Loss Reduction and Efficiency Improvement: A Critical Appraisal of Power Distribution Sector in India

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ABSTRACT: *The main purpose of the present paper is to make an appraisal of the existing Power Distribution Sector in India with special focus on loss reduction and efficiency improvement of power supply. Different major aspects of technical and non-technical losses have been identified and on the basis of that a number of remedial measures have been suggested for loss reduction and to facilitate the improvement of overall efficiency of the power distribution system. This may provide further inputs to energy planners and managers.*

Key words: *Power Distribution, Loss of Power, Loss Reduction, Energy Efficiency Improvement.*

I. INTRODUCTION

The power sector constitutes the backbone of the national economy of any country. Adequate electrical power with a high degree of reliability and quality is also the key to Indian economic growth. India is the 5th largest power producer in the world with the total power capacity of more than 1,45,000 MW. Despite growth in power generation capacity over the last 5-Year Plans, India is facing huge power deficit with peak power deficit of about 16%. Keeping in view the central position of the power sector for good quality of life and sustainable economic development, the Government of India has adopted the policy of providing "access to uninterrupted quality power supply at affordable costs to all by the year 2012. The responsibility of translating this vision into reality vests with the power sector and particularly the power distribution sector functionaries".

In last 20 years, the Indian power sector has witnessed tremendous growth both in size and capacity. In India, the current power installed capacity of power generation aims to increase it to 2,12,000 MW by the year 2012. However, in spite of such massive expansion, the power sector in India has not been able to match the rapidly growing demand for reliable and cost effective supply. Demand for power has continued to grow at a compound annual rate of 8% and has completely outstripped the supply leading to an ever widening gap. The power sector faces many challenges today in its march towards meeting its goal of "Power to All".

In the overall power development scenario in India, the transmission and distribution system constitutes the essential link between the power generating sources and the ultimate consumption of that. The optimum utilization of the generated power is not possible without the help of an adequate and efficient transmission and distribution system. In India, though the expansion of transmission systems has been carried out in a planed way based on detailed technical studies, however, the distribution system has grown in an unplanned and haphazard manner to meet the immediate objective of meeting growing demands of consumers on an urgent basis. This approach, over the years, has created an inefficient distribution system contributing to very high Aggregate Technical and Commercial losses (AT & C losses) and poor quality with low reliability of power supply to consumers. Unfortunately, it has led to tremendous consumer dissatisfaction. It has also affected the financial performance of utilities. Thus, in the ongoing power sector reforms, the focus has rightly shifted to upgrading this Sub-transmission and distribution (ST & D) system and improving its efficiency to reduce AT & C losses.

II. TRANSMISSION AND DISTRIBUTION (T & D) LOSSES

In India, the fact is that all energy supplied to a distribution utility does not reach the end consumers. A substantial amount of energy is lost in the distribution system by way of technical losses. These inherent losses in transmission and distribution of electrical energy from the generating stations to the ultimate consumers should be reduced by eliminating or minimizing the causes of losses.

T & D loss is the difference between units injected into the system and the units billed to the ultimate consumers, which is generally expressed as percentage of units injected. It is generally calculated for a period of one financial year:

Hence, T & D losses (%) = [(Energy input – Energy billed) X 100]/ Energy input
{For a financial year}

The transmission and distribution (T & D) losses in our country, which were around 15% up to 1966-67, increased gradually to 23.28% by 1989-90. After a brief spell of reduction in T & D losses to 21.13% (1994-95), there has been an upswing and the losses reached a level of 33.98% during 2001-02. Since then, a reducing trend has been observed as T & D losses have come down to 32.54% during 2002-03, 32.53% during 2003-04 and 31.25% during 2004-05.

The Transmission and Distribution losses in advanced countries of the world have been ranging between 6 to 11%. Even in many developing countries, T & D losses are less than the level obtaining in India. However, T & D losses in India are not comparable with advanced countries as the system operating conditions there are different from those obtainable in India. As per the T & D losses issued by CEA, taking into consideration the Indian conditions, it would be reasonable to aim for containing T & D losses within 10 to 15% in different States (Table 1):

