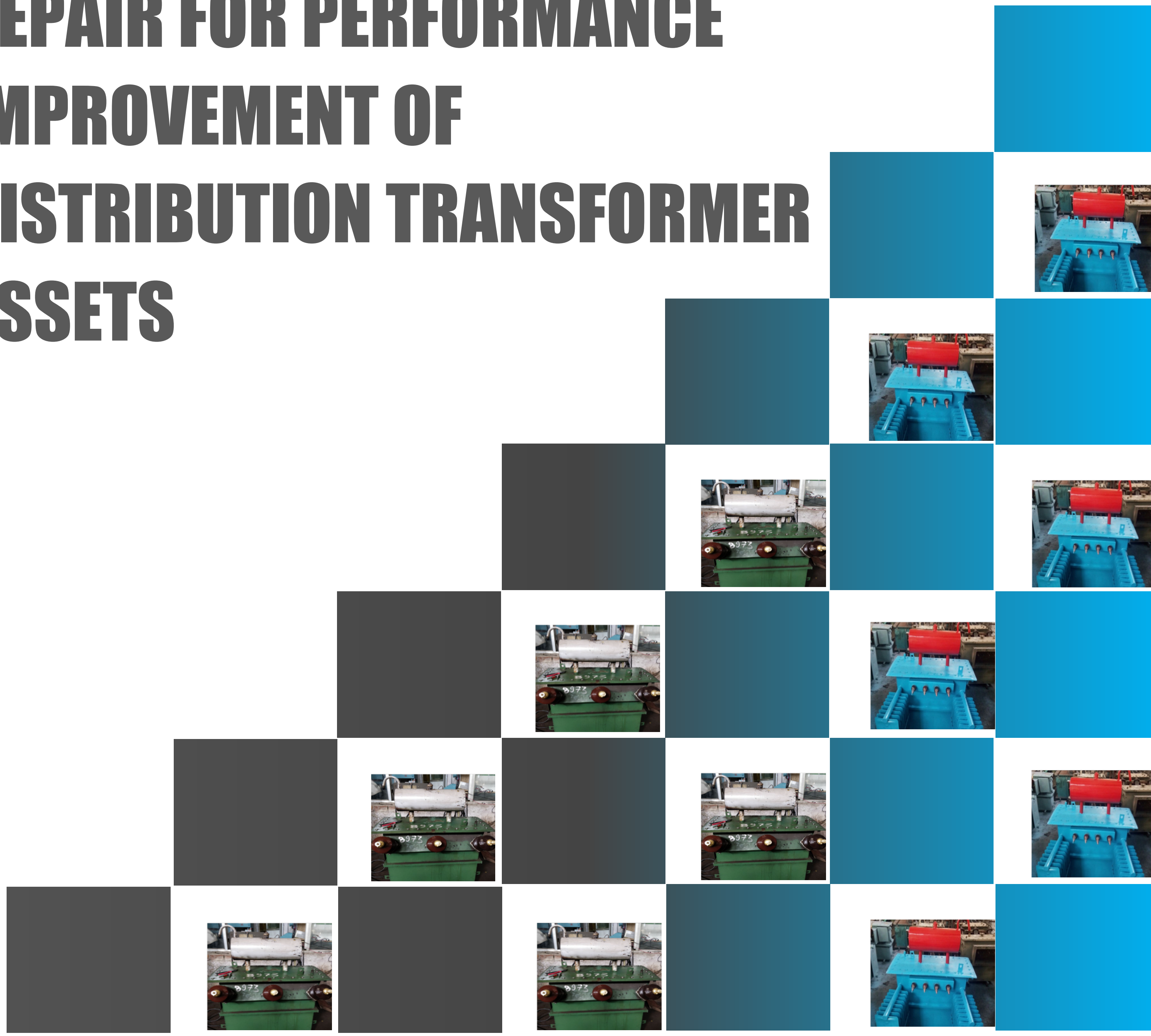
REPAIR FOR PERFORMANCE IMPROVEMENT OF DISTRIBUTION TRANSFORMER ASSETS



Report on Repair for Performance Improvement of Distribution Transformer for MPPKVVCL

