PERFORMANCE IMPROVEMENT OF OLD DISTRIBUTION TRANSFORMER ASSETS

Report on Active Repair for Performance Improvement of Old Distribution Transformer for TANGEDCO

February 2020

International Copper Association India
Copper Alliance

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1. About the Research Concept

Transformers play a crucial role in the power distribution network. After overhead distribution lines, transformers are the second largest loss-making equipment in electricity networks. Distribution Transformer (DT) is one of the critical and high value CAPEX assets for DISCOMs. For overall DISCOM viability, it is important that each DT must turn into a profit centre. It is estimated that out of 20%[1] national average AT&C losses, at least 3-4%[2] comes from Technical losses in DTs, and it can be brought down to 0.5% and below. Earlier RAPDRP program envisaged feeder energy audits however, there was no separate loss estimation for DT alone. Unfortunately, DT technical losses are not generally measured unless it breaks down and only broken-down DTs are sent for repair. There is minimum to none pro-active asset management approach to DT, it's repair and O&M.

DT failure rate is one of the important Key Performance Indicator (KPI) for Indian DISCOMs. The losses associated with DT failure are relatively higher in the Indian context compared to the global benchmark. In India, 12-15%[3] DTs fail every year and average rate of failure of aluminium wound DTs is more than copper wound DTs. Overloading is cited as one of the root causes of DT failure besides various other reasons. DTs are frequently overloaded during seasons than their actual capacity resulting in deterioration of their operating health and eventually its lifespan. Any failure of the DT before the expiration of its designed lifespan (25 years by CEA guideline[4]) results in an unplanned outage, production loss, unavailability of critical services and in most cases substantial financial losses to both utilities and customers. Overall, it affects the reliability of the network.

Considering the current financial state of DISCOMs, performance improvement in DT becomes a crucial factor in protecting DISCOMs from further losses. Currently, due to lack of funds to procure new DTs, utility operates the DTs beyond their useful life by inefficiently repairing it several times, resulting in lower efficiency of operation. All these result in reduced efficacy of DTs and high technical losses in the distribution system. Therefore, DISCOMs need to utilize their existing old DTs cost-effectively to get the best out of it. There is a need to save the DISCOMs from the financial burden of investing in the procurement of new DTs to meet the currently growing energy demand.

Realizing the need to improve reliability of DTs, one opportunity to be explored is by improving the performance of DTs through better-quality repair practices. The proposed performance improvement repair practice will give new extended life to the old DTs and enhance their performance equivalent to Energy Efficiency Levels specified by BIS. In this context, a Proof of Concept (PoC) was carried out at TANGEDCO on a 100 kVA DT for performance improvement repair options.

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[1] UDAY Portal

[2] Based on multiple primary interactions with industry experts

[3] Presentation made before CEA 28th Feb 2019 based on study conducted by Frost & Sullivan

[4] Standard Bidding Document of DDUGVY under Guidelines for Distribution Utilities for development of Distribution Infrastructure, Page 45, June 2018

2. About the pilot

A proposal to utility for proof of concept (PoC) is submitted on the pilot focuses on developing a mass replicable approach to undertake repairs of legacy DTs (old or conventionally-repaired failed DTs) coming for service and bring down the technical losses and enhance reliability. With mass replicability objective, the core, if healthy, is decided to be kept unchanged and all correction to be effected through windings redesign and/or change of material. The core is restacked tightly to reduce air gaps between laminations.

Under this PoC (confirmed by utility under its MoU dated 21st October 2019 – annexure 1), pre-repair testing, repair execution & post-repair testing activities were conducted at places (including the NABL lab) suggested by TANGEDCO under it's (R&D Dept) direct supervision. The Repair involved correcting loss levels of the DT & bringing it closer to the ideal values as specified by Indian Standards for similar type of DTs. After conducting baseline measurement, different design solutions were worked out, post which Repair was undertaken based on optimum design that is techno commercially viable.

No Load Losses, Full Load Losses and Temperature Rise Tests were carried out under the supervision of TANGEDCO representative and ICA experts. Technical loss reduction and post repair kVA capacity enhancement was further validated by NABL accredited lab tests. Experts & team recorded data for analysis of No-load loss & Full load loss post repair and some key conclusions were made as mentioned below:

- Reduces technical losses, thereby saving power costs
- Improves efficiency of transformers, a key component of distribution network stated in the objective of BEE in PAT-2 cycle
- Improves transformer reliability, thereby reducing downtime
- Increases kVA capacity of the transformer that helps DT sustain overloading condition; thus, deferring fresh capex investment to meet load growth locally
- Cost-benefit analysis suggests payback period of less than 2-3.5 years based on OPEX model
- Incremental repair cost is lower by 50-60% than its equivalent new DT procurement cost with similar performance
- Creates an opportunity for the DT OEM or repairer to become a stakeholder in network O&M
- Controls the recurring losses by improved reliability of DTs

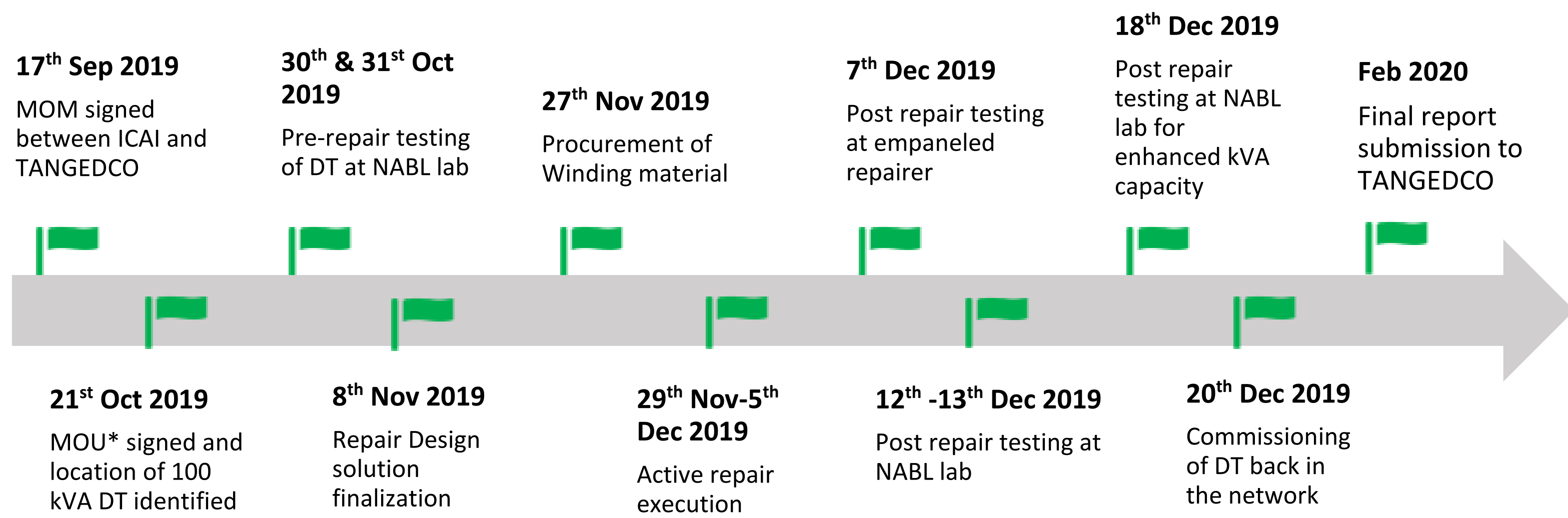
Thus, proposed Active Repair concept has the potential for improving the Energy Efficiency and reliable performance of Distribution Transformer.

3. Methodology

A step-by-step approach was adopted during the Repair execution to ensure checks & validation at each level (See below methodology)

DT selection	Pre Repair testing	Design Options & Finalization	Repair Execution	Post Repair Testing	Reporting
▪ Requested conventionally-repaired DT, nominated by TANGEDCO R&D wing, from authorized Repair Centre for PoC	▪ Loss levels were measured at empaneled repairer and at NABL accredited lab in presence of TANGEDCO representatives	▪ Multiple design options were prepared, and commercial viability assessed ▪ Final Design Option was reviewed & approved by TANGEDCO team	▪ Undertook repair based on finalized design based on performance improvement repair options	▪ Loss was measured at empaneled repairer in presence of TANGEDCO representatives ▪ The results were further validated by NABL accredited lab by conducting loss and impedance measurement test and temperature rise test	▪ Test results were recorded & reported to TANGEDCO
					

4. Timelines



**Please Refer Annexure- 1 for MoU signed between TANGEDCO and ICAI*

5. Repair Execution for performance improvement of 100 KVA old DT

The Active Repair executed envisions to achieve lowest losses and kVA capacity enhancement of existing repaired DT sample. The focus is on reduction of full load losses (as most of DTs are reported to be loaded 80% and above) and thereby getting maximum possible efficiency, as well as the capability to perform under overloading conditions. Design of existing HV has been altered with use of copper, being mechanically and electrically superior, as winding material while LV winding material has been kept unchanged (i.e. Aluminium).

5.1.1. 'Baseline' measurement

The below table summarizes key baseline parameters, measured at NABL lab, of acquired failed 100kVA DT and its related details:

Parameters	Units	GTP Values	Test Value	% Deviation from GTP values
Capacity	kVA		100	**-**
Make			KEL	-
Year of Mfg.			2010	-
Sr. No.			64428	-
LV winding material			Al	-
HV winding material			Al	-
Total Winding Weight	kg		46.62	-
Impedance	%	5.06	4.40	-
No load loss	Watts	260	474.74	82% higher
Full load loss	Watts	1760	2067.60	17% higher
Total loss	Watts	2020	2542.00	26% higher

Table 1. Key Baseline Parameters of Distribution Transformer-100kVA

**Kerala Electrical and Allied Engg. Co. Ltd*

5.1.2. Solution Design

Based upon the baseline measurements, design options for repairs was worked out initially. Thereafter, in consultation with TANGEDCO R&D team & design experts they were finalized as below:

Rating	Solution Design	Core unchanged	Designed LV winding (Material, ID, OD, Height)	Designed HV winding (Material, ID, OD, Height)	Estimated No load Loss as per design (Watts)	Estimated Full load Loss as per design (Watts)	Estimated Total Loss as per design (Watts)
100 kVA	LV Al & HV Cu (Reduced losses; increased kVA)	Yes	Al, 122, 163, 408	Copper, 183, 243, 383	474 (with existing core used)	1700	2174

Table 2. Design Solution finalized for ActiveRepair-100kVA

5.1.3. Active Repair Execution

5.1.3.1. Pre-repair testing

The execution process was undertaken with pre-repair testing of failed DT *(see Annexure-2 for detailed Pre-repair test report)* No-load loss value and full load loss value was measured. The testing was undertaken in presence of TANGEDCO representative as per IS 2026 at NABL lab. Some images are shown below:

Figure 1. Acquiring conventionally repaired DT

Figure 2. Dismantling and inspection of transformer

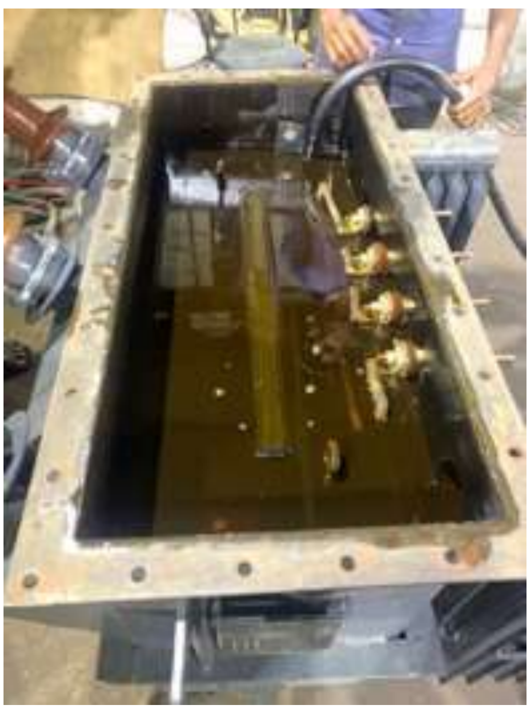


Figure 3. Pre-repair condition of coil

Figure 4. Pre-repair coil sectional view

Figure 5. NABL Pre-repair Testing with TANGEDCO representatives

Figure 6. TANGEDCO representative & team recording the data

5.1.3.2. Repair Activity

After pre-repair testing, the Active Repair was undertaken as per finalized designs. Sequence of repair activities which was undertaken reflecting best practice norms is as follows:

