POWER PLANNERS
INTERNATIONAL (PVT.) LTD.
PPI
E-mail: info@powerplannersint.com
Website: www.powerplannersint.com

Ref. No. PPI/KE/1183
Dated: 15-October-2025

Head of Distribution, Operations & Strategy (K-Electric)
2nd Floor, KE House‹ 39-B Sunset Boulevard,
D.H.A. Phase 2 Ext Defense Housing Authority
Karachi, 75500, Pakistan

Subject: **Peer Review of Fichtner-PITCO (FP) Study for KE Distribution Technical Losses for the FY Year 2021-22**

Dear Sir,

Pursuant to Purchase Order No. 7200001082 dated 19th September 2025 issued by K-Electric Limited (KE) to Power Planners International (Pvt.) Ltd., the Undersigned is pleased to submit the Final Study Report titled "Peer Review of Fichtner-PITCO (FP) Study for K-Electric Technical Losses" after incorporation of all the comments and suggestions by KE Team.

In line with the agreed Scope of Work and Terms & Conditions, this submission represents the final deliverable of the assignment, encompassing all research analyses and evaluations conducted during the course of the review. The study focuses on assessing the accuracy of the technical loss estimation carried out in the loss assessment study undertaken by Fichtner-PITCO.

For your reference, the following document is enclosed herewith:

- Final Study Report - Peer Review of Fichtner-PITCO (FP) Study for K-Electric Distribution Technical Losses for FY 2021-22

Soft copy of this report (pdf) along with the working file (xls) are being shared through email.

With this submission, Power Planners International (Pvt.) Ltd. has successfully completed all activities related to the project titled "Review of Study Executed by Fichtner-PITCO for Assessment of Technical Losses in K-Electric's Network for FY 2021-22".

Look forward to continuing our association with K-Electric through future projects, with the shared objective of contributing to sustainable and efficient operations across K-Electric's network.

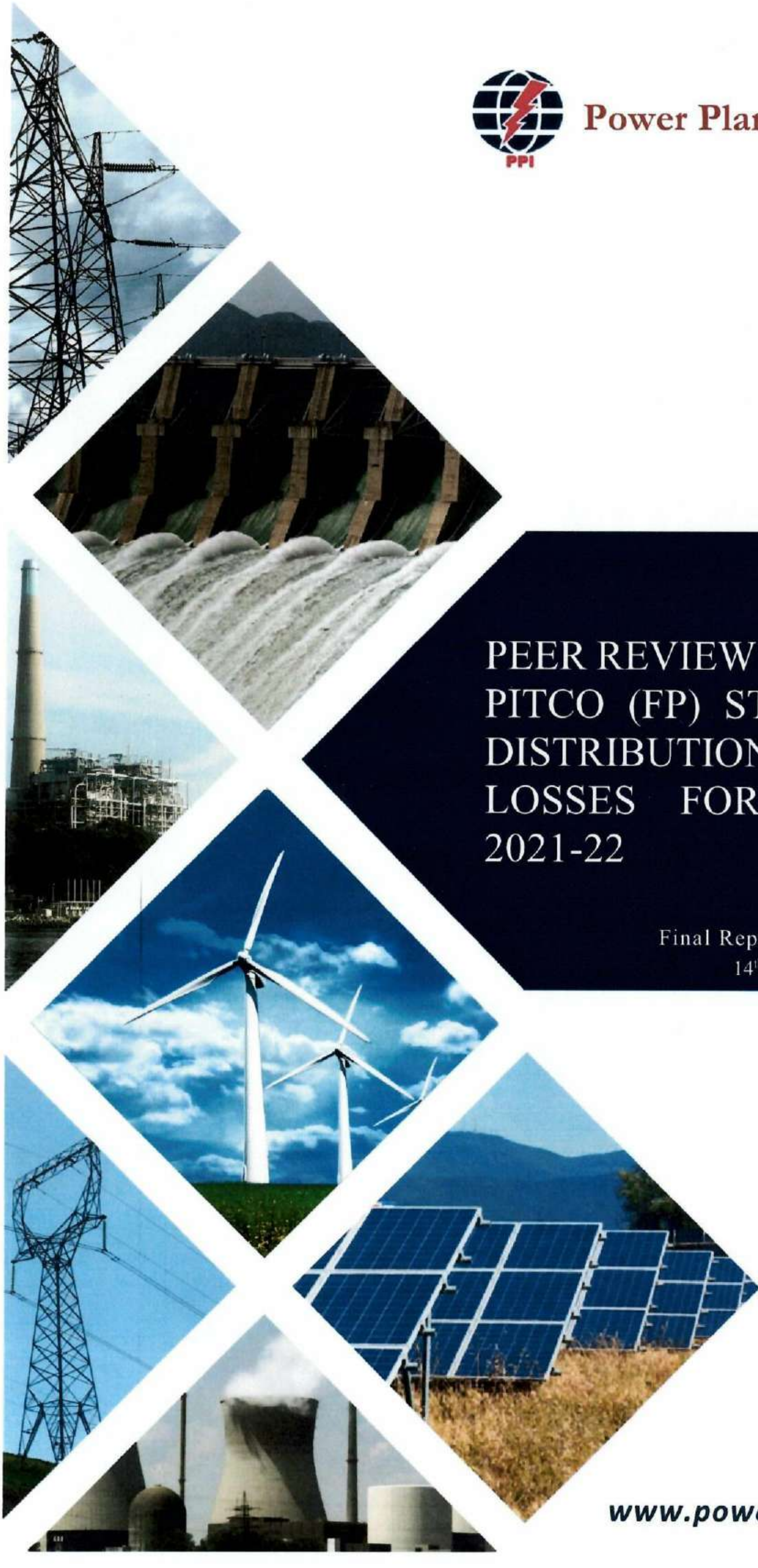
Salis Usman
Project Manager / Senior Executive Consultant
Power Planners International (Pvt.) Ltd.