Table 1: Percentage of T & D Losses in States/ UTs of India

Sl. No	States/ UTs	2002-03	2003-04	2004-05
1	Haryana	37.65	32.07	32.11
2	Himachal	21.16	22.76	28.90
3	Jammu & Kashmir	45.55	45.54	41.08
4	Punjab	24.42	25.96	25.42
5	Rajasthan	42.61	43.74	44.68
6	Uttar Pradesh	34.16	35.17	34.39
7	Uttaranchal	25.17	49.23	39.30
8	Chandigarh	24.06	39.06	30.37
9	Delhi	45.82	43.66	45.40
10	BBMB	5.20	1.22	0.98
11	Gujarat	28.52	24.20	30.43
12	Madhya Pradesh	43.31	41.44	41.30
13	Chhattisgarh	37.86	42.55	28.06
14	Maharashtra	34.01	34.12	32.40
15	D & N Haveli	40.26	15.10	16.00
16	Goa	40.26	45.05	35.97
17	Daman & Diu	14.95	16.88	15.56
18	Andhra Pradesh	30.11	27.73	23.96
19	Karnataka	24.57	23.29	26.08
20	Kerala	27.45	21.63	22.48
21	Tamilnadu	17.31	17.16	19.28
22	Lakshadweep	11.29	11.85	10.20
23	Pondicherry	21.10	11.60	18.15
24	Bihar	37.98	36.66	38.88
25	Jharkhand	21.19	25.35	19.62
26	Orissa	45.36	57.09	44.02
27	Sikkim	54.85	54.99	50.49
28	*West Bengal*	*25.93*	*31.01*	*28.54*
29	A & N Islands.	19.78	25.95	12.63
30	DVC	3.34	2.69	2.69
31	Assam	38.30	39.31	51.76
32	Manipur	63.66	65.18	70.61
33	Meghalaya	21.92	16.73	28.35
34	Nagaland	56.71	55.00	48.26
35	Tripura	40.64	46.44	59.54
36	Arunachal Pradesh	38.95	47.54	42.96
37	Mizoram	46.91	55.54	66.14
	All India	**32.54**	**32.53**	**31.25**

Technical Losses

Technical loss is inherent in electrical systems, as all electrical devices have some resistance and the flow of current causes a power loss (I^2R loss). Integration of this power loss over time, i.e., $I^2R.dt$ is the energy loss. The summery of different types of technical losses is given in Table 2:

Table 2: Losses due to Technical Reasons

• Line loss	♦ Loss in conductors/ cables where lower size conductors are used. This causes sags and temperature rise in conductors which further aggravate the loss, ♦ Loss in higher loaded phase wires due to unbalanced loading, ♦ Losses due to current in neutral for cases of unbalanced where neutral wires of lower size are used (like 3 ½ core cables, and neutral wires of size lower than phase wires), ♦ Loosening of strands (in multi-strand conductors like ACSR, AAC, AAA, etc.).
• Losses in mid-span joints (or any joint) at terminations	♦ Contacts of joints due to improper installation and looseness, ♦ Contacts of joints due to inadequate surface area of contact.
• Losses in transformers (typically DTs)	♦ Loose connections at brushings, ♦ Bend in jumpers at connectors where the strands are not tightly held, ♦ High no-load loss depending on type of core used, ♦ High no-load loss in repaired transformers, where the core has not been properly tightened, ♦ No-load loss in case a large number of lightly loaded DTs, ♦ High copper loss for transformers operating at sub-optimal loading which is not commensurate with the designed optimal loading.
• Losses in service cables and connections	♦ Under sized service cables, ♦ Loss in joints of service cables at the poles or junction boxes, ♦ Use of inappropriate fasteners without spring washer at the crimped joints.

• Loss due to high impedance faults	♦ Tree touching, creepers, bird nesting, ♦ Insulator breakages and tracking on the surface of the insulator.
• Losses in re-wired fuses/ jumpers	♦ Loose connection, ♦ Inadequate size of fuse wires – often a source of hot spots.

Commercial Losses

Commercial losses are caused by non-technical or commercial factors namely pilferage, theft, defective meters, errors in meter reading, estimating un-metered supply of energy etc. The summery is given in Table 3:

Table 3: Commercial Losses

• Loss at consumer end meters	♦ Poor accuracy of meters, ♦ Large error in capital CTs / PTs, ♦ Voltage drop in PT cables, ♦ Loose connection in PT wire terminations, ♦ Overburdened CT.
• Tampering / bypass of meters	♦ Where meter without tamper-proof-tamper-deterrent/tamper-evident meters are used, ♦ Poor quality sealing of meters, ♦ Lack of seal issue, seal monitoring and management system, ♦ Shabby installation of meters and metering systems, ♦ Exposed CTs/ PTs where such devices are not properly securitized.
• Pilferage of energy	♦ From overhead 'bare' conductors, ♦ From open junction boxes (in cabled systems), ♦ Exposed connection/ joints in service cables, ♦ Bypassing the neutral wires in meters.
• Energy accounting system	♦ Lack of proper instrumentation (metering) in feeders and DTs for carrying out energy audits, ♦ Not using meters with appropriate data login features in feeders and DT meters, ♦ Lack of a system for carrying out regular (monthly) energy accounting to monitor losses, ♦ Errors in sending end meters, CTs and PTs, ♦ Losses connections in PT wires (which results in low voltage at feeder meter terminals), ♦ Energy accounting errors (by not following a scientific method for energy audits).
• Errors in meter reading	♦ Avoiding meter reading due to several causes like house locked, meter not traceable, etc. ♦ Manual (unintentional errors) in meter reading, ♦ Intentional errors in meter reading (collusion by meter readers), ♦ Coffee shop reading, ♦ Data punching errors by data entry operators, ♦ Lack of validation checks, ♦ Lack of management summaries and exception reports on meter reading.
• Error in bills	♦ Errors in raising the correct bill, ♦ Manipulation/ changes made in meter reading at billing centres – lack of a system to assure integrity in data, ♦ Lack of system to ensure that bills are delivered.
• Receipt of payment	♦ Lack of system to trace defaulters including regular defaulters, ♦ Lack of system for timely disconnection, ♦ Care to be taken for reliable disconnection of supply (where to disconnect).

Revenue Loss due to Loss of Opportunity to serve

The revenue loss due to 'loss of opportunity to serve' is a very relevant but less visible aspect of revenue loss. Guarding against technical and non-technical losses is one aspect, but there is an equal need to guard against loss of revenue due to lost opportunity (Table 4):

Table 4: Reasons for Loss of Opportunity to Serve

• System outage (any part or total systems) leading to loss of revenue	♦ Due to break down, ♦ Due to preventive maintenance, ♦ Due to load shading.
• Overloading and unbalancing	♦ High voltage drop in lines leading to low voltage at consumer premises and lesser consumption, ♦ High voltage drop at tail end of affected phases in case of unbalance, leading to lesser consumption, ♦ High voltage drop due to large reactive currents causing I^2R drop in lines and resulting in lesser voltage and low consumptions.
• Tree touching	♦ Voltage sags at consumer premises, leading to lower power consumption.

Aggregate Technical and Commercial Loss

The aggregate of T & D loss and loss due to non-realization of billed demand is termed as aggregate technical and commercial loss (AT & C loss).

AT & C loss (%) = [(Energy input – Energy realized) × 100] / Energy input

Energy realized = [Energy billed X Collection efficiency]

Collection efficiency (%) = [Amount Realized X 100] / Amount billed

AT & C loss is a transparent measure of the overall efficiency of the distribution business as it measures technical as well as commercial losses. The schematic diagram (Fig.1) shown below captures the essential components of AT & C losses and is translated in terms of units both at the physical level of transmission and distribution and at the financial level of billing and collection:

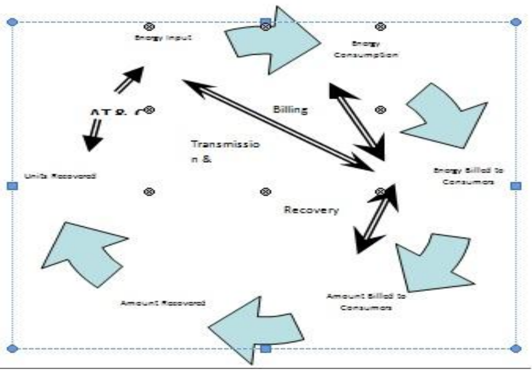

Fig.1: Schematic Diagram Showing Components of AT & C Losses

The AT & C losses are presently in the range of 18 % to 62% in various States. The national average AT & C loss of the distribution companies in the year 2002-03 was 36.63% and has reduced to 33.82% in the year 2004-05, though there is a wide variation of losses among the States and variation among Districts within the State.

III. SCOPE OF LOSS REDUCTION

Technical Loss Reduction

The technical losses in our power systems are high especially in distribution systems. The causes of high technical losses are varied and require different remedial measures to be implemented to bring them down to acceptable levels.