For MPPKVVCL, Indore

October 2019

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1. About the Research

The high monetary value of a transformer has placed the transformer life-time optimization into the focus of asset management. Distribution Transformer (DT) is one of the critical and high CAPEX assets for DISCOMs. For overall DISCOM viability, it is important that each DT must turn into a profit centre. It is estimated that of 24% national average AT&C losses, at least 3-4%[1] comes from Technical losses in DTs, and it can be brought down to 0.5% and below. Restructuring reforms like RAPDRP has envisaged utilities to carry out an energy audit of a DT for monitoring inherent losses (at least on a sampling basis). However, unfortunately, this keeps missing the attention, to the extent that DT technical losses are not even measured till it breaks down and only broken-down DTs are sent for repair. There is minimum to none pro-active approach to DT repair and O&M.

DT failure rate is one of the important 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% DTs fail every year and average rate of failure of aluminium wound DTs is more than copper wound DTs. Overloading is one of the root causes of DT failure. DTs are ~30-40% frequently overloaded than their actual capacity resulting in deterioration of their operating efficiency and eventually its lifespan. Any failure of the DT before the expiration of its designed lifespan 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 this result in reduced efficacy of DTs and high technical losses in the distribution system. Therefore, DISCOMs need to utilize their existing 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 current 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 practice. The proposed performance improvement repair practice will give new life to the DT and enhance its performance equivalent to Energy Efficiency Levels specified by BIS. In this context, a Proof of Concept (PoC) was carried out at MPPKVVCL at Major Transformer Repairing Unit (MTRU), Indore on three DTs with two different performance improvement repair options.

2. About the pilot

The pilot focuses on developing a mass replicable approach to undertaking repairs of DTs in service and bring down the technical losses and enhance reliability. With mass replicability objective, the core was decided to be kept unchanged and all correction to be affected through windings redesign and/or change of material. The core was restacked tightly to reduce air gaps between laminations.

The proposed repair practice for performance improvement of legacy DTs used two different options to carry out repairs.

[1] Based on multiple primary interactions with industry experts

- Option-1: Improvement for Best Performance
- Option-2: Improvement for Cost effective capacity enhancement

Under this PoC, pre-repair testing, repair execution & post-repair testing activities were conducted at MTRU. The Repair involved correcting loss levels of the DT & bringing it closer to the ideal values as specified by Indian Standards. After conducting baseline measurement, different design solutions were worked out, post which Repair was undertaken.

Various tests like Open Circuit & Short Circuit test were carried out under the supervision of MPPKVVCL representative at MTRU and technical loss reduction was validated by ERDA. Experts & team recorded data for analysis of No-load loss & Full load loss post repair and some key conclusions were made as mentioned:

- Reduces technical losses, thereby saving power procurement costs
- Improves efficiency of transformers as mandated by BEE in PAT-2 cycle
- Improves transformer reliability, thereby reducing downtime
- Increases kVA capacity of the transformer that helps DT sustain overloading condition
- Cost-benefit analysis suggests payback period of less than 2-3.5 years
- Incremental repair cost is lower by 30-60% than its equivalent new DT procurement cost with almost same performance
- Creates an opportunity for the DT OEM or repairer to become a stakeholder in network O&M
- Reduces O&M expenses, thereby improving financial health of DISCOMs

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

3. Background

MPPKVVCL has total 2,48,611[2] DTs in service in two regions - Indore and Ujjain. Annually, ~20k DTs are procured across different capacities based on the field demands

During the year 2019-20 up to 31st September 2019, total 6,905[2] DTs failed across different capacities (average failure rate of DTs is 15-17%). The prominent reason for winding failure is reported to be prolonged overloading of the DTs. It has been observed that no factual data is collected on loading of the transformers. Overloading of the transformer goes unnoticed till the DT fails. As per DT assessment study, bursting of LV and/or HV winding is reported to be one of the major types of failure occurring in DTs as compared core damage (~2% DTs).