Power Planners International

PEER REVIEW OF FICHTNER-PITCO (FP) STUDY FOR KE DISTRIBUTION TECHNICAL LOSSES FOR THE YEAR 2021-22

Final Report No. PPI-742/25

14th October 2025



www.powerplannersint.com

PEER REVIEW OF FICHTNER-PITCO (FP) STUDY FOR KE DISTRIBUTION TECHNICAL LOSSES FOR THE YEAR 2021-22

Version	Date	Prepared By	Checked By	Report Status
1.	02-Oct-2025	• Engr. Muhammad Zeeshan • Engr. Eeman Manan • Engr. Naqeeb ullah Kakar • Engr. Hamza Qureshi • Engr. Zakwan Shafiq • Engr. Saqlain Hyder • Engr. Hammad Waseem	• Engr. Salis Usman • Engr. Hussain Zaigham Alvi • Engr. Muhammad Masood Akhtar	Draft Report
2.	14-Oct-2025	• Engr. Muhammad Zeeshan • Engr. Eeman Manan • Engr. Naqeeb ullah Kakar • Engr. Hamza Qureshi • Engr. Zakwan Shafiq • Engr. Saqlain Hyder • Engr. Hammad Waseem	• Engr. Salis Usman • Engr. Hussain Zaigham Alvi • Engr. Muhammad Masood Akhtar	Final Report

Power Planners International (Pvt.) Ltd.

UK Office:

3-Sylvester Road, Sudbury Town, Middlesex, HA0 3AQ, UK

Phone & Fax: +44-(0)208-9223219

Pakistan Office:

95-H/2, WAPDA Town, Lahore 54770, Pakistan

Phone: +92-42-35182835

info@powerplannersint.com

www.powerplannersint.com

Table of Contents

List of Tables ... 4

List of Figures ... 5

List of References ... 6

List of Acronyms ... 7

1. Introduction ... 8

2. Objective of the Task ... 8

3. Explicit Exceptions Taken by Fichtner-PTCO (FP) ... 8

4. Other Technical Factors Likely to Effect Distribution Technical Losses ... 9

5. List of Pre-requisite Data Sought from KE for the Peer Review Study ... 10

6. Key Technical Aspects Potentially Effecting Distribution Technical Losses ... 11

6.1 Loose Joints ... 11

6.2 Repaired Distribution Transformers ... 15

6.3 Deteriorated Wires (Equipment Aging) ... 19

6.4 Equipment Loss ... 22

6.5 Unequal Load Distribution / Phase Imbalanace ... 26

7. Preliminary Findings of the Study ... 29

List of Tables

Table 1: Data Requirements and Category-Wise Gaps for FY 2021–2022 10

Table 2: Hormozgan Power Network Study Data 13

Table 3: Finding & Results of the Loose Connection Study 14

Table 4: Transformer Losses by Type 16

Table 5: Deviation in Losses, from Rated Specifications, Post Conventional Repair 16

Table 6: Finding & Results of the repaired Distribution Transformers 17

Table 7: Findings/Results of Deteriorated Wires 21

Table 8: Findings/Results of Equipment Losses 23

Table 9: Findings/Results of Assessment of Unequal Load Distribution Loss 28

List of Figures

Figure 1: Sankey Diagram of KE Network Component Wise Distriutioin (D) Losses 29

List of References

#	Reference Description and Title	Reference Link
1.	**Loose Connections** • IEEE Guide 1283-2013 • IEEE 16th Conference-2011	• IEEE Guide for Determining the Effects of High-Temperature Operation on Conductors, Connectors, and Accessories • Asset management: condition-based monitoring effect on utility coasts and lose power consumption
2.	**Repaired Transformer** • IEC 60076 • ICAI (DT Policy Paper) • DOE-2019	• What Is the IEC Standard Losses for Dry Type and Oil Type Transformer (Jiangsu Ryan Electric Co., Ltd) • Policy Paper Distribution Transformer Refurbishment 31 Jan 22 • DOE EERE-2019-BT-STD-0018Policy
3.	**Deteriorated Wires** • CIGRE Research Paper (CIGRE-615)	• On the Degradation Assessment of ACSR Condor Conductors Aged in Operational Conditions and Environment Using Electrical and Thermal Analysis'
4.	**Equipment Loss** • EPRI Reports Papers	• Distribution System Losses Evaluation • Assessment of Transmission and Distribution Losses in New York
5.	**Unequal Load Distribution / Phase Imbalance** • Manchester Research Study (Brazil & IEEE Test Systems) • Regression Model, IET University Study	• Assessment of Additional Phase Energy Losses Caused by Phase Imbalance for Data-Scarce LV Networks • Evaluation of distribution system losses due to load unbalance

List of Acronyms

ACSR	Aluminum Conductor Steel-Reinforced
AAC	All Aluminum Conductor
CYME	Power Engineering Software for studying transmission, distribution and industrial networks.
FP	Fichtner-PTCO
GIS	Geographic Information System
HT	High Tension
KE	Karachi Electric
LF	Load Factor
LLF	Loss Load Factor
LT	Low Tension
NEPRA	National Electric Power Regulating Authority
PVC	Poly Vinyl Chloride
PPI	Power Planners International
Synergi	Electric 'Application Software for Simulating, Analyzing and Planning Distribution Feeders, Networks and Substations'
T/F	Transformer
T/Well	Tube Well
TOR	Terms of Reference
T&D	Transmission and Distribution

1. Introduction

KE is an integrated utility supplying electricity to the consumers of Karachi. As part of regulated sector, KE can only charge the tariff from its consumers as determined by NEPRA. It is, therefore, imperative that all those elements constituting the overall costs of service to KE are precisely and accurately worked out. Transmission and Distribution (T&D) loss is certainly one of the most critical components of tariff for KE which directly impacts KE's financial viability. Since no annual reviews are allowed and even mid-term revisions are discouraged by the regulator and general public alike, therefore, KE assigns very high priority for precisely assessing its T&D losses. While the overall number, attributable to T&D loss, can be directly calculated through energy input and output records, it is the segregation of technical and non-technical losses which is challenging for KE and the regulator.