Short-term Measures

The immediate improvement and reduction of losses in the technical system are based upon sample studies, statistical scrutiny/ analysis of the information/ data collected from the existing system detail. These are:

i. Network Reconfiguration – It gives an option to handle the increased demand and increases system reliability. It is effective when voltage drops between the nodes to be linked is rich and the distance between the nodes is short. Within a feeder it is effective only when the zigzag factor is high.

ii. Network Reconductoring – The size of conductor/ cable determines the current density and the resistance of the line. A lower conductor size can cause high I^2R losses and high voltage drop which causes a loss of revenue as consumer's consumption and hence revenue is reduced. The recommended practice is to find out whether the conductor is able to deliver the peak demand of the consumers at the correct voltages, that is, the voltage drop must remain within the allowed limits specified in Electricity Act, 2003.

iii. Preventing Leakages at Insulators - Cracking of insulator and flashover across insulators often cause outages and result in loss of revenue. Use of appropriate material for insulators, depending on the nature of pollution, and designed protected creepage path helps in reducing insulator failure. Preventive actions are regular inspection and hot line washing.

iv. Automatic Voltage booster – it is similar to that of the series capacitor as an on-load tap changer it boosts the voltage at its point of location in discrete steps. This, in turn, improves the voltage profile and reduces the losses in the section beyond its point of location towards the receiving end. It has a total voltage boosts of 10% in four equal steps and the loss reduction is directly proportional to voltage boosts.

v. Better Management of Distribution Transformers – the following measures can be taken in this regard:

a. Augmentation/ addition of distribution transformers ;

b. Relocation of distribution transformers at load centers;

c. Low voltage (less than declared voltage) appearing at transformers consumers terminals;

d. Guarding against loss in transformers through oversized transformers operating at low loading, undersized transformers, unbalanced loads in secondary side, connector at bushings, low oil level/ oil leakages, hot spots in core, use of energy efficient transformers etc.

vi. Load Balancing and Load Management – if the loads on each of the three phases of a distribution lines or among feeders are redistributed, the losses will be reduced. The best method to identify load balance is to construct current duration curves for all three phases. In the scenario of overloaded distribution systems, load management plays a very important role for reduction of technical losses. Distribution automation along with SCADA (Supervisory Control and Data Acquisition System) is an important tool for load management which should be introduced.

vii. Capacitor Installation – the use of capacitors to correct for poor power factor is a well established and cost effective means of reducing distribution system losses and maximizing the revenue. In most LT distribution circuits, it is found that the power factor (PF) ranges from 0.65 to 0.75. For low PF the amount of current drawn increases to meet the same kW demands of load. Overall improvement in the operating condition can be brought about by reducing the system reactance. This can be done by the application of shunt capacitor in the following ways – across individual customers, advantage points on LT and 11 kV feeders, at distribution transformers and at 33/11 kV sub stations.

viii. Improving joints and connections – Improper joints are a source of energy loss in both overhead and underground systems. The conductivity of joints should not be less than an equivalent length of the conductor. Joints should be capable of carrying maximum fault current without failure or deterioration for the time required for the protective system to operate.

ix. Increase in HT/LT ratio – It is well known that for high HT/ LT ratio, the losses will be low. The losses for a given quantum of power supplied by a line are inversely proportional to the square of its operating voltage. Higher the operating voltage, lower will be the line losses. Therefore, by increasing the HT lines the losses will be reduced.

x. Adoption of high voltage distribution system (HVDS) – Adoption of HVDS by converting existing LVDS to HVDS reduces the technical losses appropriately.

xi. Preventive and regular maintenance – These components of the distribution system are necessary to reduce/ eliminate breakdowns. Care should be taken to optimize preventive maintenance, because each shutdown due to preventive maintenance is also a source of revenue loss. It can be minimized by careful design and healthy installation practices. The following activities should be undertaken for preventive maintenance:

a. Maintenance of overhead lines,
b. Correction of bent poles,
c. Rewinding transformer,
d. Monitoring transformer tank temperature,
e. Use of protective devices,
f. Improved bushings,
g. Transformer oil testing,
h. Repairing of broken parts.

Long-term Measures

Long-term measures for technical loss reduction involve all measures that need to be taken for the improvement of quality and reliability of power supply and reduction of T & C losses in a given area. These include upgrading, strengthening and improvement of the sub-transmission and distribution system in a circle to meet the future load demand for the next five years. The activities for preparation of a long term plan are listed below:

i. Data collection regarding existing loads, operating conditions, forecast of expected loads, etc. from grid sub-station upto consumers level;
ii. Mapping of existing system;
iii. Analysis of existing system;
iv. Load forecast;
v. Plan for upgrading the network;
vi. Technology options including integration of features for modernization of system;
vii. Evaluation of various alternatives for least cost optimal solution;
viii. Firming up of scope of works;
ix. Preparation of cost estimation;
x. Phasing of works and their cost;
xi. Financial analysis.