- Unstacking of core laminations and restacking them tightly to reduce air gap between laminations
- Procuring right kind of material for winding
- Providing oil flow duct while preparing winding sections
- Making LV and HV winding as per design specification and assembling
- Assembled transformer was moved for oven drying to remove moisture
- Eventually, oven dried transformer was placed in tank as final assembly

Some images during the process are shown below:

Figure 7. LV winding

Figure 8. HV winding

Figure 9. Core and coil assembly

Figure 10. Final repaired DT ready for post repair testing

5.1.3.3. Post Repair Testing

After repair, post repair testing was undertaken in presence of TANGEDCO representative as per IS 2026 *(see Annexure-3 for detailed Post-repair test report)* . Some images are shown below:

Figure 11. Setting up connections for testing

Figure 12. Post Repair testing and recording measurements

Figure 13. Post Repair Testing at NABL lab

Figure 14. Setting up connections for enhanced capacity testing at NABL

Figure 15. Testing at NABL on 13-12-2019 SE R&D with the team

Figure 16.Testing at NABL on 12-12-2019 CE R&D with the team

Figure 17. Testing for enhanced capacity testing at NABL

Figure 18. Final repaired DT ready for reconnecting in the network

After conducting all tests, results were obtained for various parameters in reference to the baseline measurements. Post-repair enhanced capacity testing was further validated by NABL by conducting loss, impedance measurement and Heat Run tests. The capacity enhancement of 8 kVA was noted. The transformer losses at enhanced capacity of 108 kVA was also measured and heat run test was conducted at this enhanced capacity (see annexure 3a post repair enhanced capacity test report). Following are the results obtained:

Key Design Parameters	Unit	Specification	Baseline (As-Is)	Post repair results (measured at NABL)	Post repair results measured at enhance kVA capacity at NABL
Capacity	kVA	100.00	100	100	108
Year of Manufacturing		-	2010	-	
Flux Density	Tesla	1.55	-	-	
LV Winding Material		-	DPC Al	DPC Al	DPC Al
HV Winding Material		-	DPC Al	DPC Cu	DPC Cu
No Load Loss	Watt	260	474	472	472
Full Load Loss	Watt	1760	2067	1559	1833
Total Loss	Watt	2020	2542	2035	2306
Impedance	%	5.00	4.40	4.54	4.64

Table 3. Comparative Pre and Post repair results

5.1.4. Post Repair reconnection of DT in the network

Post Repair and testing the DT was collected back from NABL lab. It is immediately connected back in the network at CEDC Chengalpet Electricity Distribution Circle and commissioned. Energy meter was also connected on LT side along with the DT erected in the pole.

Figure 19. Collecting Active Repaired DT from NABL lab

Figure 20. Removing existing DT for replacing it with Active Repaired DT

Figure 21. Connecting Active Repaired DT back into the DT at Chengalpet Electricity Distribution Circle

Figure 22. APFC Panel and Energy Meter connected at pole

5.1.5. Cost-Benefit Analysis

5.1.5.1. Top Results

Summary of Cost Benefit Analysis (CBA) is indicated below. The detailed CBA and assumptions are attached separately *(Please refer Annexure-4).*

Parameter		Unit	Value
Total Normal Repair cost (with Al winding)	A	Rs.	**22,946**
Labour and transportation cost		Rs.	2,700
Material cost (Rs. 304/kg for DPC Al/kg)		Rs.	20,246
Total Active Repair cost (HV-Cu, LV-Al)	B	Rs.	**68,930**
Labour and transportation cost		Rs.	2,700
Material cost (Rs. 304 for DPC Al/kg + Rs.635 for DPC Cu/kg)		Rs.	66,230
Incremental cost for To-Be Active Repair over and above Normal Repair	C=B-A	Rs.	**45,983**
Yearly units saved over baseline		kWh/year	2,198
Money saved in 10 years		Rs.	2,04,933
Payback period		years	**3.20**

Some key assumptions made for payback calculations:

1. DT loading – 70% (for urban area as per the TOC formula recommended by CEA)
2. Average Cost of Supply (ACoS)of 5.85 Rs. /kWh[5]
3. 10% CAGR assumed for Average Cost of Supply[6]
4. Normal As-Is repair cost for 100 kVA Al DT is INR 22,946 (as per base price of Discom)
5. Incremental repair cost over and above normal repair is used for payback calculation. (The labour rates for repair remain similar to that of Normal repair)

[5] TNERC Tariff Order 2017-18, Page no. 292

[6] This trend has been seen across Discoms from states (like Maharashtra, MP) and hence a normalized value of 10% is assumed

6. 70% term loan assumed with 9.93% rate of interest[7]

5.1.5.2. Scenario Analysis

A sensitivity analysis determines how different values of an independent variable affect a particular dependent variable under a given set of assumptions. In other words, sensitivity analysis study shows how various sources of uncertainty in a business economy model contribute to the model's overall uncertainty. For example, we have calculated the sensitivity of CAGR of Avg. Cost of Supply to payback period by changing the values of %CAGR while keeping all other values same.

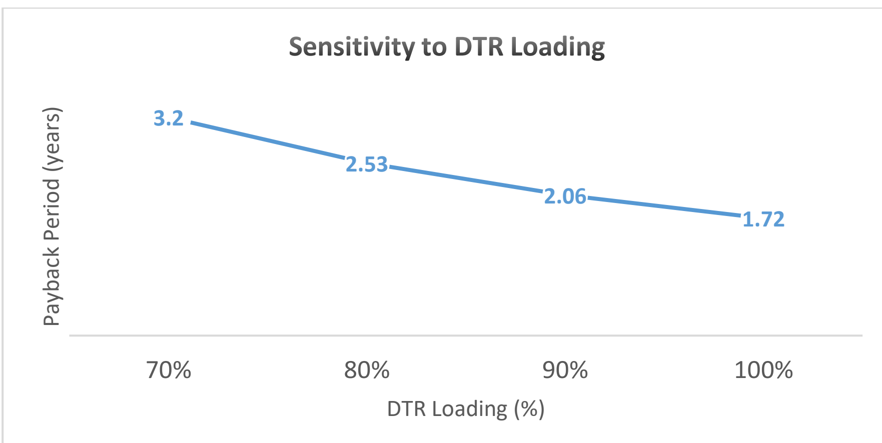
Sensitivity to **CAGR of Avg. Cost of Supply**

Solution	Payback period (years)		
	For 0% CAGR	**For 5% CAGR**	**For 10% CAGR**
	3.58	3.37	**3.20**

Sensitivity to **DTR Loading**

As case for increasing DTR load, payback period will further reduce

Solution	Payback period (years)			
	70% DTR Load	**80% DTR Load**	**90% DTR Load**	**100% DTR Load**
	3.20	2.53	2.06	1.72



Sensitivity to **increased kVA capacity**

If an additional benefit of increased kVA capacity (**108 kVA from 100 kVA**) is considered, then payback will reduce further.

Solution	Payback period (years)	
	Increase in kVA capacity not considered	**Considering Increase in kVA capacity**
	3.20	**2.19**

[7] Power Utilities operate with a debt equity ratio of 70:30 as per national tariff policy. Hence the 70% loan is considered.

Sensitivity to **Salvage value of Cu at the end of service Life**

The salvage value of Cu does not impact the payback but improves the Project IRR (Internal Rate of Return). *Please refer Annexure-5 for detailed analysis of IRR*

	Project IRR (%) without Cu Salvage value	Project IRR (%) with Cu Salvage value
@ACoS 5.85 Rs./kWh		
100kVA	44.42	45.81

6. Key Observations

Following are some key observations drawn from tests and cost benefit analysis:

1. Old DT has high technical losses with large deviation from spec values as seen from pre-repair testing:

No Load Loss	+82%
Full Load Loss	+17%
Total Loss	+26%

2. Repair does help in technical loss reduction (compared to baseline values). Total loss was reduced by 26% from the baseline.

3. Actual Repair results were close to the design estimations and even better than expected

	Assumed Designed values	Actual observed (at NABL)
	For 100 kVA	
Total Loss (W)	2,174	2,035

4. Cost Benefit Analysis is as follows *(Please refer Annexure-4)*

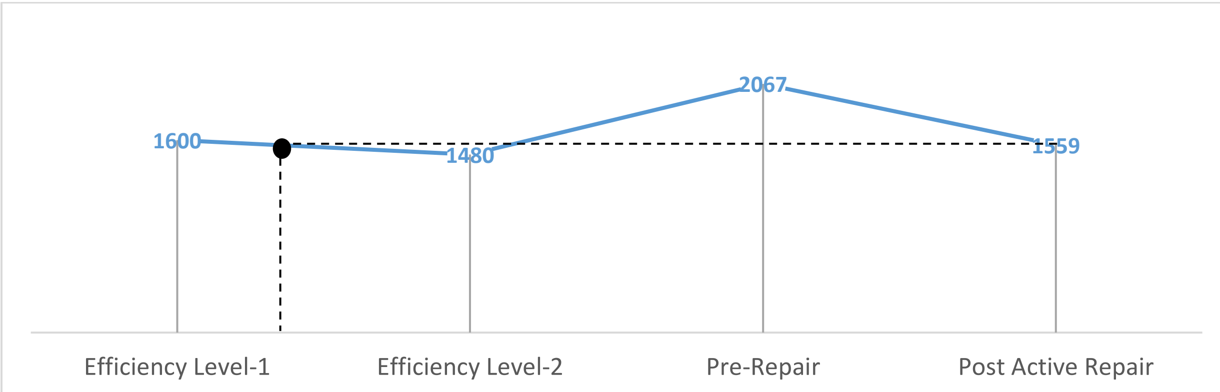
Payback Period (Yrs.)	
Without kVA Enhancement	3.20
With kVA Enhancement	**2.19**

4.1. In additional sensitivity analysis carried out shows possible **1.72-2.19 years' payback period with capacity enhancement** *(as seen in section 5.1.5.2)* for real life assumptions, indicating high potential opportunity.

5. It is evident from the Post repair test results that, in addition to the increased efficiency the continuous loading ability/capacity of 100kVA Transformers is increased to 108kVA without affecting the Temperature Rise limits & Impedance Parameters as per IS 2026.

6. The design values and actual post-repair loss are fairly close and lower than the design. At 108 kVA the temperature rise values are lowered but the test value was marginally above the IS limits. Hence it can be inferred that DTs can have a baseline for technical losses at on-site. Thus, the close estimation of 'To-Be' loss levels and associated CBA can be undertaken. Further, business as usual repair practices do not address the issue of higher losses thus causing further deterioration in efficiency level post repair.

7. **Upgradation of old DTs**: Active Repair enhances the performance of the old DT to a level closer to Energy Efficiency Level-1 loss stipulated as per IS 1180 at 100% loading. The post active repair full load losses have been compared with full load loss computed at 100% loading (with reference to no-load loss computation done by PGVCL (Gujarat Discom)). *(Please refer Annexure-6 IS 1180 relevant efficiency page)*



7. Key Recommendations

1. **Modify existing in-house or contracted DT repair process:** DTs being repaired in-house should go through a process change to improve the repair practices. Some suggested changes are:
   a. Pre-repair testing of DTs to be done to check the loss levels. This may not be feasible in failed DT except for no load loss assessment. It is recommended to carry out no load test at rated voltage with healthy LV/dummy LV turns to ensure that the no load losses do not exceed 1.5 times the original no load losses measured as per IS 2026 (Part 1). In case, if no load losses exceed 1.5 times the original no load losses, the transformer should be redesigned or transformer core to be scrapped. It is also recommended to measure the resistance of any one Healthy LV & HV Coil & calculation for estimation of approximate Full load Loss can be done thereof.
   b. DTs to be opened to check for core/ winding damage
   c. Design improvement option to be explored to enhance capacity and reliability of the DT
   d. Winding replacement to be done by using standard material (preferably copper)
   e. Provide adequate ducts in the windings, to ensure effective cooling and reduced temperature rise.
   f. Post repair testing to be conducted to measure losses and at times temperature rise test to be conducted on sample active repaired DT to check capacity enhancement
   g. On a sample basis, repaired DTs to be tested at NABL accredited lab
   h. Internal painting should be mandatorily done to reduce the stray losses through tank

2. **Introduce performance-tied repair contract:** DTs being repaired by the vendors (outsourced) must be tied with its performance. A performance-tied repair contract needs to be drafted for improvement in the loss levels/kVA capacity of the DT. Under this contract, repairer will have to improve the DT

performance (i.e. losses) by certain percentage, which on achievement will gain incentives to repairer whereas underachievement will be liable to penalty.