For its tariff petition 2021-22, KE commissioned study by Fichtner - PITCO (FP) for assessing its Distribution loss. FP carried out a study and recommended 6.5% (±0.5%) technical loss. It also highlighted certain non-simulation factors which were not considered by FP in its study, and which are likely to increase the technical losses.

Accordingly, to ensure a true representation of its technical losses, KE requires a more detailed analysis of the additional factors identified by FP that were not included in their report. PPI has been engaged to review these additional loss factors and, through comprehensive research and analysis of literature and data from international and regional organizations, to provide an estimate of their impact on technical losses. Furthermore, any additional aspects that PPI considers relevant for inclusion in the loss calculation have also been examined and incorporated within this report. The analysis would act as recommendations for KE to assess its technical loss attributable to those areas, in line with prudent utility practices.

2. Objective of the Task

Assess whether non-simulated and fixed loss factors contribute to an increase in technical losses, and if so, to determine the potential extent of such additional losses (%) in line with international, national, or regional standards and practices.

3. Explicit Exceptions Taken by Fichtner-PTCO (FP)

While working out the losses, FP report has identified the following factors which have not been considered in the analysis and that their inclusion is likely to result in increase in the Distribution Technical Losses.

According to the FP report:

a. **Loose connections** contribute towards increasing distribution losses. Joints are a source of power loss, and the quality of the joint and the number of joints have an impact on the overall losses that joints contribute in the system. Secondly, connections to the transformer bushing-stem, drop out fuse, isolator, and LT switch etc. (if not periodically inspected and ensured that proper connection is maintained to avoid sparking and heating of contacts) will also add further to the overall technical losses within the system.

b. **Repairs of distribution transformers** leads to higher load losses (copper losses) than the theoretical standard. There are approximately 1500-2000 PMTs that are repaired on an annual basis, and the quality of these repaired and replaced transformers cannot be ascertained for the purpose of this load flow study.

c. Use of **deteriorated wires and services** are also a cause of leaking and loss of power and will add to the technical losses.

d. **Current imbalances** along the 3-phase circuits is also another loss contributor. The feeder phase unbalance may vary during the day and with different seasons, and these cannot be simulated in any kind of load flow study.

e. **Unequal load distribution** among the three phases in L.T system causes high neutral currents.

4. Other Technical Factors Likely to Effect Distribution Technical Losses Identified by PPI

a. The transformer losses are based on standard new equipment specifications, and the IEC tolerance of 10% has been added. It is widely known that losses increase with the age of the equipment. Therefore, FP assumptions will need review in this perspective. Similarly, the same phenomenon of ageing applies to cables & conductors.

b. PPI also notes that, in-line with international practices and relevant research studies, fixed losses associated with miscellaneous equipment such as energy meters, protection relays, and other control devices are also incurred by the utility and should be included in the assessment of technical losses.

5. List of Pre-requisite Data Sought from KE for the Peer Review Study

Table 1: Data Requirements and Category-Wise Gaps for FY 2021–2022

Data Requirements for FY 2021–2022		
#	**Category-Wise Data Gaps**	**Description of Data Requirement**
1.	Cable Deterioration Data	• Age details of HT conductors, LT conductors & service cables: Up to 10 yrs / 10 - 15 yrs / 15 - 20 yrs / Above 20 yrs • Age-wise resistance of deteriorated conductors/cables • Feeder-wise demand (Amperes) • HT/LT line loss of all feeders
2.	Repaired Distribution Transformers	• No-load & load loss of repaired DTs • Number of repaired transformers (by category) • Number of transformer repairs (by category) • Age of repaired transformers (from installation date) for year 2012-2022
3.	Unequal Load Distribution Data	• Feeders under balanced vs. unbalanced condition • Load details (A, B, C phase currents) under balanced condition • Load details (A, B, C, N) under unbalanced condition • Neutral wire cross-section vs. phase wire (details)
4.	Equipment Losses Data	• Nameplate data sheets of equipment showing losses (meters, etc.)
5.	Loose in Cable/Conductor Joints	• Total length of KE network (segregated length category-wise) • Total Sent-Outs per feeder

6. Key Technical Aspects Potentially Effecting the Distribution Technical Losses (Other Than Those Already Considered by the Fitchner-PITCO Study) Based on the Literature Review

This section provides a detailed discussion on the technical aspects/factors which have not been included as acknowledged by FP or the additional factors as noted by PPI. These factors, according to the best utility practices, add to the Distribution Technical Losses.

6.1 Loose Joints

Field observations indicate that existing cable and conductor joints in distribution networks often develop into recurrent points of failure over time. The degradation of electrical joints is a gradual process influenced by multiple factors, including oxidation, corrosion, accumulation of contaminants, mechanical wear, and ageing of materials. These factors collectively reduce the effective metal-to-metal contact area, resulting in an increase in contact resistance.