The high DT failure rate and losses in DTs usually originates from weak practices in asset life-cycle management. These include procurement, regular O&M and repairs. Some of the practices observed are as mentioned below:

- The DT procurement often ignores life-cycle cost or the total cost of ownership as against meticulously observed in case of power transformers.

[2] Report of failure / replacement of distribution transformers during the year 2019-20 upto 31/8/2019 (*This document gets updated periodically). During the year 2017-18 up to 31st March 2018, total 26,3322 DTs failed across different capacities.*

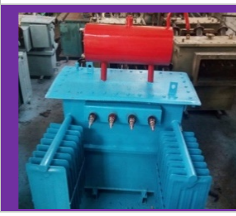
- Tendering process is more on standard bidding philosophy (accepting lowest bid) rather than performance-based contract.
- DTs normally fail much before completion of its service life (20-25 years) impacting the cost of capital deployed to service customers. Part of the reason for such high failure rate is overloading, absence of Condition based/Preventive monitoring, protection and Routine/Periodic maintenance
- The repair practice follows a passive approach to attend the DT when it fails. The focus is merely to get the DT back into the service, rather than availing the opportunity to completely renovate with eye for preventing energy loss and improving asset health.
- Current practice is to measure the no-load and load losses in the DT post repair only, leaving no scope for further improvement. Also, the current repair contract and defined Service Level Agreements (SLAs) do not encourage technical loss reduction.
- The DT repairer's staff is adept in routine repair practices and do not consider design optimization for loss reduction or enhancing reliability. This at times lead to adoption of sub optimal practices.
- The equipment used for losses measurement or estimation are not well kept as needed to be maintained in laboratory environment, calibrated and updated for accuracy.

Further, as per the studied post repair reports, the DT technical losses were observed to be fairly deviated *(No-load loss and Full load loss was observed to be 3% and 11% deviated respectively*) from the ideal values. Few DTs were observed to be deviated even to a level against norms in practice.

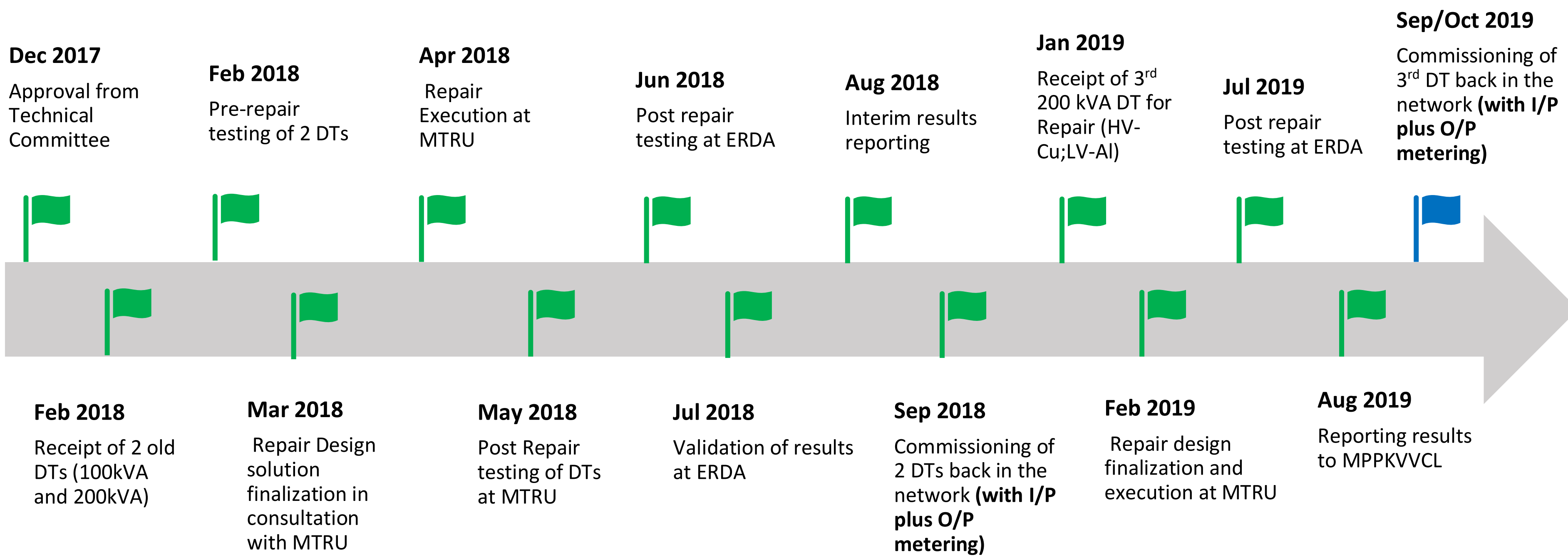
With above realities and challenges, using the breakdown repair window opportunity for old DTs, *(considering the fact that there are many old DTs with highly deviated technical losses)*. Repair approach can be adopted for old DTs to modernize them. This can yield attractive payback and reduce total cost of ownership. It can also be applied to selective functional DTs based on loss data if tracked well from previous conventional repairs. Additional benefits of repair come in form of increased kVA capacity, higher reliability (i.e. reduced failure rate) and increased asset life. The performance-based contract can be designed to encourage the OEM/repairer to improve performance of the DTs. The contract will incentivize OEM/repairer on overachievement while underachievement will be liable for penalty.