3. **Strengthen Repair Standard Operating Procedure (SOP) for repair:** A standardized repair practice must be followed for efficient repair of DTs. Strengthening the SOP shall benefit the DISCOM in acquiring good quality repaired DTs, thereby increasing its operational life in the network. In addition, these repaired DTs shall perform equivalent to new procured DTs and help DISCOM in reducing procurement costs.

4. **Proactive preventive maintenance:** Continue implementation of periodic condition monitoring of DTs. This effort definitely helps Discom monitor the health of DTs for effective asset management.

5. **Monitor and control DT loading through remote metering** of DTs and selective APFC installation for mitigating re-active load on the DTs. Supervision with monitoring DTs' health on a continuous basis including periodic checks on the loads and load pattern will enhance their life and ensure continuous performance near to designed parameters.

8. Applicability to broader TANGEDCO Utility

1. TANGEDCO is the large power distribution company in India, catering State of Tamil Nadu, with total DTs count of 2,93,301. The AT&C losses is around 13.64% as per UDAY portal.
2. The above concept has been explored for sample DT only. However, depending on the condition of old DTs, some of them may have to be scrapped while some of them can be repaired under this concept.
3. Also, the concept involves costing which may be different for different manufacturers depending on the design specifications.
4. There can be other business models like incentivizing vendors to reduce NL and FL losses below ideal values, etc. with payback period ranging from 1-2.3 years.
5. Based on the estimation of loss deviations (based on the **assumptions** that legacy DTs at TANGEDCO currently have No-load loss deviation of 15% and full load loss deviation of 30%) of Discom data and representing at TANGEDCO level, it is observed that DTs contribute ~5.22% of technical losses at overall utility level, resulting into 2,257 Cr. loss (assuming avg. cost of power supply as 5.85 kWh/unit). *(Please refer Annexure-7)*

	Scenario 1 (if DTs perform as per specs)	Scenario 2 (if DTs are at acceptable loss levels)	Scenario 3 (if losses are high deviated from spec)	Scenario 4 (if DTs are Active Repaired with reduced losses)
%loading	70%	70%	70%	70%
%deviation of No-load loss	0%	15%	15%	10%
%deviation of Full load loss	0%	15%	30%	-30%
Estimated total losses (MUs/year)	3,391	3,730	3,859	2,696

% Total losses with respect to energy input	4.58%	5.04%	**5.22%**	3.65%
Total DT technical losses (Cr.)	1,983	2,182	2,257	1,577

Assumptions		
Total Transformers	#	2,93,301
Avg. Loading	%	70%
Avg. Cost of power supply	kWh/unit	5.85
Total revenue of TANGEDCO (as per ARR)	Cr.	43,686
Energy Input (as per ARR 2017-18)	MU/year	73,761

6. If 5.22% technical loss can be brought down to 3.6% (based on best performing utility's standard) through effective & DT repair & maintenance, it can save nearly INR 680 Cr. per year (approx. 1.5% of Avg. revenue)

6.1. Even if only 100 kVA DTs (assuming 1,10,000 DTs i.e. ~37% of the MVA capacity) are Active Repaired it can save nearly **~200 Cr./year**

- **Old conventionally-repaired DTs have potentially higher technical losses than being thought (i.e. ~5.22%) causing loss of INR 2,257 Cr. annually.**
- **Performance Based Repair has the potential to reduce the technical losses and upgrade the DTs performance equivalent to Energy Efficiency levels as specified by IS 2026. It can save nearly INR 680 Cr. per year (approx. 1.5% of Avg. revenue)**

Annexures

Annexure-1: MoU signed between TANGEDCO and ICAI

भारतीय गैर न्यायिक

एक सौ रुपये Rs. 100

रु. 100 ONE HUNDRED RUPEES

सत्यमेव जयते

भारत INDIA

INDIA NON JUDICIAL

தமிழ்நாடு तमिलनाडु TAMILNADU BV 872565

21-10-19 INTERNATIONAL COPPER ASSOCIATION INDIA. MUMBAI.

L. No: 2, / CGL / 2010

Memorandum of Understanding (MOU)

This MOU between Tamil Nadu Generation and Distribution Company Limited (TANGEDCO) Chennai and International Copper Association India (ICAI) Mumbai is to carry out study in improving energy efficiency, reliability and life cycle management of Distribution Transformers (DTs).

ICAI has shared one proposal for undertaking a proof of concept to demonstrate effectiveness and viability of active repair of legacy DTs. The scope of the study is enclosed herewith.

This MOU entrust both organizations to engage in knowledge in DT life cycle management.

For TANGEDCO

21/10/19

Chief Engineer/IC,R&D

21/10/19

Superintending Engineer/R&D

21/x/19

Executive Engineer/R&D

Date: 21.x.19

For ICAI INTERNATIONAL COPPER ASSOCIATION INDIA

21/10/19

Manas Kundu

Designation: Director (Energy Solutions)

Date: 21st Oct' 19

Proposal for Technical Loss Reduction & Reliability Improvement in Distribution Transformers via Active Repairs

Proof of Concept (PoC) study for TANGEDCO

Background

Power Distribution in India is facing multiple challenges - increasing power demands, increasing energy costs, higher operating costs, higher losses and rising consumer Tariffs. Loss reductions (both Technical and Commercial) become one critical intervention for course correction. Commercial loss reduction has taken utility's greater attention, particularly in respect of legacy assets in the system – one critical of them being Distribution Transformers.

Proof of Concept (PoC) Introduction:

With this background, International Copper Association India (ICAI) has developed a concept to reduce Technical Losses & Improve Reliability in Distribution Transformers via Active Repair approach. It intends to establish this new Business Model with a Proof of Concept (PoC) for TANGEDCO, and hence this proposal is evolved.

M/s ICAI has proposed a study on Reliability Improvement and Technical Loss Reduction via active repair experiment. The process of active repair involves the replacement of HV-Aluminium winding available in the 100kVA Distribution Transformer by a copper winding optimally designed for the same core. If needed, the LV winding would also be replaced with an optimally designed Aluminium winding to increase the capacity of the Transformer.

Objective of the PoC

- Validation of Technical loss performance of DT in two stages - pre and post Active Repair
- Calculation of savings generated in units of electricity due to reduction in technical losses vs. active repair solution and costs
- Calculation of possible enhancement in the capacity of the Transformer by extrapolation of results and then validating the enhancement by additional test result.

DTs Selection for PoC

- **Location:** One DT from Chenglepet circle of TANGEDCO is considered for active repair.
- **Identification of DT:** It shall be carried on 1 number DT of 11kV/433V, 100kVA capacity (Make: KEL; Sl No: 64428; Year of Manufacturing: 2010).

PoC Roles & Responsibilities

- The suggested roles for the various agencies involved in this PoC implementation are enclosed in the Annexure.

Terms and Conditions

- **Funding** – This PoC phase shall be fully funded by ICAI. There will be no Financial commitment for TANGEDCO.
- **Repair Warranty** – The DTs shall be covered with repair warranty terms and conditions for one year by ICAI. ICAI agrees to replace the copper HV winding with a Aluminium winding and bear the cost of repair, if the active repaired Transformer fails within the above warranty period.
- **Time for repairs** – Total repair time is estimated around 6-8 weeks.
- **Co-operation** – TANGEDCO Technical / Operations team will extend the required coordination for timely start and close of the PoC.
- **Selection of Repair vendor** – Active repair work on the identified Transformer shall be carried out by M/s ICAI at M/s. Sakthi Transformers, Plot No 10-11, Sharma Nagar, Kundrathur, Thiruneermalai Main Road, Chennai-69 at the cost of ICAI.
- **Pre and Post Repair testing** – The active repaired Transformer will be pre and post tested for No Load Loss, Load Loss @ 50%, 70% and 100%, Heat run at the NABL facility - M/s Shree Abirami Enggineering Works, Pillaipakkam, at the cost of ICAI.
- **Released Aluminium Winding** – During active repair, M/s ICAI shall handover the released windings of HV and LV (if replaced) of the Transformer to TANGEDCO.

For TANGEDCO

Chief Engineer/IC,R&D

Superintending Engineer/R&D

Executive Engineer/R&D

Date: 21.x.19

For ICAI

INTERNATIONAL COPPER ASSOCIATION INDIA

By: Manas Kundu

Designation: Director (Energy Solutions)

Date: 21st Oct '19

ANNEXURE - ACTIVITIES INVOLVED IN THE PoC STUDY

Sl No	Activity	Work done by	Expenditure to be met by
1	Transporting the Transformer to the repair factory	ICAI	ICAI
2	Confirming the healthiness of the Transformer at the repair factory by relevant tests	Repair factory	ICAI
3	Shifting the Transformer to a NABL Testing facility	ICAI	ICAI
4	Conducting the No Load Loss, Load Loss at 50%, 70%, 100% and Heat run test	NABL Facility	ICAI
5	Witnessing the Test at NABL Facility	ICAI, TANGEDCO (CEDC,R&D)	-
6	Shifting the Tranformer back to Repair Factory	ICAI	ICAI
7	Opening the Transformer and completing the active repair	Repair Factory	ICAI
8	Confirming the healthiness of the Transformer at the repair factory	Repair Factory	ICAI
9	Shifting the Transformer to a NABL Testing facility	ICAI	ICAI
10	Conducting the No Load Loss, Load Loss at 50%, 70%, 100% and Heat run test	NABL Facility	ICAI
11	Witnessing the Test at NABL Facility	ICAI, TANGEDCO (CEDC,R&D)	-
12	Ensuring the enhanced capacity of the Transformer by extra-pulation based on the test result	ICAI, TANGEDCO (CEDC,R&D)	-
13	Confirming the enhanced capacity by doing heat run test again.	NABL Facility	ICAI
14	Witnessing the Test at NABL Facility	ICAI, TANGEDCO (CEDC,R&D)	-
15	Shifting the Tranformer back to Chenglepet EDC and re-erection	ICAI	ICAI
16	Preparing the study report	ICAI, TANGEDCO (CEDC,R&D)	ICAI

CE/IC R&D

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21/10/19

TANGEDCO/Chennai

Annexure 2: Snapshot of Pre-Repair Test Report conducted at NABL

IMPULSE TEST LAB
(Shree Abirami Engineering Works)
Survey No: 22/1 & 22/2, Sriperumbudur A Village,
Kodambakkam - Sriperumbudur High Road, SH 113,
Near TVH Svaya Apartments, Sriperumbudur -602 105.
Phone No: 044-27176120 E-mail: 2400katti@gmail.com
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)
REPORT NO: SAEW/ITL/2019-20/N-005 **DATE:** 01-11-2019

TEST REPORT

Name & Address of the Customer: International Copper Association India 302, Alpha, Hiranandani Business Park, Powai, Mumbai – 400076	**Report No.** : SAEW/ITL/2019-20/N-005 **Date** : 01-11-2019	**Location of Testing:** Impulse Test Lab
	Customer Ref No with date:	**Date of Sample Receipt:**
		25-10-2019
	Condition of the sample at time of receipt:	**Date(s) of Testing:**
	Good	30 & 31-10-2019
Sample Description : **Make:** KEL **Power Rating :** 100kVA **Voltage Rating :** 11000V/ 433V **Current Rating :** 5.24A / 133.33A **Detailed Description:** In Sheet No. 2	**Sample Identification:** N-005 **ITL Sample No :** SAEW/ITL/2019-20/N-005 **Manufacturer Serial No :** 64428 **Make :** KEL **Year Of Manufacture :** 2010 **Enclosed Drawing Numbers :** NIL	
Test Details: In Sheet No. 3	**Sample Technical Specification:** In Sheet No. 2	
Test Results: Sheet No. 4 to Sheet No. 10		
Enclosure: Photographs of test samples – Sheet No.11 and Sheet No.12		
Remarks: **NIL**	**Details of the Witnessing Officer**	

PREPARED BY **CHECKED BY** **APPROVED BY (K CHANDRASEKAR)**

NOTE: 1. This report only relates to the particular sample received for testing in good condition at ITL, Sriperumbudur.
2. This report cannot be reproduced in part under any circumstances.
3. Publication of this report requires prior permission in writing from ITL.
4. Only the tests asked for by the customer have been carried out.
5. In case of any dispute, Sriperumbudur will be the exclusive jurisdiction & shall be constructed as where the cause has arised.
Caution: ITL is not responsible for the authenticity of photocopied or reproduced test reports.
ITL provides support to consumers for verification of the authenticity of test reports issued by ITL.