Elevated resistance leads to localized heating and additional power losses, which in turn accelerate further deterioration through thermal expansion, softening, or deformation of joint components. This progressive degradation can cause loosening of connections, intermittent arcing, and in severe cases, overheating or fire hazards.

Moreover, switching operations, high fault currents and electrodynamic stresses during short-circuit events subject cable terminations and switchgear joints to intense mechanical forces. Repeated exposure to such stress can alter the joint's mechanical integrity, causing relaxation of contact pressure and eventual loosening, even when the original workmanship was within acceptable standards.

Objective

Make an assessment whether loose joints contribute to an increase in technical losses, and if so, what is the potential extent of such additional losses (%) according to international, national, or regional standards and practices.

Importance in Distribution Network

- Rising environmental concerns, costly fuels, and high-power plant investments drive governments to focus on minimizing distribution losses.
- They increase line resistance, cause faults, outages, and contribute significantly to distribution-level energy losses.
- High temperatures put electrical, mechanical, and thermal stress on connectors, weakening their long-term integrity.
- Severe degradation leads to connector/conductor failure, capacity loss, costly repairs, and potential safety hazards.

Relevant International/Regional/National Standards/Best Practices

The following standards and research papers are used for assessing loose connection effect on distribution losses:

a. IEEE Guide for Determining the Effects of High-Temperature Operation on Conductors, Connectors, and Accessories

b. Asset management: condition based monitoring effect on utility coasts and lose power consumption

Approach and Methodology

Equipment reliability may be significantly improve by effectively ascertaining the degradation of the equipment. Improved technologies of Condition based monitoring are used for minimizing downtime through integrated planning and scheduling of repairs. Conduction problems caused by loose connections or deterioration joints of contact surfaces result in local temperature rise, which contributes to the reduction of contact quality.

The effect of identifying loose joints, via thermography and then attempting to fix loose connections in Hormozgan power network resulted in power loss reduction by 10.5 MW. The issue of loose connection/deteriorated joints causes local temperature rise, deterioration of insulation material and disruption of electrical service.

Thermography, also known as infrared (IR) thermographic inspection, is a non-contact technique that uses infrared cameras to detect heat patterns on electrical equipment. In a distribution network, detoriation at joints, lugs, busbars, or terminals create increased contact resistance, which leads to localized heating when current flows. This heating is usually invisible to the naked eye but can be clearly observed through thermal imaging.

By capturing thermal images, hot spots caused by loose or deteriorated connections can be identified before they result in failures, such as insulation damage, arcing, or equipment burnout. Thermography is widely used in substations, transformers, switchgear, and distribution panels as part of preventive and predictive maintenance programs. It allows utilities to:

- Detect abnormal temperature rise due to poor or loose connections.
- Rank severity levels (normal, caution, critical) to prioritize corrective action.
- Reduce unplanned outages by addressing issues proactively.
- Improve safety by preventing fire hazards and equipment damage.

Step-by-Step Procedure for Calculating Contribution of Loose joints to Distribution Losses

Losses due to deteriorated joints can be assessed by correlating the total loss with the length of affected connections and normalizing the results to obtain an average value in watts per kilometer. Inspection results over multiple years can be used to establish a representative benchmark, which may then be applied across the entire distribution network to estimate the overall impact. By comparing the calculated loss with the system's total capacity, the contribution of loose connections to distribution losses is outlined in Table 3.

As per the data given in Hormozgan Electric Power Distribution Co (HEPDC) network study:

For the Year 2007,

Loose Connection = 2.5x106 Watts/ 1500 kM

Loose Connection = 1667 Watts / kM

Table 2: Hormozgan Power Network Study Data

Year	Length (km)	MW
2007	1,500	2.5
2008	3,515	7.5
2009	3,489	9
2010	5,700	10.5

Similarly, for the year 2008, 2009 and 2010, we can take the average as:
Loose joints = $\frac{1675+2145+2589+1895}{4}$

Loose joints = 2.08 kW / km

Finding and Results

Table 3: Finding & Results of the Loose Connection Study

Impact of Loose Connections on Technical Loss of KE for FY 2021–22								
HT Length	LT Length	Total Length	Loss Load Factor	Loose Connection	Energy Loss	Annual Sent Out Units	Annual Energy Loss	Annual Loss
	(km)		(%)	(kW/km)	(kW)	(kWh)		(%)
A	B	C = A+B	D	E	F = C*E	G	H = F*8238	I = (H*D)/G * 100
10,306	20,901	31,207	0.45	2.08	64,910.56	18,521,126,274	534733193.3	**1.30**
Reference:	Asset management: condition-based monitoring effect on utility coasts and lose power consumption							

Key Takeaways (Loose Connections)

- Deteriorated increase joint resistance, leading to heating, higher technical losses, equipment damage, and safety risks.
- The impact of loose connections on technical losses is estimated to be around 1.30%.

6.2 Repaired Distribution Transformers

Repaired Distribution Transformers refers to distribution transformers that have been taken out of service due to faults, damages, or deterioration, and then restored to working condition through maintenance or repair. This may include replacement of windings, bushings, oil, or other defective parts.

Objective

To assess whether repaired distribution transformers contribute to an increase in technical losses, and if so, what is the potential extent of such additional losses (%) according to international, national, or regional standards and practices.

Importance of assessing technical parameters losses in the distribution network

- Monitoring technical losses is essential for utilities to maintain efficiency, cost-effectiveness, and reliability.
- Repaired transformers can show 15–30% higher losses than original ratings, leading to wasted energy, higher costs, and premature failures.
- Regular assessment, timely repair-or-replace decisions, and adherence to international standards help minimize losses and ensure long-term network sustainability.

