- Provide metering for individual 11 KV feeders emanating from all substations (2).
- The difference between energy handled at 33 KV Feeder sending end and 11 kV Feeder sending end gives 33 KV Feeder and Power Transformer losses.

Calculation of Energy Losses in the Various Elements of Power System (Contd)

3. 11 KV Feeder wise And Connected Equipment Losses (Method 1) :

- Provide energy meter for each 11 KV feeder or a group of 11 KV feeders controlled by a breaker at the substation.
- Identify the distribution incident on the 11 KV feeder or group of feeders.
- Identify the High Tension services incident on the feeder and their energy consumption on the current month (HTE)

Calculation of Energy Losses in the Various Elements of Power System (cont'd)

- Obtain the energy billed, distribution wise from the reports of private account agency/departmental agency for the current month (B1) and preceding two months (B2, B3).
- The average consumption of each distribution for non high value services, considering the three cycles (PE = (B1 + B2 + B3)/3)
- Obtain meter readings of the meter on first day and last day of previous month (M1, M2).

Calculation of Energy Losses in the Various Elements of Power System (Contd)

- The energy sent out on the feeders ES = (M2-M1)
- Obtain the energy billed for high value services for the current month (HVE)
- Obtain the total horse power of the pump sets existing on the feeder (AHP)
- Estimate the Agricultural energy sales as per the average consumption per HP arrived at based on meter readings at the pilot services (EA)

Calculation of Energy Losses in the Various Elements of Power System (Contd)

- Total energy billed on the feeder = Private Accounting Agency/Departmental Agency Energy billed + High Value Energy billed + HTE
- Energy Billed (EB) = PE + HVE + HTE
- Energy losses on the feeder+ DTR loss = Energy Sent - Energy billed - Agl. Energy Sales [EL = ES – EB – EA]

Calculation of Energy Losses in the Various Elements of Power System(Contd)

3. 11 KV Feeder wise And Connected Equipment Losses (Method 2):

- Install Energy Meters at sending end of 11 KV feeders (1).
- Install Energy Meters on LV side of DTRs (2).
- The difference of Energy between (1) and (2) gives 11 KV feeder loss and DTR loss as well.
- Constraints: It is very difficult to record meter readings simultaneously without having data loggers for all the meters.

Calculation of Energy Losses in the Various Elements of Power System(Contd)

4. Low Voltage Network Losses (Method 1):

- Install Energy Meters on LV side of DTRs (1).
- Energy billed for different class of customers through each DTR can be computed from billing database (2).
- The difference of Energy between (1) and (2) gives low voltage network losses.
- It is easier to compute (2) when consumer billing database is linked with DTR location database.
- DTR coding should be done

Calculation of Energy Losses in the Various Elements of Power System (Contd)

- Transformer Location code is added as a field in the consumer database.
- Now, energy billed for different class of customers through each DTR can be computed easily (2).
- The difference of Energy between (1) and (2) gives low voltage network losses (Both Technical and commercial).

Calculation of Energy Losses in the Various Elements of Power System(Contd)

4. Low Voltage Network Losses (Method 2):

- Energy handled by each DTR is estimated (not metered) by measuring Voltage and Current.
- Energy handled = √3 x Voltage (Phase - Phase) x Current in Amps. X Load Factor x Power Factor (1).
- The load factor and power factor are estimated by taking sample readings and considering load characteristics.
- Energy billed for different class of customers through each DTR can be computed from billing database (2).
- The difference of Energy between (1) and (2) gives low voltage network losses.

ENERGY AUDIT UNITS AT STATE AND NATIONAL LEVELS

- To evolve best practices
- Exchange information
- Standardize values/benchmark parameters for energy audit
- Results of Energy Audit and accounting of each Distribution Unit are to be published by the power utility

BENEFITS AND OUTCOME

- Adoption of proper energy accounting would ultimately facilitate increased revenue realization for the energy supplied to the consumers
- Identification of areas and causes of high energy losses
- Cutting down expenses on account of the operational inefficiencies

OUTCOME:

- Estimation of technical losses element by element in the area under study
- Estimation of commercial losses, their causes and a proper data base to evolve a strategy for elimination of avoidable and undesired losses
- Increase in Billing and Revenue collection
- Improvement in financial performance of utility

- Facilitates a data base as input for upgradation/ improvement of distribution system.

These are:

- Load Management
- Details of power factor, active and reactive power flows and suitable location for reactive power injection in the system
- Assessment of diversity in the system
- Optimum utilization of equipment and services
- Improved voltage profile in the system
- Details of category wise consumption of loads and proper forecast of demand
- Better System augmentation and expansion planning

One Word Of Caution !

- All the difference between Input & Sales is not Loss !!
- Major part of it is unavoidable due to the Process of Transmission & Distribution
- Hence appropriate Term would be '**Difference between Input & Sales**' and not '**Loss**'

Location of Meters

Energy accounting and audit meters

(i) Generating Stations

(1) at the stator terminal of the generator;

(2) on HV and LV sides of the station and the unit auxiliary transformers;

(3) on feeders to various auxiliaries.

(ii) Transmission System

- All incoming and out going feeders

(iii) Distribution System

(1) all incoming feeders (11 kV and above);

(2) all outgoing feeders (11 kV and above);

(3) Sub-Station Transformer including Distribution Transformer – meter on primary or secondary side or both sides depending upon the requirement.

Standards Common To All Types of Meters

- Meter shall have downloading facilities of metered data through Meter Reading Instrument (MRI).

(4) Immunity to External Factors

- The meter shall be immune to external influences like magnetic induction, vibration, electrostatic discharge, switching transients, surge voltages, oblique suspension and harmonics .
- Necessary tests shall be carried out in accordance with relevant standard.

ENERGY ACCOUNTING & AUDIT METERS

(1)The energy accounting and audit meters shall be suitable for measurement, recording and display of cumulative active energy with date and time.

(2) The energy accounting and audit meters may also have the facility to measure, record and display one or more of the following parameters depending upon the energy accounting and audit requirement. All parameters excluding instantaneous electrical parameters shall also be stored in memory.

- (a) Apparent power
- (b) Phase wise kilowatt at peak KVA
- (c) Phase wise KVA(reactive) at peak KVA

- (d) Phase wise voltage at peak KVA
- (e) Power down time
- (f) Average power factor
- (g) Line currents
- (h) Phase voltages
- (i) Date and time
- (j) Tamper events
- meters shall have data storage capacity for at least 35 days in a non-volatile memory.

Energy accounting and audit meters shall have facility to download the parameters through meter reading instruments as well as remote transmission of data over communication network.


Thank You!