TECHNICAL SPECIFICATION OF TEST OBJECT ASSIGNED BY CUSTOMER

1	Name Of the Manufacturer	Kerala Electrical and Allied Engg. Co. Ltd
2	Serial Number	64428
3	Power Rating(kVA)	100
4	Rated Voltage H.V (Volts)	11000
5	Rated Voltage L.V (Volts)	433
6	Rated Current H.V (Amps)	5.24
7	Rated Current L.V (Amps)	133.33
8	Number Of Phases	3
9	Energy Efficiency Level	-
10	Vector Group	Dyn11
11	Winding Material	Aluminum
12	Type Of Cooling	ONAN
13	Frequency(Hz)	50
14	Guaranteed Percentage Impedance(3)	5.06
15	Guaranteed No Load Loss(Watts)	-
16	Guaranteed Load Loss at 75°C (Watts)	-
17	Total Loss at 50% Load (Watts)	-
18	Total Losses at 100% Load (Watts)	-
19	Guaranteed Temperature rise of Oil	45°C
20	Year of Manufacture	2010
21	Standard No:	IS 2026 / IEC 60076 / CBIP

1.MEASUREMENT OF WINDING RESISTANCE

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026 (Part 1): 2011 (Clause 10.2) IEC 60076-1/Edition 3.0):(2011-04) (Clause 11.2) CBIP Manual Pub.No.317/2013(Sec. BB 3.1)	SAEW/EQ/34	Transformer winding resistance meter (Prestige)	PE/040/SEP/2018
	SAEW/EQ 05	Infrared Thermometer(Metrix)	02979373

Top oil(°C)	28.0	Bottom oil(°C)	26.2	Average(°C)	27.1

A) HV Winding

Tap No	Measured Values (Ω)			R_{Avg}(Ω)	R_{Avg}(Ω) (75° C)
	1U1V	1V1W	1W1U		
NA	24.86	24.38	24.46	24.566	29.233

B) LV Winding

Tap No	Measured Values (mΩ)			R_{Avg}(mΩ)	R_{Avg}(mΩ) (75° C)
NA	2u2n	2v2n	2w2n		
	11.89	12.00	12.27	12.053	14.343

Tap No	Measured Values (mΩ)			R_{Avg}(mΩ)	R_{Avg}(mΩ) (75° C)
NA	2u2v	2v2w	2w2u		
	23.65	23.78	23.90	23.78	28.298

2.MEASUREMENT OF NO LOAD LOSS AND CURRENT

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 1): 2011 (Cl.no.10.5) IEC60076-1(Edition 3.0) :(2011-04) (Cl.no 11.5) CBIP Manual Pub.No.317/2013(Sec. BB 3.3)	SAEW/EQ/12	Digital Power Meter(Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer (Excel power)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a /07b/07c	Current Transformer (Kalpa)	R-133287/17 Y-133288/17 B-133289/17

WINDING EXCITED	HV
WINDING OPENED	LV
HV RATED VOLTAGE (kV)	11
BASE KVA	100
TAP NO	NA
FREQUENCY (Hz)	50Hz

% VOLTAGE	APPLIED VOLTAGE (Line) (kV)	RMS CURRENT in Amps	NO LOAD LOSS in W	
			Measured Loss	Corrected Loss
90	9.873	0.0879	325	325.888
100	11.006	0.1697	475	474.74
110	12.096	0.4548	746	746.246

3.MEASUREMENT OF SHORT CIRCUIT IMPEDANCE AND LOAD LOSS

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 1): 2011 (Clause 10.4), IEC 60076-1(Edition 3.0):2011-04) (Clause 11.4), CBIP Manual Pub.No.317/2013 (Sec. BB 3.4)	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a /07b/07c	Current Transformer (Kalpa)	R-187708/17, Y- 187709/17, B-187710/17
	SAEW/EQ/05	Infrared Thermometer(Metrix)	02979373

WINDING SHORTED	LV
WINDING SUPPLIED	HV
RATED KVA	100

Top oil(°C)	28.0	Bottom oil(°C)	26.2	Average(°C)	27.1

Rated Voltage HV (kV)	11
Rated Voltage LV (kV)	0.433
Rated Current HV (A)	5.24
Rated Current LV (A)	133.33

MEASURING PARAMETERS:

Tap No	Average Current (A)	Average Voltage(line) (V)	Total Power (W)
NA	5.2351	484.08	1769

CALCULATING PARAMETERS:

Tap No	Current in Amps		Resistance at 75°C (mΩ)		I^2R AT 75°C (W)		Total I^2R AT 75°C (W)
	HV WDG	LV WDG	HV WDG	LV WDG	HV WDG	LV WDG	
NA	5.24	133.33	29233	14.343	1204	764.921	1968.921

Tap No	Impedance Voltage(V)	Corrected Power(W)	At Rated KVA (75°C)		%Impedance (% Z)
			Stray Losses (W)	Load Losses (W)	
NA	484	1772	98.697	2067.618	4.40

4.TEMPERATURE RISE TEST

Test Standard	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026 (Part 2): 2010 IEC 60076-2 : 2011 CBIP Manual Pub. no. 317/2013, (Sec.BB 3.8)	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a/07b/07c	Current Transformer (Kalpa)	R-187708/17, Y- 187709/17, B-187710/17
	SAEW/EQ/03	Infrared Thermometer(Metrix)	02979373
	SAEW/EQ/34	Transformer winding resistance meter (Prestige)	PE/040/SEP/2018

A) Total Losses injection

Total Loss feed = No Load Loss + Load Loss = 474.4W + 2067.618W = 2542W=2.542kW

Time	Average Voltage (V)	Average Current (A)	Average Power (kW)	Ambient Temp 1 (°C)	Ambient Temp 2 (°C)	Ambient Temp 3 (°C)	Average Temp. (1+2+3)/3 (a) (°C)	Top oil Temp. (b) (°C)	Top oil Temp. raise (b-a) (°C)
12.30	335.28	6.270	2.543	26.1	26.1	26.0	26.07	28	1.93
13.30	325.83	5.979	2.549	26.1	26.0	26.3	26.13	38.9	12.27
14.30	321.66	5.890	2.547	26.5	26.7	27.0	26.73	49.7	22.97
15.30	320.60	5.825	2.547	27.3	27.6	28.1	27.67	57.5	29.83
16.30	319.76	5.796	2.542	27.0	26.7	28.1	27.27	63.1	35.83
17.30	318.73	5.753	2.536	26.8	26.8	28.1	27.23	67.2	39.97
18.30	316.69	5.715	2.536	26.3	26.2	27.7	26.73	69.6	42.87
19.30	316.90	5.7063	2.542	26.1	26.1	27.5	26.57	71.5	44.93
20.30	316.22	5.696	2.543	26.1	26.3	27.4	26.60	72.5	45.90
21.30	314.93	5.664	2.526	26.6	26.5	27.8	26.97	73.7	47.63
22.30	315.98	5.690	2.538	26.7	26.5	28.0	27.07	74.7	47.63

Measured temperatures at radiator:-Top: 56.8°C , Bottom: 41.2°C

B) Rated current injection

22.30	291.15	5.246	2.164	26.7	26.5	28.0	27.07	74.7	47.63
22.45	291.09	5.248	2.162	26.8	26.6	28.0	27.13	75.4	48.27
23.00	290.65	5.2355	2.146	26.7	26.5	28.0	27.07	75.2	48.13
23.15	290.86	5.2360	2.144	26.8	26.5	28.0	27.10	74.9	47.80
23.30	292.21	5.261	2.163	26.8	26.5	28.0	27.10	74.6	47.50

Measured temperatures at radiator:-Top: 55.7°C , Bottom: 41.2°C

IMPULSE TEST LAB
(Shree Abirami Enggineering Works)
Survey No: 22/1 & 22/2, Sriperumbudur A Village,
Kodambakkam - Sriperumbudur High Road, SH 113,
Near TVH Svaya Apartments, Sriperumbudur- 602 105.
Phone No: 044-27176120 E-mail:2400kvitl@gmail.com
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)

REPORT NO: SAEW/ITL/2019-20/N-005 **DATE:** 01-11-2019

3.MEASUREMENT OF SHORT CIRCUIT IMPEDANCE AND LOAD LOSS

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 1): 2011 (Clause 10.4), IEC 60076-1(Edition 3.0) 2011-04) (Clause 11.4), CBIP Manual Pub.No.317/2013 (Sec. BB 3.4)	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a /07b/07c	Current Transformer (Kalpa)	R-187708/17, Y- 187709/17, B-187710/17
	SAEW/EQ/05	Infrared Thermometer(Metrix)	02979373

WINDING SHORTED	LV
WINDING SUPPLIED	HV
RATED KVA	100

Top oil(°C)	28.0	Bottom oil(°C)	26.2	Average(°C)	27.1

Rated Voltage HV (kV)	11
Rated Voltage LV (kV)	0.433
Rated Current HV (A)	5.24
Rated Current LV (A)	133.33

MEASURING PARAMETERS:

Tap No	Average Current (A)	Average Voltage(line) (V)	Total Power (W)
NA	5.2351	484.08	1769

CALCULATING PARAMETERS:

Tap No	Current in Amps		Resistance at 75°C (mΩ)		I^2R AT 75°C (W)		Total I^2R AT 75°C (W)
	HV WDG	LV WDG	HV WDG	LV WDG	HV WDG	LV WDG	
NA	5.24	133.33	29233	14.343	1204	764.921	1968.921

Tap No	Impedance Voltage(V)	Corrected Power(W)	At Rated KVA (75°C)		%Impedance (% Z)
			Stray Losses (W)	Load Losses (W)	
NA	484	1772	98.697	2067.618	4.40

IMPULSE TEST LAB
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Survey No: 22/1 & 22/2, Sriperumbudur A Village,
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Near TVH Svaya Apartments, Sriperumbudur- 602 105.
Phone No: 044-27176120 E-mail:2400kvitl@gmail.com
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)

REPORT NO: SAEW/ITL/2019-20/N-005 **DATE:** 01-11-2019

4.TEMPERATURE RISE TEST

Test Standard	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 2): 2010 IEC-60076-2 : 2011 CBIP Manual Pub.no.317/2013, (Sect BB 3.8)	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a/07b/07c	Current Transformer (Kalpa)	R-187708/17, Y- 187709/17, B-187710/17
	SAEW/EQ05	Infrared Thermometer(Metrix)	02979373
	SAEW/EQ/34	Transformer winding resistance meter (Prestige)	PE/040/SEP/2018

A) **Total Losses injection**

Total Loss feed = No Load Loss + Load Loss = 474.4W + 2067.618W = 2542W=2.542kW

Time	Average Voltage (V)	Average Current (A)	Average Power (kW)	Ambient Temp 1 (°C)	Ambient Temp 2 (°C)	Ambient Temp 3 (°C)	Average Temp. (1+2+3)/3 (a) (°C)	Top oil Temp. (b) (°C)	Top oil Temp. raise (b-a) (°C)
12.30	335.28	6.270	2.543	26.1	26.1	26.0	26.07	28	1.93
13.30	325.83	5.979	2.549	26.1	26.0	26.3	26.13	38.9	12.27
14.30	321.66	5.890	2.547	26.5	26.7	27.0	26.73	49.7	22.97
15.30	320.60	5.825	2.547	27.3	27.6	28.1	27.67	57.5	29.83
16.30	319.76	5.796	2.542	27.0	26.7	28.1	27.27	63.1	35.83
17.30	318.73	5.753	2.536	26.8	26.8	28.1	27.23	67.2	39.97
18.30	316.69	5.715	2.536	26.3	26.2	27.7	26.73	69.6	42.87
19.30	316.90	5.7063	2.542	26.1	26.1	27.5	26.57	71.5	44.93
20.30	316.22	5.696	2.543	26.1	26.3	27.4	26.60	72.5	45.90
21.30	314.93	5.664	2.526	26.6	26.5	27.8	26.97	73.7	47.63
22.30	315.98	5.690	2.538	26.7	26.5	28.0	27.07	74.7	47.63