Relevant International/Regional/National Standards/Best Practices

Following standards are widely recognized and adopted in both national and international practices:

a. Repair of Distribution Transformer IS18284_2023

b. Report on Repair for Performance Improvement of Distribution Transformer for MPPKVVCL_Oct 2019 (1)

c. Technical Loss Reduction through Active Repair of Distribution Transformers for Mahadiscom_2018

d. What Is the IEC Standard Losses for Dry Type and Oil Type Transformer (Jiangsu Ryan Electric Co., Ltd)

e. Policy Paper Distribution Transformer Refurbishment_31 Jan 22

f. DOE EERE-2019-BT-STD-0018Policy

Formulas and Approaches for Accessing the Losses Due to Impact of Different Technical Parameters

Step-by-step Procedure for Calculation of Losses

The methodology for calculating technical losses of distribution transformers covers their performance in new, pre-repair, and post-repair conditions, taking into account international standards, transformer age, rating, and field-related degradation factors. Variations in repair quality can influence system efficiency, and when repair deviations are observed to exceed typical benchmarks, overall distribution losses tend to rise. A more detailed analysis with supporting data is presented in Table 6.

Step 1. Identify Transformer Parameters

1. Nameplate Information:
    - Rated Power (kVA or MVA)
    - Rated Primary and Secondary Voltages
    - Vector Group
    - Cooling Type (ONAN, ONAF)
    - Original no-load loss and load loss values
2. Operational Information:
    - Age of transformer (years in service)
    - Number of major repairs conducted previously
    - Loading pattern and duty cycle
    - Operating temperature and ambient conditions

Step 2. Determine Rated Loss Values (Reference)

Using IEC 60076-1 and IEC 60076-8, determine standard loss ranges based on the rated capacity:

Table 4: Transformer Losses by Type

Transformer Type	No-load Loss (% of kVA)	Load Loss (% of kVA)
Oil-Immersed (ONAN)	0.2 – 0.3%	0.5 – 1.5%
Dry-Type (AN/AF)	0.3 – 0.5%	1.0 – 2.0%

Step 3. Expected Additional Post-Repair Loss

Studies mentioned in "Policy Paper on Refurbishment of Distribution Transformer (DT)" suggest following deviation from standard losses:

Table 5: Deviation in losses, from rated specifications, post conventional repair, as observed in PoC studies Loss

Loss	Deviation
No-Load Loss	+15%
Full Load Loss	+30%

Step 4.. Final Reporting and Documentation

By applying the above factors to the total population of repaired Distribution Transformers in the KE network, an estimate of the additional losses associated with repaired transformers has been derived and provided through Table 6:

Finding and Results

Table 6: Finding & Results of the repaired Distribution Transformers

Impact of Repaired Distribution Transformers on Technical Loss of KE for FY 2021–22													
#	Transformer Rating	Number of Repaired Distribution Transformers	No-Load (Core) Losses	Load (Copper) Losses	Post Re-Pair No-Load (Core) Losses +15%	Post Re-Pair Load (Copper) Losses +30%	Annual No-Load (Core) Loss	Annual Load (Copper) Loss	Total Annual Transformer Losses	Loss with Allowable Tolerance (±10%)	Annual Send outs	Annual Loss	References
	kVA	Qty	Watts				kWh				kWh	%	
A	B	C	D	E	F=D*0.15	G=E*0.3	H=F*8238	I=G*0.45*8238	J=H+I	K=(J*0.1+J)	L	M = (K/L) *100	N
1	10	7	52	256	8	77	64,256	284,705	348,962	383,858	18,521,126,274	0.48	DDS 84-2007 Cont
1	15	191	68	348	10	104	84,028	387,021	471,049	518,154			DDS 84-2007 Cont
2	25	266	98	512	15	154	121,099	569,411	690,509	759,560			
3	50	1,651	180	1,000	27	300	222,426	1,112,130	1,334,556	1,468,012			Policy Paper Distribution Transformer Refurbishment 31 Jan 22
4	100	723	280	1,750	42	525	345,996	1,946,228	2,292,224	2,521,446			
5	150	622	380	2,000	57	600	469,566	2,224,260	2,693,826	2,963,209			
6	200	589	396	2,728	59	818	489,337	3,033,891	3,523,228	3,875,551			
7	250	6,428	600	3,500	90	1,050	741,420	3,892,455	4,633,875	5,097,263			
8	400	298	850	4,900	128	1,470	1,050,345	5,449,437	6,499,782	7,149,760			
9	500	2,032	935	5,715	140	1,715	1,155,380	6,355,823	7,511,202	8,262,323			Indoor & Outdoor Oil Type Distribution Transformer
10	630	30	1,080	6,520	162	1,956	1,334,556	7,251,088	8,585,644	9,444,208			
11	750	301	1,250	7,250	188	2,175	1,544,625	8,062,943	9,607,568	10,568,324			
12	1,000	144	1,500	10,000	225	3,000	1,853,550	11,121,300	12,974,850	14,272,335			
13	1,500	31	2,250	14,500	338	4,350	2,780,325	16,125,885	18,906,210	20,796,831			
	Total	**13,313**								**88,080,832**			

Key Takeaways (Repaired Distribution Transformers)

- Repaired distribution transformers often exhibit higher no-load and load losses than original specifications, increasing technical losses.
- While new transformers meet strict loss benchmarks, repaired units typically show 15–30% higher losses.
- Poor repair practices lead to additional energy waste, higher costs, and reduced system reliability.
- The impact of Repaired Transformer on technical losses is estimated to be around 0.48%.