Acceptable Technical loss levels

Acceptable technical loss levels depend on economic factors such as cost of power and energy, costs of equipment and discount rates rather than purely on technical factors. The achievable level of losses is subject to various factors given below in Table 5:

Table 5: proposed Targets for economic loss levels

S. No.	System Component	Levels for Peak Power losses	
		Target Level %	Max Tolerable %
1.	Step up transformer and EHV transmission system	0.50	1.00
2.	Transmission to intermediate voltage level, transmission system and step-down to sub-transmission voltage level	1.50	3.00
3.	Sub-transmission system and step-down to distribution voltage level	2.25	4.50
4.	Distribution lines and service connections	4.00	7.00
	Total power losses	**8.25**	**15.50**

Commercial Loss Reduction

Almost all the commercial losses occur at the distribution stage and that is where action has to be taken to control that.

Reasons for commercial losses

The major reasons for commercial losses are:

i. Direct tapping by non-customers – unscrupulous consumers extract electricity illegally by bypassing the energy meter or by connecting leads directly to distribution lines. This kind of power theft takes place mainly in domestic and agricultural sectors. This should be tackled on a priority basis by the utility.

ii. Pilferage and theft of energy by existing customers – theft of electrical energy by existing customers is causing an increase in revenue losses. Emphasis can be given on inspecting high value services for more effective and immediate gains.

iii. Defective metering, billing and collection – commercial losses are also caused by some deficiencies in commercial function of the utility, viz., metering, billing and collection. Though these losses are not due to any deliberate action of the customers, they are due to internal short coming of utility which can be tackled easily.

Measures for commercial loss reduction

The measures for reducing commercial losses depend on the factors that cause them. These are:

i. Measures for controlling direct tapping by non-customers and customers –
  a. Stopping theft by direct taping;
  b. Use of aerial bunched cables/ partial insulated LT lines;
  c. Public relation and awareness campaigns by utility;

ii. Measures for controlling pilferage of energy by existing customers –
  a. The energy meter should be housed in a separate box sealed and made inaccessible to the consumers. The fuse cut-outs should be provided after the meter;
  b. Multi-core PVC cables should be used as service mains instead of single core wires,
  c. Severe penalties may be imposed for tampering with metering seals, etc.;
  d. Theft of electricity should be publicized as a social and economic crime and people should be informed of the provisions in electricity laws in this regard.

iii. Measures for reducing defective metering –
  a. Stuck up meters;
  b. No reading furnished by the meter reader, for a good no. of services, at times continuously;
  c. Constant nil consumption cases reported without any comment;
  d. Progressive readings recorded in disconnected services;
  e. No relation between the meter capacity and the load;
  f. Adoption of wrong multiplication factors (MF) for billing as the change in MF in not intimated to the billing agency.

iv. Meter installation –
It is often considered as a low skill, labor oriented activity. It must be given due importance to against revenue loss. Certain installation practices to prevent this are;
  a. Having a visually traceable and joint free incoming cable, shrink wrapped sealed joint;

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  b. Having clearly visible and accessible seals that can be subjected to easy inspection;
  c. Mounting the meter and CTs inside a box with a clear window;
  d. Ensuring height and location of installation for easy readability of meters;
  e. Locating meters in public domain in full public view;

v. Measures for improvement in billing and collection – Correct billing and timely delivery of bills go a long way in improving the revenue collections. The normal complains viz. non-receipt / late-receipt of bills, wrong bills, wrong reading status, wrong calculations etc. should be avoided.

vi. Users' Associations, Panchyats and Franchisees in Billing and Collection –
The electricity Act, 2003, visualizes the role of users' associations, co-operatives, panchayats and franchisees in electricity
distribution management be successfully inculcated to develop a sense of belonging to and stake in the entity.

vii. Legal Measures for Reducing Commercial Losses –
The Electricity Act, 2003, has brought radical changes in all the facets of the electricity sector. The relevant Sections of the Act are 55, 126, 127, 135, 138, 145, 150, 151, 152, 153, 154, 156, 157, 168, 169, 170 and 171.

IV. CONCLUSION

From the above discussions it is found that there are various factors responsible for AT & C losses which need to be eliminated. The approaches taken over the years in India has created an inefficient distribution system contributing to very high AT & C losses and poor quality and reliability of power supply to consumers. It has led tremendous consumes dissatisfaction as well as it has affected the financial performance of the utilities. As it is extremely difficult to eliminate all the causes simultaneously in our country, strategically measures should be taken to reduce or marginalize the major causes of losses. In the ongoing power sector reforms, the focus has rightly been shifted to upgrading the sub-transmission and distribution (ST & D) system and improving its efficiency to reduce AT & C losses. Ultimately, this may contribute in the process of overall national development.

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