Measured temperatures at radiator:-Top: 56.8°C , Bottom: 41.2°C

B) **Rated current injection**

22.30	291.15	5.246	2.164	26.7	26.5	28.0	27.07	74.7	47.63
22.45	291.09	5.248	2.162	26.8	26.6	28.0	27.13	75.4	48.27
23.00	290.65	5.2355	2.146	26.7	26.5	28.0	27.07	75.2	48.13
23.15	290.86	5.2360	2.144	26.8	26.5	28.0	27.10	74.9	47.80
23.30	292.21	5.261	2.163	26.8	26.5	28.0	27.10	74.6	47.50

Measured temperatures at radiator:-Top: 55.7°C, Bottom: 41.2°C

IMPULSE TEST LAB

(Shree Abirami Enggineering Works)
Survey No: 22/1 & 22/2, Sriperumbudur A Village,
Kodambakkam - Sriperumbudur High Road, SH 113,
Near TVH Svaya Apartments, Sriperumbudur- 602 105.
Phone No: 044-27176120 E-mail:2400kvitl@gmail.com
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)

REPORT NO: SAEW/ITL/2019-20/N-005 **DATE:** 01-11-2019

Winding Resistance Test

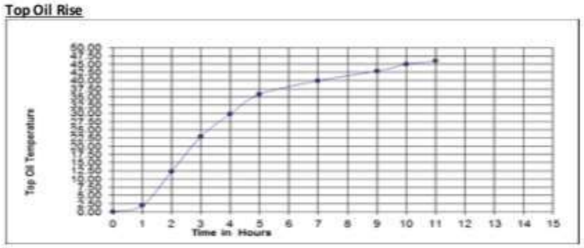
A) **HV Side**

Time	Resistance in Ω
120	30.48
135	30.45
150	30.42
165	30.39
180	30.36
185	30.33
210	30.30
225	30.27
240	30.25
255	30.22
270	30.19
285	30.17
300	30.14
315	30.12
330	30.09
345	30.07
360	30.04
375	30.02
380	30.00
405	29.98
420	29.95
435	29.93
450	29.91
465	29.89
480	29.87

B) **LV Side**

Time	Resistance in mΩ
120	29.93
135	29.93
150	29.92
165	29.9
180	29.87
195	29.85
210	29.82
225	29.8
240	29.79
255	29.77
270	29.75
285	29.72
300	29.7
315	29.69
330	29.67
345	29.65
360	29.64
375	29.65
390	29.63
405	29.63
420	29.62
435	29.6
450	29.59
465	29.58
480	29.56

Top Oil Rise



IMPULSE TEST LAB

(Shree Abirami Enggineering Works)
Survey No: 22/1 & 22/2, Sriperumbudur A Village,
Kodambakkam - Sriperumbudur High Road, SH 113,
Near TVH Svaya Apartments, Sriperumbudur- 602 105.
Phone No: 044-27176120 E-mail:2400kvitl@gmail.com
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)

REPORT NO: SAEW/ITL/2019-20/N-005 **DATE:** 01-11-2019

CALCULATIONS

Drop in average oil temp after reducing to rated current

at Steady state with rated loss

Top oil temp rise = 47.63° C

Ave oil temp rise = Top Oil rise – [Rad Gradient/2]
= 39.83 ° C

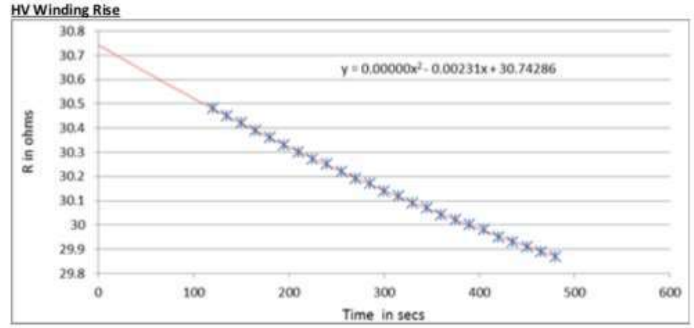
at Shut down with rated current

Top oil temp rise = 47.50° C

Ave oil temp rise = Top Oil rise – [Rad Gradient/2]
= 40.25° C

Drop in average oil temp after reducing to rated current = 0.42° C

HV Winding Rise

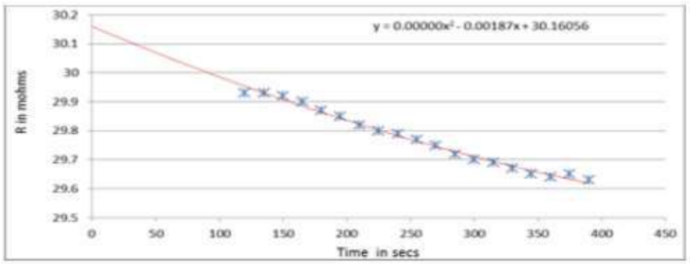


Corrected HV Winding temp rise with rated load = HV Winding temp rise with rated current + drop
In average oil temp after one hour with rated current

= 63.379+ 0.42
= **63.80° C**

IMPULSE TEST LAB
(Shree Abirami Enggineering Works)
Survey No: 22/1 & 22/2, Sriperumbudur A Village,
Kodambakkam - Sriperumbudur High Road, SH 113,
Near TVH Svaya Apartments, Sriperumbudur- 602 105.
Phone No: 044-27176120 E-mail:2400kvitl@gmail.com
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)
REPORT NO: SAEW/ITL/2019-20/N-005 **DATE:** 01-11-2019

LV Winding Rise



Corrected LV Winding temp rise with rated load = LV Winding temp rise with rated current + drop
In average oil temp after one hour with rated current

= 67.64 + 0.42
= **68.06°C**

Result:

	Measured	Guaranteed
Top Oil Temperature Rise (°C)	47.63	45
HV Winding Temperature (°C)	63.80	-
LV Winding Temperature (°C)	68.06	-

IMPULSE TEST LAB
(Shree Abirami Enggineering Works)
Survey No: 22/1 & 22/2, Sriperumbudur A Village,
Kodambakkam - Sriperumbudur High Road, SH 113,
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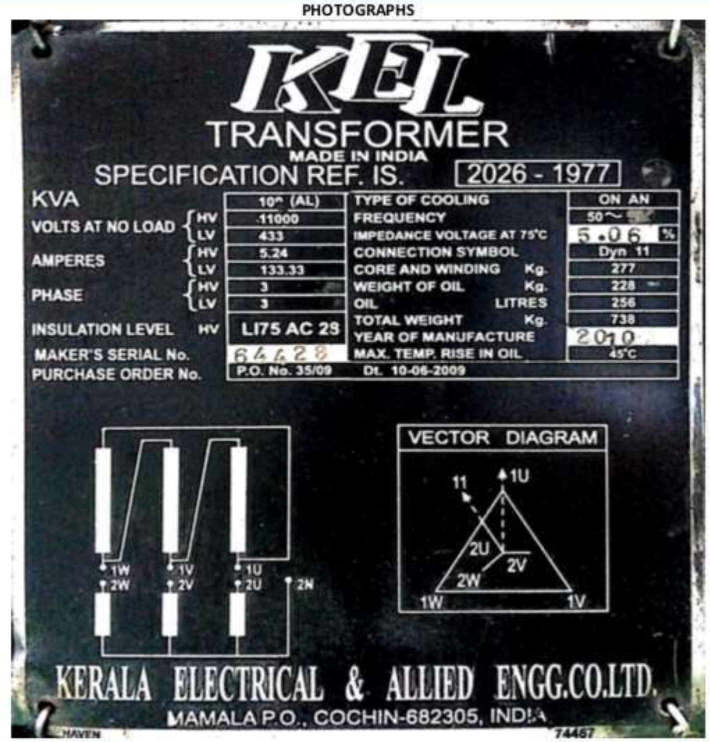
REPORT NO: SAEW/ITL/2019-20/N-005 **DATE:** 01-11-2019

PHOTOGRAPHS



Annexure 3: Snapshot of Post Repair test report conducted at NABL for 100 kVA DT

IMPULSE TEST LAB
(Shree Abirami Engineering Works)
Survey No: 22/1 & 22/2, Sriperumbudur A Village,
Kodambakkam - Sriperumbudur High Road, SH 113,
Near TVH Svaya Apartments, Sriperumbudur- 602 105.
Phone No: 044-27176120 E-mail:2400kviti@gmail.com
Certificate No: TC-7608
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)
ULR NO: TC760819000000016F
REPORT NO: SAEW/ITL/2019-20/N-010 **DATE:** 13-12-2019

TEST REPORT

Name & Address of the Customer: INTERNATIONAL COPPER ASSOCIATION INDIA UNIT 1401-03, WING A, KAILASH BUSINESS PARK, PARKSITE, VIKHROLI, MUMBAI-400079	**Report No. :** SAEW/ITL/2019-20/N-010 **Date** : 13-12-2019	**Location of Testing:** Impulse Test Lab
	Customer Ref No with date:	**Date of Sample Receipt:**
	DT/ICAI/TANGEDCO/NABL/ 19-20 dated 22-10-2019	10-12-2019
	Condition of the sample at time of receipt:	**Date(s) of Testing:**
	Good	12 & 13-12-2019
Sample Description : **Make:** KEL **Power Rating :** 100kVA **Voltage Rating :** 11000V/ 433V **Current Rating :** 5.24A / 133.33A **Detailed Description:** In Sheet No. 2	**Sample Identification:** **ITL Sample No :** N-010 **Manufacturer Serial No :** 64428 **Make :** KEL **Year Of Manufacture :** 2010 **Enclosed Drawing Numbers :** NIL	
Test Details: In Sheet No. 3	**Sample Technical Specification:** In Sheet No. 2	
Test Results: Sheet No. 4 to Sheet No. 10		
Enclosure: Photographs of test samples – Sheet No.11 and Sheet No.12		
Remarks: NIL	**Details of the Witnessing Officer** Er.M.Chandran EE/R&D CHENNAI; Er.R.Usha AEE/R&D CHENNAI; Er.N.Sarathy AE/Op. Maintenance CHENGALPATTU; Er.S.Baskar ICAI	
PREPARED BY	**CHECKED BY**	**APPROVED BY** (R DHILIPKUMAR)

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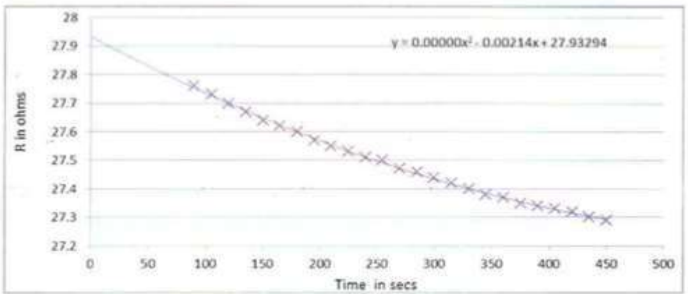
ULR NO: TC760819000000016F
REPORT NO: SAEW/ITL/2019-20/N-010 DATE: 13-12-2019

LV Winding Rise



Cold Resistance measured: 1U1V = 23.60 ohms (R cold)@29.1°C
Hot Resistance observed at shut down (from graph) = 27.933 ohms (R hot)
LV Winding ave temp rise with RATED CURRENT = R hot / R cold x [225 +29.1] – [225 +29.53]

= 46.22°C

To correct the winding temperature to rated load condition

Corrected LV WINDING temp rise = 46.22 + 1.22 = **47.44**°C

Result:

	Measured	Guaranteed
Top Oil Temperature Rise (°C)	38.37	45
HV Winding Temperature (°C)	46.02	55
LV Winding Temperature (°C)	47.44	55