6.3 Deteriorated Wires (Equipment Aging)

These are wires that have lost their mechanical strength and electrical performance over time due to aging factors such as heat, moisture, corrosion, overloading, UV exposure, and poor maintenance, leading to insulation breakdown, increased resistance, and higher risk of faults or failures.

Objective

Make an assessment whether deteriorated wires contribute to an increase in technical losses, and if so, what is the potential extent of such additional losses (%) according to international, national, or regional standards and practices.

Importance in Distribution Network

- Provides accurate estimation of technical losses in HT and LT networks by considering the increased resistance of deteriorated conductors and cables.
- Emphasizes the impact of aging infrastructure on overall system efficiency and reliability.
- Supports effective planning, monitoring, identification of critical areas, and implementation of remedial measures to meet NEPRA's regulatory targets.

Relevant International/Regional/National Standards/Best Practices

According to the CIGRE Canada research paper (CIGRE-615) titled 'On the Degradation Assessment of ACSR Condor Conductors Aged in Operational Conditions and Environment Using Electrical and Thermal Analysis', the resistance of ACSR conductor increases significantly over time due to deterioration. The study reports that after 60 years of operation, ohmic power losses rise by about 11%, and after 84 years, the increase reaches 44%.

Formulas and Approaches for Accessing the Losses Due to Conductor Deterioration:

1. There are two approaches for calculating these losses depending on availability of data.
   - If the HT and LT line loss data along with the aging details of all the conductors are available, an average aging factor can be determined for the network. Based on CIGRE international research, this aging factor translates into an increased resistance, which directly increases the power loss percentage. This calculated increased power loss can then be applied to the actual HT and LT line losses of feeders, resulting in revised loss figures that reflect the additional impact of conductor deterioration.
   - If the resistance data of deteriorated HT and LT conductors and the demand current of all feeders are available, then the average resistance of deteriorated conductors can be determined, and the total feeder current can be summed. Using these values, the total power loss, including the effect of conductor deterioration, can be calculated by applying the standard power loss formula ($P = I^2R$).
2. Step-by-step procedure for calculation of losses:

The assessment of conductor-related losses involves collecting key parameters for both high-tension and low-tension segments of 11 kV feeders, including line losses, conductor aging, change in resistance and demand currents. Standard calculation methods are then applied using average aging factors and adjusted resistance values to estimate losses attributable to conductor deterioration. By consolidating results across the network, the overall impact of conductor condition on system efficiency can be determined, with acceptable ranges defined to benchmark performance and identify anomalies, further detailed analysis is provided in Table 7.

Finding and Results

Table 7: Findings/Results of Deteriorated Wires

Impact of Deterioration of Conductors/Cables on Technical Loss of KE for FY 2021–22									
According to CIGRE Research Paper (CIGRE-615)			Per Year Line Loss increase according to 24.75% deterioration After 70 years	Average Age of KE Network Conductors/Cables	Line Loss Increase for Avg. Age of KE Conductors due to Deterioration (18 Years)	HT & LT Annual Energy Loss of 1973 Feeders	Annual Increase in HT & LT Energy Loss due to Deterioration	Units Sent Out by KE (2021-22)	Annual Loss
Line Loss Increase After 60 years Deterioration	Line Loss Increase After 70 years Deterioration	Line Loss Increase After 84 years Deterioration							
%				Years	%	(kWh)			%
A	B	C	D = B/70	E	F = D*E	G	H = G*(F/100)	I	J = (H/I) *100
11.0	24.75	44.00	0.354	18	6.36	882,630,496	56,173,127	18,521,126,274	**0.30**
Average Age of KE Conductors/Cables ≈ 18 Years									
Increase in Conductor/Cable Loss due to Deterioration according to Average Age = 6.36% (As per CIGRE Research)									
Reference:	CIGRE Research paper (CIGRE-615)								
	Aging Details of All HT, LT Conductors of KE Network								

Key Takeaways (Deteriorated Wires (Equipment Aging)

- Aging and deterioration of conductors gradually increase their resistance, which in turn causes higher power losses, reduced efficiency, and higher operational costs.
- Over the years, this degradation can significantly affect system reliability, stability, and the ability to meet demand without unnecessary strain on the network.
- The impact of deteriorated wires on technical losses is estimated to be around 0.30%.

6.4 Equipment Loss

Miscellaneous equipment in the distribution network, such as protection relays, fuses, CTs/PTs, circuit breakers and metering equipment contribute to fixed losses. These losses are inherent, specified in nameplate data, and occur regardless of system loading.

Objective

To assess whether equipment losses contribute to an increase in technical losses, and if so, what is the potential extent of such additional losses (%) according to international, national, or regional standards and practices.

Importance in Distribution Network

Importance of Assessing Equipment Losses in the Distribution Network is outlined below:

- Helps in identifying inefficient or aging equipment contributing disproportionately to losses.
- Supports better planning, equipment selection, and compliance with NEPRA's regulatory targets.
- Enhances reliability and efficiency of the distribution network through targeted remedial actions.

Relevant International/Regional/National Standards/Best Practices

1. Two reference papers from EPRI are widely recognized as international practices which are as follows:
    - Distribution System Losses Evaluation
    - Assessment of Transmission and Distribution Losses in New York
2. According to the aforementioned EPRI papers, the formula for determining total equipment losses is as follows:

$$\text{Total Equipment Losses (kWh)} = \sum_{n=1}^{N} (\text{Equipment Loss}_n) * (T)$$

Where,

n = Each type of equipment

T = Annual Time Period = 8760 hours

Step-by-step procedure for calculating total equipment losses

Equipment-related losses are assessed by considering the nameplate characteristics of devices such as relays, current transformers, potential transformers, and other metering equipment. Using standard calculation approaches, the combined impact of these components is evaluated to estimate their contribution to overall network losses. Acceptable ranges are then defined in accordance with industry benchmarks to ensure reliable performance monitoring and early detection of deviations. Further the deratiled calculation are outlined in Table 8.