4. 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
▪ Requisitioned failed DTs from Repair Centre for PoC	▪ Loss levels were measured at MTRU in presence of MPPKVVCL representatives	▪ Multiple design options were prepared ▪ Final Design Option was reviewed & approved with MPPKVVCL team	▪ Undertook repair based on finalized design based on performance improvement repair options	▪ Loss levels was measured at MTRU in presence of MPPKVVCL representatives ▪ The results were also validated by ERDA by conduction loss and impedance measurement test and temperature rise test	▪ Test results were recorded & reported to MPPKVVCL
					

5. Timelines


Dec 2017
Approval from Technical Committee
Feb 2018
Receipt of 2 old DTs (100kVA and 200kVA)
Feb 2018
Pre-repair testing of 2 DTs
Mar 2018
Repair Design solution finalization in consultation with MTRU
Apr 2018
Repair Execution at MTRU
May 2018
Post Repair testing of DTs at MTRU
Jun 2018
Post repair testing at ERDA
Jul 2018
Validation of results at ERDA
Aug 2018
Interim results reporting
Sep 2018
Commissioning of 2 DTs back in the network (with I/P plus O/P metering)
Jan 2019
Receipt of 3rd 200 kVA DT for Repair (HV-Cu;LV-Al)
Feb 2019
Repair design finalization and execution at MTRU
Jul 2019
Post repair testing at ERDA
Aug 2019
Reporting results to MPPKVVCL
Sep/Oct 2019
Commissioning of 3rd DT back in the network (with I/P plus O/P metering)


Completed
To be done

6. Repair Options

Repair options explored for performance improvement of DTs are discussed in detailed.

6.1. Option-1(A): Improvement for Best Performance – 100 KVA

This option envisages to achieve lowest losses and kVA capacity enhancement of existing failed DT. The focus is on reduction of full load losses & thereby getting maximum possible efficiency, as well as the capability to perform under overloading conditions. Design of existing LV & HV both have been altered along with use of copper in place of existing aluminum, as winding material.