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CALCULATIONS

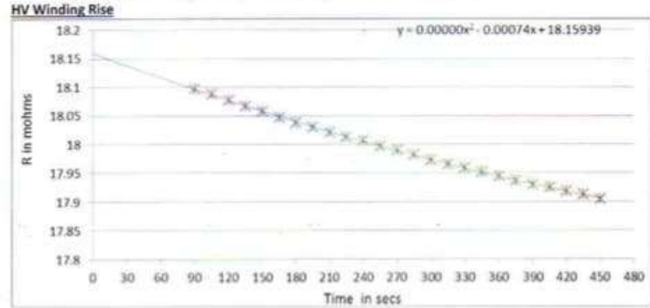
Drop in average oil temp after reducing to rated current

at Steady state with rated loss
Top oil temp rise = 38.37° C
Ave oil temp rise = Top Oil rise – [Rad Gradient/2]
= 30.07 ° C

at Shut down with rated current
Top oil temp rise = 36.6° C
Ave oil temp rise = Top Oil rise – [Rad Gradient/2]
= 28.85° C

Drop in average oil temp after reducing to rated current = 1.22° C

HV Winding Rise



Cold Resistance measured: 1U1V = 15.504 ohms (R cold)
Hot Resistance observed at shut down (from graph) = 18.159 ohms (R hot)
HV Winding ave temp rise with RATED CURRENT = R hot / R cold x [235 +29.1] – [235 +29.53]

=44.80°C

To correct the winding temperature to rated load condition

Corrected HV WINDING temp rise = 44.80 +1.22 = **46.02**°C

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Winding Resistance Test

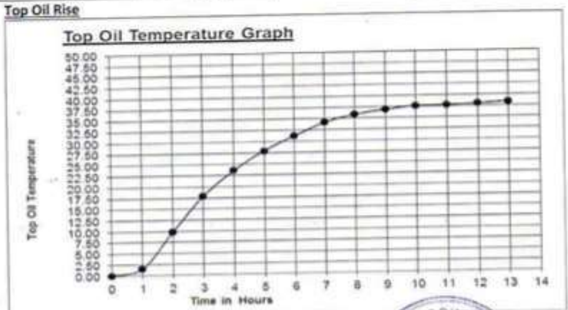
A) HV Side(1V-1W)

Time	Resistance in Ω
90	18.097
105	18.087
120	18.077
135	18.067
150	18.058
165	18.047
180	18.038
195	18.03
210	18.021
225	18.013
240	18.007
255	17.997
270	17.99
285	17.982
300	17.972
315	17.966
330	17.958
345	17.952
360	17.945
375	17.937
390	17.930
405	17.925
420	17.918
435	17.913
450	17.905

B) LV Side(2v-2w)

Time	Resistance in mΩ
90	27.76
105	27.73
120	27.70
135	27.67
150	27.64
165	27.62
180	27.6
195	27.57
210	27.55
225	27.53
240	27.51
255	27.5
270	27.47
285	27.46
300	27.44
315	27.42
330	27.4
345	27.38
360	27.37
375	27.35
390	27.34
405	27.33
420	27.32
435	27.30
450	27.29

Top Oil Rise



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4.TEMPERATURE RISE TEST

Test Standard	Equipment Used		
IS 2026(Part 2): 2010 IEC-60076-2 : 2011 CBIP Manual Pub.no.317/2013, (Sect BB 3.8)	EQ ID	Name with Make	Serial Number
	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a/07b/07c	Current Transformer (Kalpa)	R-133287/17 Y-133288/17 B-133289/17
	SAEW/EQ 05	Infrared Thermometer(Metrix)	02979373
	SAEW/EQ/34	Transformer winding resistance meter (Prestige)	PE/040/SEP/2018
	SAEW/EQ/22	Data logger with sensor	KB179A2001014

A) **Total Losses injection**

Total Loss feed = No Load Loss + Load Loss = 472.760W + 1562.217W = 2034.977W=2.035kW

Time	Average Voltage (V)	Average Current (A)	Average Power (kW)	Ambient Temp 1 (°C)	Ambient Temp 2 (°C)	Ambient Temp 3 (°C)	Average Temp. (1+2+3)/3 (a) (°C)	Top oil Temp. (b) (°C)	Top oil Temp. raise (b-a) (°C)
23.00	332.55	6.3807	2.034	25.5	25.5	26.0	25.6	27.6	1.54
00.00	324.41	6.1773	2.028	25.4	25.5	25.8	25.56	35.4	9.84
01.00	324.12	6.1627	2.031	25.2	25.3	25.7	25.4	43.3	17.9
02.00	321.80	6.1068	2.031	26.3	25.4	25.8	25.83	49.4	23.57
03.00	319.99	6.4960	2.029	26.6	25.8	26.1	26.16	54.1	27.93
04.00	319.71	6.0294	2.030	26.7	25.8	26.1	26.2	57.6	31.24
05.00	315.23	6.0191	2.030	26.7	25.9	26.1	26.23	60.4	34.17
06.00	320.96	6.0701	2.045	26.4	25.7	25.9	26	61.9	35.90
07.00	318.61	6.0412	2.070	26.4	25.7	25.9	26	62.9	36.90
08.00	316.98	5.9829	2.039	26.9	26.0	26.3	26.4	64.0	37.6
09.00	316.81	5.9889	2.048	27.4	26.9	27.0	27.1	64.8	37.7
10.00	315.17	5.9535	2.035	29.1	28.1	28.7	28.63	66.6	37.97
11.00	316.59	5.9646	2.045	29.4	28.5	29.2	29.03	67.4	38.37

Measured temperatures at radiator:-Top: 56.9°C, Bottom: 40.3°C

B) **Rated current injection**

11.02	278.04	5.2418	1.579	29.4	28.5	29.2	29.03	67.4	38.37
12.05	277.32	5.2438	1.564	30.0	28.9	29.3	29.53	66.1	36.6

Measured temperatures at radiator:-Top: 56.5°C, Bottom: 41.0°C

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3.MEASUREMENT OF SHORT CIRCUIT IMPEDANCE AND LOAD LOSS

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 1): 2011 (Clause 10.4), IEC 60076-1(Edition 3.0):2011-04) (Clause 11.4), CBIP Manual Pub.No.317/2013 (Sec. 8B 3.4)	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a/07b/07c	Current Transformer (Kalpa)	R-133287/17 Y-133288/17 B-133289/17
	SAEW/EQ/05	Infrared Thermometer (Metrix)	02979373

WINDING SHORTED	LV
WINDING SUPPLIED	HV
RATED KVA	100

Temp-29.1°C

Rated Voltage HV (kV)	11
Rated Voltage LV (kV)	0.433
Rated Current HV (A)	5.24
Rated Current LV (A)	133.33

MEASURING PARAMETERS:

Tap No	% Current Applied	Average Current (A)	Average Voltage(line) (V)	Total Power (W)
NA	50	2.6289	235.97	337.00
NA	70	3.6788	330.90	661.10
NA	100	5.2449	472.44	1351

CALCULATING PARAMETERS:

Tap No	Current in Amps		Resistance at 75°C (mΩ)		I^2R AT 75°C (W)		Total I^2R AT 75°C (W)
	HV WDG	LV WDG	HV WDG	LV WDG	HV WDG	LV WDG	
NA	5.24	133.33	18196	14.002	749.435	746.754	1496.189

Tap No	Impedance Voltage(V)	Corrected Power(W)	At Rated KVA (75°C)		%Impedance (% Z)
			Stray Losses (W)	Load Losses (W)	
NA	499.4	1348.477	66.028	1559.045	4.54

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REPORT NO: SAEW/ITL/2019-20/N-010 **DATE:** 13-12-2019

2.MEASUREMENT OF NO LOAD LOSS AND CURRENT

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 1): 2011 (Cl.no.10.5) IEC60076-1(Edition 3.0) :(2011-04) (Cl.no 11.5) CBIP Manual Pub.No.317/2013(Sec. 8B 3.3)	SAEW/EQ/12	Digital Power Meter(Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer (Excel power)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a /07b/07c	Current Transformer (Kalpa)	R-133287/17 Y-133288/17 B-133289/17

WINDING EXCITED	HV
WINDING OPENED	LV
HV RATED VOLTAGE (kV)	11
BASE KVA	100
TAP NO	NA
FREQUENCY (Hz)	50Hz

APPLIED ON HV SIDE

%Voltage	90%	100%	110%
Average Line Voltage (kV)	9.9027	11.0053	12.0885
Average Phase Voltage (kV)	5.7175	6.3541	6.9795
Average Current (A)	0.0948	0.1926	0.5820
Measured Loss (kW)	0.330	0.473	0.743
Corrected Loss (kW)	0.3299	0.4727	0.7437
Frequency (HZ)	50.103	49.992	49.956

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Sheet No. 5 of 12

Annexure 3.a: Snapshot of Post Repair test report conducted at NABL for enhanced kVA capacity (108 kVA)

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REPORT NO: SAEW/ITL/2019-20/N-011 DATE: 18-12-2019

TEST REPORT

Name & Address of the Customer: INTERNATIONAL COPPER ASSOCIATION INDIA UNIT 1401-03, WING A, KAILASH BUSINESS PARK, PARKSITE, VIKHROLI, MUMBAI-400079	**Report No. :** SAEW/ITL/2019-20/N-011 **Date** : 18-12-2019	**Location of Testing:** Impulse Test Lab
	Customer Ref No with date:	**Date of Sample Receipt:**
	ICAI/2019-20/0034 dated 16-12-2019	10-12-2019
	Condition of the sample at time of receipt:	**Date(s) of Testing:**
	Good	17 & 18-12-2019
Sample Description : **Make:** KEL **Power Rating :** 108kVA **Voltage Rating :** 11000V/ 433V **Current Rating :** 5.66A / 143.99A **Detailed Description:** In Sheet No. 2	**Sample Identification:** **ITL Sample No :** N-011 **Manufacturer Serial No :** 64428 **Make :** KEL **Year Of Manufacture :** 2010 **Enclosed Drawing Numbers :** NIL	
Test Details: In Sheet No. 3	**Sample Technical Specification:** In Sheet No. 2	
Test Results: Sheet No. 4 to Sheet No. 10		
Enclosure: Photographs of test samples – Sheet No.11		
Remarks: NIL	**Details of the Witnessing Officer** Er.M.Chandran EE/R&D CHENNAI; Er.R.Usha AEE/R&D CHENNAI	Er.S.Baskar ICAI
PREPARED BY	**CHECKED BY**	**APPROVED BY (R DHILIPKUMAR)**

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ULR NO: TC760819000000017F
REPORT NO: SAEW/ITL/2019-20/N-011 **DATE:** 18-12-2019

1.MEASUREMENT OF WINDING RESISTANCE

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026 (Part 1): 2011 (Clause 10.2) IEC 60076-1(Edition 3.0):(2011-04) (Clause 11.2) CBIP Manual Pub.No.317/2013(Sec. 8B 3.1)	SAEW/EQ/34	Transformer winding resistance meter (Prestige)	PE/040/SEP/2018
	SAEW/EQ 05	Infrared Thermometer (Metrix)	02979373

Temp-27.9°C

A) HV Winding

Tap No	Measured Values (Ω)			R_{Avg}(Ω)	R_{Avg}(Ω) (75° C)
	1U1V	1V1W	1W1U		
NA	15.450	15.433	15.415	15.432	18.196

B) LV Winding

Tap No	Measured Values (mΩ)			R_{Avg}(mΩ)	R_{Avg}(mΩ) (75° C)
NA	2u2n	2v2n	2w2n		
	11.86	11.79	11.75	11.8	13.998

Tap No	Measured Values (mΩ)			R_{Avg}(mΩ)	R_{Avg}(mΩ) (75° C)
NA	2u2v	2v2w	2w2u		
	23.57	23.46	23.47	23.5	27.877

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REPORT NO: SAEW/ITL/2019-20/N-011 **DATE:** 18-12-2019

2.MEASUREMENT OF NO LOAD LOSS AND CURRENT

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 1): 2011 (Cl.no.10.5) IEC60076-1(Edition 3.0) :(2011-04) (Cl.no 11.5) CBIP Manual Pub.No.317/2013(Sec. 8B 3.3)	SAEW/EQ/12	Digital Power Meter(Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer (Excel power)	R-633/18, Y- 634/18, B - 635/18
	SAEW/EQ/07a /07b/07c	Current Transformer (Kalpa)	R-133287/17 Y-133288/17 B-133289/17