Finding and Results

Table 8: Findings/Results of Equipment Losses

Impact of Equipment Losses on Technical Loss of KE for FY 2021–22				
Protection Equipments	Number of Protection Equipments	Active Power Consumption Per Protection Equipment	Total Losses	Reference
	Qty	W		
HT Fuses	26,202	10	1,376,016	Reference values from Cooper Bussmann Catalog for MEDIUM VOLTAGE DIN Fuse-Links MV DIN 12kV, Current Limiting Back-Up Fuse-Links, 6.3 to 200 Amps
	39,096	16		
	17,445	28		
LT Fuses	44,414	23	7,061,792	23-3080-80 GAR SPEC
	177,655	34		23-4200-80 GAR SPEC
				23-4250-80 GAR SPEC
				23-4315-80 GAR SPEC
				23-4400-80 GAR SPEC
LT MCCBs	673	16.41	1,663,641	LVPED221001EN ComPacT NSX&NSXm AC
	3,773	26.31		
	2,442	41.85		
	1,846	46.2		
	890	56.25		
	12,142	57.6		
	1,059	119.1		
	4,756	45		
	71	66		
	981	132		
	640	222		
Relays	2,022	4	13,651.25	MiCOM P115
	2,023	2.75		MiCOM P116 EN M A11v2.7

Impact of Equipment Losses on Technical Loss of KE for FY 2021–22					
Protection Equipments	Number of Protection Equipments		Active Power Consumption Per Protection Equipment	Total Losses	Reference
	Qty		W		
HT CTs	16,634		25	415,850	KE-P&E-NE-TS-41 MV (11kV) Current Transformer
LT CTs	162,438		5	812,190	KE-P&E-NE-TS-194-LT Current Transformer
PTs	4,500		100	450,000	KE-PE-NE-TS-273-11kV PT
Metering Equipments	Consumer Type	Number of Consumers	Active Power Consumption Per Metering Equipment	Total Losses	Reference
		Qty	W		
CE-26-05 - Three Phase Four Wire Multi Rate Whole Current Static Energy Meter	Domestic	1,414,592	2	3,504,824	CE-26-05-Brochure
	Commercial	251,391			
	Industrial	23,363			
	Others	16,340			
	Total	1,705,686			
CE-44-07 - Static Single Phase Two Wire Energy Meter	Domestic	1,414,592	2	3,364,650	CE-44-07-Brochure
	Commercial	251,392			
	Others	16,341			
	Total	1,682,325			
Total Equipment Losses (W)				18,662,614.31	
Total Equipment Losses (kW)				18,662.61	
Total Equipment Losses (kWh)				153,742,616.69	
Total Equipment Losses (GWh)				153.74	
Total Units Sent Out (kWh)				18,521,126,274	
Total Equipment Losses (%)				**0.83**	

Key Takeaways (Equipment Loss)

- Equipment losses (relays, CTs, PTs, meters, etc.) stem from inherent inefficiencies; excessive losses may signal overloading and risk of failure.
- Analyzing these losses improves energy efficiency, reliability, sustainability, and infrastructure planning.
- Study and reduction of equipment losses support better equipment selection.
- The impact of Equipment Loss on technical losses is estimated to be around 0.83%.

6.5 Unequal Load Distribution / Phase Imbalanace

A condition in which electrical loads are not evenly shared across phases or feeders, causing phase imbalance, higher losses, voltage fluctuations, overheating of equipment, and reduced system efficiency.

Objective

Assess whether unequal load distribution contribute to an increase in technical losses, and if so, what is the potential extent of such additional losses (%) according to international, national, or regional standards and practices.

Key impacts of unbalancing highlighted in the study include

- Energy Losses: Extra I^2R losses in conductors and transformers.
- Voltage Drops: Uneven voltages received at the consumer end, affecting supply quality.
- Neutral Line Safety Risks: Neutral current increases ground potential rise, posing shock hazards.
- Equipment Stress: Transformers and motors face overheating, vibration, and reduced efficiency.

Relevant International/Regional/National Standards & Best Practices

a. Assessment of Additional Phase Energy Losses Caused by Phase Imbalance for Data-Scarce LV Networks (Regression Model, IET University Study)

b. Evaluation of distribution system losses due to load unbalance (Manchester Research Study (Brazil & IEEE Test Systems)

1. Formulas and approaches for accessing the No-Load Losses due to fixed loss factors:
   - Manchester Research Study (Brazil & IEEE Test Systems)

     This research applied a three-phase, four-wire power flow model to quantify imbalance losses.

     - LV-29 (Brazil, LV Feeder):
       - A 15% load unbalance under constant demand increased total real power losses by 4.1%.
       - Highlighted significance of considering neutral conductor losses.
     - IEEE-34 (USA, MV Feeder):
       - Under unbalanced loading conditions, total real power losses increased by 4.9% compared to balanced loading conditions.
       - Validated the four-wire model's accuracy for practical scenarios.