WINDING EXCITED	HV
WINDING OPENED	LV
HV RATED VOLTAGE (kV)	11
BASE KVA	108
TAP NO	NA
FREQUENCY (Hz)	50Hz

APPLIED ON HV SIDE

%Voltage	90%	100%	110%
Average Line Voltage (kV)	9.9027	11.0053	12.0885
Average Phase Voltage (kV)	5.7175	6.3541	6.9795
Average Current (A)	0.0948	0.1926	0.5820
Measured Loss (kW)	0.330	0.473	0.743
Corrected Loss (kW)	0.3299	0.4727	0.7437
Frequency (HZ)	50.103	49.992	49.956

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3.MEASUREMENT OF SHORT CIRCUIT IMPEDANCE AND LOAD LOSS

TEST STANDARD	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 1): 2011 (Clause 10.4), IEC 60076-1(Edition 3.0):2011-04) (Clause 11.4), CBIP Manual Pub.No.317/2013 (Sec. BB 3.4)	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y-634/18, B-635/18
	SAEW/EQ/07a/07b/07c	Current Transformer (Kalpa)	R-133287/17 Y-133288/17 B-133289/17
	SAEW/EQ/05	Infrared Thermometer (Metrix)	02979373

WINDING SHORTED	LV
WINDING SUPPLIED	HV
RATED KVA	108

Temp-27.9°C

Rated Voltage HV (kV)	11
Rated Voltage LV (kV)	0.433
Rated Current HV (A)	5.66
Rated Current LV (A)	143.99

MEASURING PARAMETERS:

Tap No	% Current Applied	Average Current (A)	Average Voltage(line) (V)	Total Power (W)
NA	50	2.8371	255.366	398.4
NA	70	3.9691	357.641	780.6
NA	100	5.6556	510.109	1577

CALCULATING PARAMETERS:

Tap No	Current in Amps		Resistance at 75°C (mΩ)		I^2R AT 75°C (W)		Total I^2R AT 75°C (W)
	HV WDG	LV WDG	HV WDG	LV WDG	HV WDG	LV WDG	
NA	5.66	143.99	18196	13.998	874.414	870.642	1745.056

Tap No	Impedance Voltage(V)	Corrected Power(W)	At Rated KVA (75°C)		%Impedance (% Z)
			Stray Losses (W)	Load Losses (W)	
NA	510.40	1579.455	88.149	1833.205	4.64

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REPORT NO: SAEW/ITL/2019-20/N-011 DATE: 18-12-2019

4.TEMPERATURE RISE TEST

Test Standard	Equipment Used		
	EQ ID	Name with Make	Serial Number
IS 2026(Part 2): 2010 IEC-60076-2 : 2011 CBIP Manual Pub.no.317/2013, (Sect BB 3.8)	SAEW/EQ/12	Digital Power Meter (Yokogawa)	C3SH12030E
	SAEW/EQ/06	Potential Transformer(Excel)	R-633/18, Y-634/18, B-635/18
	SAEW/EQ/07a/07b/07c	Current Transformer (Kalpa)	R-133287/17 Y-133288/17 B-133289/17
	SAEW/EQ 05	Infrared Thermometer(Metrix)	02979373
	SAEW/EQ/34	Transformer winding resistance meter (Prestige)	PE/040/SEP/2018
	SAEW/EQ/22	Data logger with sensor	KB179A2001014

A) Total Losses injection

Total Loss feed = No Load Loss + Load Loss = 472.760W + 1833.205W = 2305.965W=2.036kW

Time	Average Voltage (V)	Average Current (A)	Average Power (kW)	Ambient Temp 1 (°C)	Ambient Temp 2 (°C)	Ambient Temp 3 (°C)	Average Temp. (1+2+3)/3 (a) (°C)	Top oil Temp. (b) (°C)	Top oil Temp. raise (b-a) (°C)
23.00	354.80	6.5375	2.303	25.7	25.6	25.7	25.66	25.5	-
00.00	345.18	6.5052	2.303	24.8	25.4	25.4	25.20	35.0	9.8
01.00	341.44	6.4785	2.303	26.1	25.4	25.8	25.76	42.5	16.74
02.00	340.12	6.4562	2.301	26.3	25.5	26.0	25.93	49.1	23.17
03.00	338.71	6.4102	2.308	26.5	25.6	26.0	26.03	54.2	28.17
04.00	337.30	6.3719	2.305	26.4	25.6	26.0	26.00	57.9	31.9
05.00	336.32	6.3479	2.306	26.3	25.4	25.8	25.80	62.9	37.10
06.00	335.61	6.3248	2.303	26.2	25.4	25.8	25.80	62.9	37.10
07.00	333.93	6.3137	2.305	26.3	25.4	25.9	25.86	64.4	38.54
08.00	334.27	6.3048	2.308	27.0	26.0	26.1	26.36	64.9	38.54
09.00	333.64	6.2883	2.306	28.1	26.7	27.6	27.46	65.7	38.24
10.00	331.72	6.2770	2.309	30.0	28.5	30.2	29.56	68.0	38.44
11.00	332.92	6.2645	2.306	30.3	29.1	31.4	30.27	68.6	38.33

Measured temperatures at radiator:-Top: 58.3°C, Bottom: 40.9°C

B) Rated current injection

11.01	301.77	5.6779	1.894	30.3	29.1	31.4	30.27	68.6	38.33
12.00	300.62	5.6676	1.873	30.6	29.4	31.6	30.53	62.7	32.17

Measured temperatures at radiator:-Top: 58.1°C, Bottom: 41.0°C

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IMPULSE TEST LAB

(Shree Abirami Enggineering Works)
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Kodambakkam - Sriperumbudur High Road, SH 113,
Near TVH Svaya Apartments, Sriperumbudur- 602 105.
Phone No: 044-27176120 E-mail:2400kvitl@gmail.com
Certificate No: TC-7608
(Accredited by the National Accreditation Board for Testing and Calibration Laboratories, Govt. of India)
ULR NO: TC760819000000017F
REPORT NO: SAEW/ITL/2019-20/N-011
DATE: 18-12-2019

Winding Resistance Test

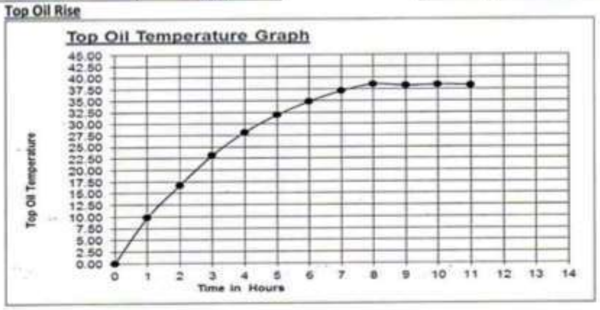
A) HV Side(1V-1W)

Time	Resistance in Ω
75	18.406
90	18.393
105	18.38
120	18.368
135	18.357
150	18.347
165	18.335
180	18.325
195	18.313
210	18.304
225	18.295
240	18.285
255	18.274
270	18.265
285	18.257
300	18.247
315	18.24
330	18.229
345	18.223
360	18.215
375	18.206
390	18.198
405	18.189
420	18.184
435	18.176

B) LV Side(2v-2w)

Time	Resistance in mΩ
75	28.06
90	27.97
105	27.89
120	27.83
135	27.76
150	27.72
165	27.67
180	27.63
195	27.59
210	27.55
225	27.53
240	27.49
255	27.47
270	27.45
285	27.43
300	27.41
315	27.38
330	27.35
345	27.33
360	27.31
375	27.29
390	27.27
405	27.26
420	27.25
435	27.22

Top Oil Rise



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CALCULATIONS

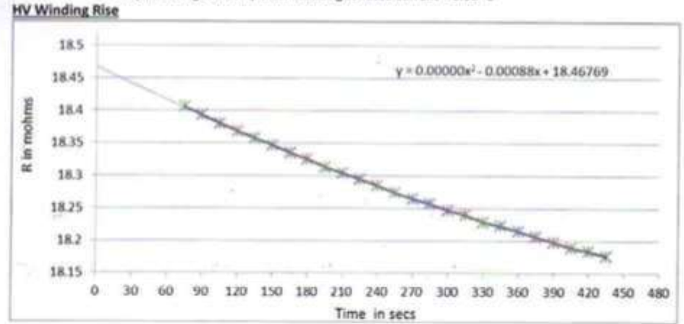
Drop in average oil temp after reducing to rated current

at Steady state with rated loss
- Top oil temp rise = 38.33° C
- Ave oil temp rise = Top Oil rise – [Rad Gradient/2] = 29.63 ° C

at Shut down with rated current
- Top oil temp rise = 32.17° C
- Ave oil temp rise = Top Oil rise – [Rad Gradient/2] = 23.62° C

Drop in average oil temp after reducing to rated current = 6.01° C

HV Winding Rise



Cold Resistance measured: 1U1V = 15.433 ohms (R cold)@27.9°C
Hot Resistance observed at shut down (from graph) = 18.468 ohms (R hot)
HV Winding ave temp rise with RATED CURRENT $= \frac{R\ hot}{R\ cold} \times [235 + 27.9] - [235 + 30.53]$

=49.07°C

To correct the winding temperature to rated load condition

Corrected HV WINDING temp rise =49.07+6.01 = 55.08°C

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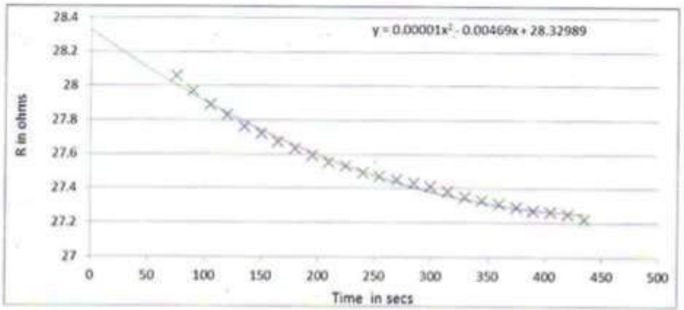
REPORT NO: SAEW/ITL/2019-20/N-011 **DATE:** 18-12-2019

LV Winding Rise



Cold Resistance measured: 1U1V = 23.46 ohms (R cold) @27.9°C
Hot Resistance observed at shut down (from graph) = 28.330 ohms (R hot)
HV Winding ave temp rise with RATED CURRENT $= \frac{R\ hot}{R\ cold} \times [225 + 27.9] - [225 + 30.53]$

= 49.87°C

To correct the winding temperature to rated load condition

Corrected LV WINDING temp rise = 49.87 + 6.01 = 55.88°C

Result:

	Measured	Guaranteed
Top Oil Temperature Rise (°C)	38.33	45
HV Winding Temperature (°C)	55.08	55
LV Winding Temperature (°C)	55.88	55

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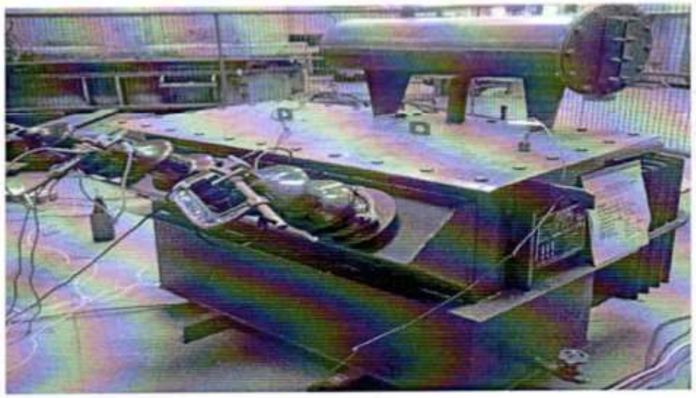
PHOTOGRAPHS



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Annexure-4: Cost Benefit Analysis

Key Design Parameters	Unit	GTP Values	As-Is (Baseline)	Actual (as per NABL)	Calculation for enhanced kVA	% Change from baseline
Capacity	kVA	100.00	100.00	100.00	108.00	0%
Year of Manufacturing		-	2013	-	-	
Flux Density	Tesla	-	1.55	-	-	
LV Winding Material		-	DPC Al	DPC Al	DPC Al	
HV Winding Material		-	DPC Al	DPC Copper	DPC Copper	
No Load Loss	Watts	260.00	474.00	472.00	473.00	0%
Full Load Loss	Watts	1,760.00	2,067.00	1,559.00	1,833.00	-25%
Total Loss @100% loading	Watts	2,020.00	2,541.00	2,035.00	2,306.00	1%
LV Winding Weight			24.00	23.08	23.08	
HV Winding Weight			42.60	93.25	93.25	
Total Winding Weight	kg		66.60	116.33	116.33	
% No Load Loss Deviation from GTP values	%	-	82%	82%		
% Full Load Loss Deviation from GTP Values	%	-	26%	1%		
% Total Loss Deviation from GTP values	%	-	26%	1%		

Losses and Savings Calculations

5	Unit	As-Is	Actual (as per NABL)	Savings (as per NABL)
Lost units from Technical Losses	kWh/year	13,024.63	10,826.57	2,198.06

		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Units saved	kWh	2,198.06	2,198.06	2,198.06	2,198.06	2,198.06	2,198.06	2,198.06	2,198.06	2,198.06	2,198.06	**21,980.59**
Avg. Cost of Supply	INR/kWh	5.85	6.44	7.08	7.79	8.56	9.42	10.36	11.40	12.54	13.79	
Money saved	**INR/year**	**12,858.65**	**14,144.51**	**15,558.96**	**17,114.86**	**18,826.34**	**20,708.98**	**22,779.88**	**25,057.86**	**27,563.65**	**30,320.02**	**2,04,933.71**

Active Repair for Performance Improvement of DTs for TANGEDCO

Estimated Repair Cost		
As-Is Repair Costs		
Labour and Transpotation Cost for As-Is Repair	INR	2,700.00
Material Cost for As-Is Repair	INR	20,246.40
Total Cost for As-Is Repair	INR	22,946.40
To-Be Repair Costs		
Labour Cost for To-Be Repair	INR	2,700.00
Material Cost for To-Be Repair (using Copper)	INR	66,230.07
Total Cost for To-Be Repair	INR	68,930.07
Incremental cost for To-Be Active Repair over and above Normal Repair	INR	45,983.67

Project Payback

	0	1	2	3	4	5	6	7	8	9	10
Cash inflow	-	12,859	14,145	15,559	17,115	18,826	20,709	22,780	25,058	27,564	84,575
Cumulative cash inflow	-	12,859	27,003	42,562	59,677	78,503	99,212	1,21,992	1,47,050	1,74,614	2,59,188
Cash Outflow	45,983.67										
Cumulative cash outflow	45,984	45,984	45,984	45,984	45,984	45,984	45,984	45,984	45,984	45,984	45,984
Payback ratio		0.28	0.59	0.93	1.30	1.71	2.16	2.65	3.20	3.80	5.64
		-		-	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		-		-	1.00	-	-	-	-	-	-
		-	-	-	**3.20**	-	-	-	-	-	-

Annexure-5: Sensitivity to Cu Salvage value at the end of service

Without Cu Salvage Value

Project IRR											
	Year0	Year1	Year2	Year3	Year4	Year5	Year6	Year7	Year8	Year9	Year10
Cash Inflow		28,859	14,145	15,559	17,115	18,826	20,709	22,780	25,058	27,564	30,320
Cash inflow from Salvage value											-
Cash outflow	45,983.67										
Net Cash Inflow	**(45,984)**	**28,859**	**14,145**	**15,559**	**17,115**	**18,826**	**20,709**	**22,780**	**25,058**	**27,564**	**30,320**
Discount factor	**10%**										
	100%	**91%**	**83%**	**75%**	**68%**	**62%**	**56%**	**51%**	**47%**	**42%**	**39%**
NPV of cash inflow	(45,983.67)	26,235.13	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68
WACC	9.43%										
ProJECT IRR	44.42%	31.29%									

With Cu Salvage Value

Project IRR											
	Year0	Year1	Year2	Year3	Year4	Year5	Year6	Year7	Year8	Year9	Year10
Cash Inflow		28,859	14,145	15,559	17,115	18,826	20,709	22,780	25,058	27,564	30,320
Cash inflow from Salvage value											54,255
Cash outflow	45,983.67										
Net Cash Inflow	**(45,984)**	**28,859**	**14,145**	**15,559**	**17,115**	**18,826**	**20,709**	**22,780**	**25,058**	**27,564**	**84,575**
Discount factor	**10%**										
	100%	**91%**	**83%**	**75%**	**68%**	**62%**	**56%**	**51%**	**47%**	**42%**	**39%**
NPV of cash inflow	(45,983.67)	26,235.13	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	11,689.68	32,607.25
WACC	9.43%										
ProJECT IRR	45.81%	32.56%									

Note: INR. 28,859 is the sum of net savings (Savings from transformer, Increased kVA Capacity Capex Savings, Interest On Term Loan) and financing costs (interest to be paid on 70% debt on incremental cost of repair) in year-1

Annexure-6: Energy Efficiency Level as per IS 1180:2014

Sl No.	Rating (kVA)	Impedance (Percent)	Maximum Total Loss (W)					
			Energy Efficiency Level 1		Energy Efficiency Level 2		Energy Efficiency Level 3	
			50 % Load	100 % Load	50 % Load	100 % Load	50 % Load	100 % Load
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	6.3	4.0	53	245	48	225	42	205
ii)	10	4.5	72	270	65	240	58	215
iii)	16	4.5	150	480	135	440	120	400
iv)	20	4.5	175	575	160	525	145	485
v)	25	4.5	210	695	190	635	175	595
vi)	40	4.5	277	914	249	834	224	774
vii)	63	4.5	380	1 250	340	1 140	300	1 050
viii)	100	4.5	520	1 800	475	1 650	435	1 500
ix)	160	4.5	770	2 200	670	1 950	570	1 700
x)	200	4.5	890	2 700	780	2 300	670	2 100

Maximum allowable losses at PGVCL

LOSSES OF LABELED TRANSFORMERS IN WATTS

Capacity in KVA	5	10	16	25	63	100	200	500
Energy Efficiency Level -1								
Maximum No Load Losses	15	45	60	75	150	200	310	550
Maximum total losses at 50% loading	40	72	150	210	380	520	890	1600
Maximum *total losses at 100% loading	115	270	480	695	1250	1800	2700	4750
Energy Efficiency Level -2								
Maximum No Load Losses	15	40	50	60	125	170	270	545
Maximum total losses at 50% loading	35	65	135	190	340	475	780	1510
Maximum *total losses at 100% loading	95	240	440	635	1140	1650	2300	4300

*Total Losses in watt at 100 % loading = No Load losses in watt + Full Load losses in watt at 75 Deg. C

EE-1: At 100% loading, Full load loss = Total Loss- No load loss = 1800-200= 1600W

EE-2: At 100% loading, Full load loss = Total Loss- No load loss = 1650-170= 1480W

Annexure-7: Applicability to broader TANGEDCO Utility

Overall Discom Savings Model

Below model is prepared to understand applicability of Proactive repair to broader Discom

Fields marked in yellow are inputs to the model

Total Transformers	2,93, 301				Assumed no-load deviation	10%
Assumed Acceptable % deviation permissible limits of losses (NL & FL) for repaired DTs	10%				Assumed full load deviation	-30%
Assumed no-load deviation	10%					
Assumed full load deviation	15%					
Avg. Loading	70%					
Avg. Cost of power supply	5.85	kWh/unit				
Total revenue of Discom	43,686	Cr.			71%	
Energy Input	73,961	MU/year	Updated data			

Capacity (KVA)	Percentage	No. of transformers	Total MVA DT capacity	Ideal No load Loss (W)	Ideal Full Load Loss (W)		No load loss acceptable (W)	Full load loss acceptable (W)	Estimated No load deviation (W)	Estimated Full load deviation (W)	Active Repair No load Loss (W)	Active Repair Full load Loss (W)
Below 25	7%	20000	200	80	470	11,000	88	517	88	541	88	329
25	10%	30000	750	130	660	29%	143	726	143	759	143	462
63	12%	35000	2,205	180	1,230		198	1353	198	1414.5	198	861
100	38%	110000	11,000	260	1760		286	1936	286	2024	286	1,232
200	22%	63000	12,600	500	3000		550	3300	550	3450	550	2,100
Above 200	12%	35000	11,025	580	4200		638	4620	638	4830	638	2,940
	100%	**2,93,000**	**37,780**	3,14,405	24%							
				2,20,084	34%							

Capacity	Ideal Total Losses (W)	Annual Total Losses for 1 DT (kWh units)	Total Technical Losses (kWh/year)	Acceptable Total Losses (W)	Annual Total Losses for 1 DT (kWh units)	Total Technical Losses (kWh)	Estimated Actual Total Losses (W)	Estimated Actual Annual Total Losses for 1 DT (kWh units)	Estimated Actual Total Technical Losses (kWh)	Estimated Actual Total Losses (W)	Estimated Actual Annual Total Losses for 1 DT (kWh units)	Estimated Actual Total Technical Losses (kWh)
Below 25	310	2718	5,43,64,560	341.33	2990	5,98,01,016	352.85	3091	6,18,18,444	249.21	2183	4,36,61,592
25	453	3972	11,91,53,520	498.74	4369	13,10,68,872	514.91	4511	13,53,18,348	369	3236	9,70,73,064
63	782.7	6856	23,99,75,820	860.97	7542	26,39,73,402	891.105	7806	27,32,12,793	620	5430	19,00,58,274
100	1122.4	9832	1,08,15,44,640	1234.64	10815	1,18,96,99,104	1277.76	11193	1,23,12,49,536	890	7794	85,72,95,648
200	1970	17257	1,08,72,03,600	2167	18983	1,19,59,23,960	2240.5	19627	1,23,64,87,140	1,579	13832	87,14,18,520
Above 200	2638	23109	80,88,10,800	2901.8	25420	88,96,91,880	3004.7	26321	92,12,41,020	2,079	18209	63,72,98,760
			3,39,10,52,940			**3,73,01,58,234**			**3,85,93,27,281**			**2,69,68,05,858**

	Scenario-1			Scenario-2		Scenario-3		Scenario-4		
Total technical losses	3,39,10,52,940	kWh units		3,73,01,58,234	kWh units	3,85,93,27,281	kWh units	2,69,68,05,858	kWh units	
	3,391.05	MU		3,730.16	MU	3,859.33	MU	2,696.81	MU	
Input Energy (2019-20)	73,961	MU		73,961	MU	73,961	MU	73,961	MU	
% DT Technical Annual Losses with respect to energy input	4.58%			5.04%		5.22%		3.65%		
DT technical losses (INR)	**19,83,76,59,699**	4.58%		**21,82,14,25,669**	5.04%	**22,57,70,64,594**	5.22%	**15,77,63,14,269**	3.65%	
								12,98,01,55,500	3%	
	1,983.77	**Cr.**		**2,182.14**	**Cr.**	**2,257.71**	**Cr.**	**1,298.02**	**Cr.**	
Total revenue of Discom	43,686	Cr.	As per ARR	43,686	Cr.	43,686	Cr.	43,686	Cr.	
%revenue lost of current revenue	**4.54%**			**5.00%**		**5.17%**		**2.97%**		
Potential Savings from DT loss reduction (INR)								680	Cr.	3.65%
								960	Cr.	3%

Acknowledgement

TANGEDCO (Tamil Nadu Electricity Board – Powering the Progress of Tamil Nadu)	• Director Distribution • Chief Engineer R&D • Superintendent Engineer R&D • Executive Engineer R&D • R&D Department
International Copper Association India – Copper Alliance	• Mr. Manas Kundu, Director, Energy Solutions • Mr. Mayur Karmarkar, Regional Director Sustainable Energy • Mr. Baskar Sivaraman, ICAI Associate
TRISTAR TECHNOCRATES (Transformers Design Consultants)	• Mr. Rajesh Joshi, Transformer Design Expert
SAKTHI TRANSFORMERS (ISI CERTIFIED COMPANY)	• Utility Nominated Transformer Repairer