Calculation of Parameter wise Technical Losses Using Relevant Methodologies and KE Data

- Loss Estimation Approaches:

  Strategy 2 (Incremental Loss Factors, Manchester Study):

- According to the study due to 15% imbalancing the losses increased 4.1% or Between 4-5%,
- for 1% imbalanced system the losses will be increased 0.273%
- for 4% Imbalanced System the losses will be increased 4*0.273= 1.093
- So, the KE Network Average 4% imbalanced when applying the formula, the KE Losses Increased 0.07% Losses Increased, it means the losses due to Imbalancing is 0.07%

Finding and Results

Table 9: Findings/Results of Assessment of Unequal Load Distribution Loss

Impact of Unequal Load Distribution on Technical Loss of KE Network for FY 2021-22									
Annual Sent Out Units	Impact on Losses Due to 15% Imbalancing Factor	Impact Ratio	KE - Imbalance Factor	Impact Ratio on KE Imbalance Network	Total Technical Losses of KE (PITCO)	Total Loss of KE (With 4% Imbalance Factor)	KE Techncial Loss (W/O Imbalance Factor)	KE Techncial Loss (With Imbalance Factor)	Annual Loss
kWh	%				(kWh)		%		
A	B	C=B/15	D	E=DxC	F	G=FxE	H=F/A*100	I=G/A*100	J=I-H
18,521,126,274.40	4.1	0.2733	4	1.0933	1,206,026,301.44	1,219,212,189.00	6.5116	6.5828	**0.07**

Key Takeaways (Unequal Load Distribution)

- Unequal load distribution increases I^2R losses in lines and transformers, causes voltage drops, neutral current risks, and accelerates transformer aging.
- Phase imbalance in KE's distribution network is a persistent issue, varying significantly across feeders and affecting both LT lines and transformers.
- The impact of Unequal Load Distribution on technical losses is estimated to be around 0.07%.

7. Preliminary Findings of the Study

PPI notes that international research and analysis by highly reputed organizations such as CIGRE, IEEE, DOE, and others have identified several factors that contribute to energy losses in power utilities. The available research papers and literature provide indicative ranges and benchmarks for each of these factors, based on practical applications and real-time experience. As highlighted in the earlier sections, the FP report has not taken these factors into account in its assessment of KE's technical losses. Similarly, PPI has also identified certain areas that were overlooked by FP in their evaluation.

Based on the current availability of KE's network data, PPI observes that these factors collectively contribute to an estimated 2.98% in technical losses for the FY 2021-22. However, if all the aforementioned methodologies is implemented across the complete KE dataset, and considering data variations from FY 2021-22 to FY 2024-25, such as an increase in the number of repaired transformers per year, aging of conductors, and network expansion (e.g., increase in total line length, which naturally leads to a higher incidence of loose connections) the estimated losses are expected to fluctuate within the range of 2.90% to 3.30%.

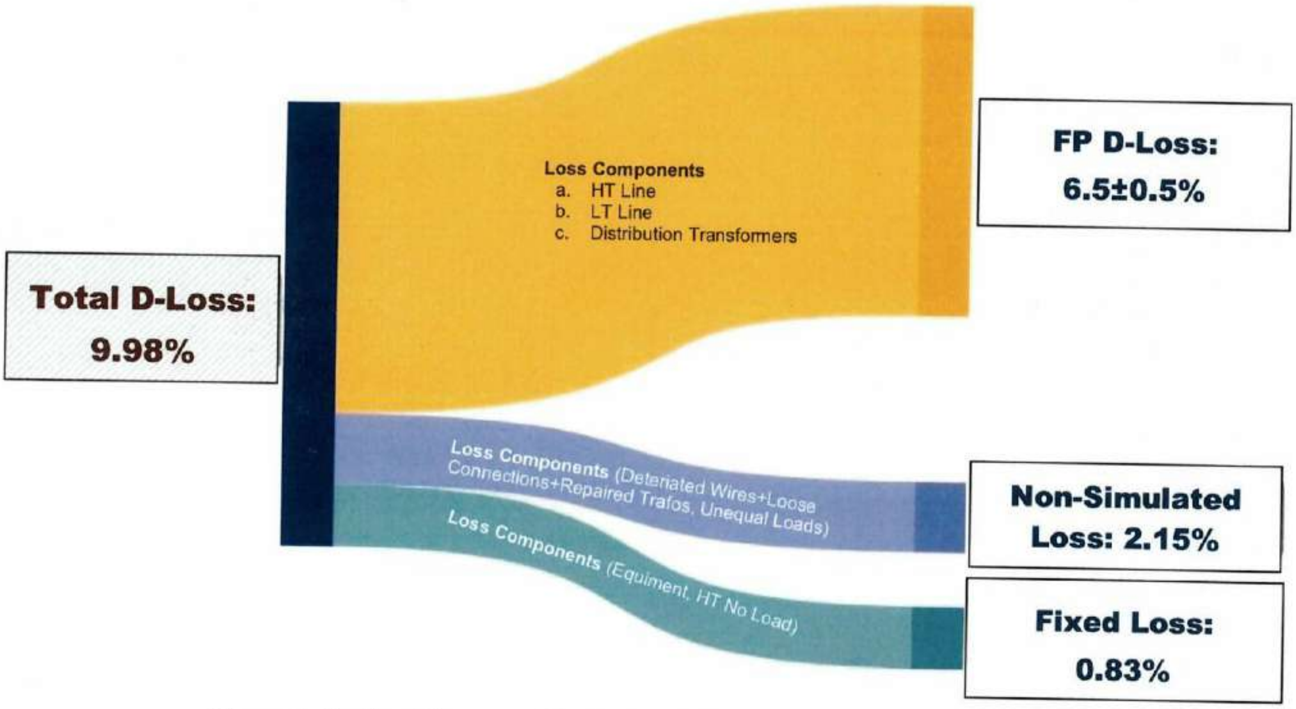


Figure 1: Sankey Diagram of KE Network Component Wise Distribution (D) Losses