6.1.1. 'As-Is' measurement

The below table summarizes key baseline parameters of acquired failed 100kVA DT and its related details:

Parameters	Units	Value	% Deviation from ideal values*
Capacity (kVA)	KVA	100	-
Make		Swastik Copper	-
Year of Mfg.		2013	-
Sr. No.		SC/119243	-
Flux Density	Tesla	1.55	-
LV winding material		DPC Al	-
No. of turns (LV winding)	#	76	-
HV winding material		DPC Al	-
No. of turns (HV winding)	#	3344	-
Total Winding Weight	kg	46.62	-
Impedance	%	3.84	-
Total loss	Watts	2616	30% higher*

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

**1-star as per old BIS standard: Total Loss 2020 Watts*

6.1.2. Solution Design

Based upon the baseline measurements, design options for repairs was worked out initially. Thereafter, in consultation with MPPKVVCL team & design experts they were finalized as below (detailed design solution is mentioned in Annexure-A):

Rating	Solution Design	Core unchanged	Designed LV winding (Material, # of turns, ID, OD, Height)	Designed HV winding (Material, # of turns, ID, OD, Height)	Estimated Total Loss as per design (Watts)
100 kVA	LV & HV Copper with same no. of turns & optimally using window space (Reduced losses; increased kVA)	Yes	DPC Copper, 76, 122, 163, 432	DPC Copper, 3344, 181, 241, 95.5	1469

Table 2. Design Solutions for Repair-100kVA

6.1.3. Repair Execution

6.1.3.1. Pre-repair testing

The execution process was undertaken with pre-repair testing of failed DT at MTRU. No load loss value and full load loss value were measured. The testing was undertaken in presence of MPPKVVCL representative as per IS 2026. Some images are shown below:

Figure 1. Acquired failed DT

Figure 2. Setting up connections for testing

Figure 3. Pre-repair Test Measurements

Figure 4. MPPKVVCL representative & team recording the data

6.1.3.2. Repair

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

- Unstacking of core laminations and restacking them tightly to reduce air gap between laminations
- Procuring right kind of material (electrolytic grade copper in this case) for winding
- Placing LV and HV winding as per design spec and assembling
- Assembled transformer was moved for oven drying to remove moisture
- Eventually, oven dried transformer was placed in tank as final assembly
- Completing painting process following norms

Some images during the process are shown below:

Figure 5. LV winding

Figure 6. HV winding

Figure 7. Tank Placement on assembled DT

Figure 8. Final repaired DT

6.1.3.3. *Post Repair Testing*

After repair, post repair testing was undertaken in presence of MPPKVVCL representative as per IS 2026. Some images are shown below:

Figure 9. Setting up connections for testing

Figure 10. Testing Connections

Figure 11. Post Repair Test Measurements

Figure 12. MPPKVVCL representative & team recording the data

After conducting all tests, results were obtained for various parameters in reference to the baseline measurements. Following are the results obtained:

Key Design Parameters	**Unit**	**Specification**	**Baseline (As-Is)**	**Actual Post repair results (measured at MTRU)**	**Actual Post repair results (measured at ERDA)**
Capacity	kVA	100.00	86.41*	100	**109****
Year of Manufacturing		-	2013	-	-
Flux Density	Tesla	1.55	-	-	-
LV Winding Material		-	DPC Al	DPC Cu	DPC Cu
# of LV Turns	#	-	76	76	76
HV Winding Material		-	DPC Al	DPC Cu	DPC Cu
# of HV Turns	#	-	3344	3344	3344
Total Loss	Watt	2020	2616	1461	1463
Impedance	%	4.5	3.84	4.12	4.21
Total Winding Weight	kg	-	46.62	192.36	192.36

Table 3. Baseline v/s Actual results as per design specifications for 100kVA

Post-repair enhanced efficiency levels were also validated by ERDA by conducting loss and impedance measurement tests.

**86kVA rating was detected based on pre-repair test results and when calculated with reference to specified losses by below formula:*

2358 Watt (Measured) = 1760 Watt (Required) x Square of (100kVA / 86.41kVA)

***kVA enhancement inferred and estimated from ERDA results of Temperature rise test as per limits of IS 2026 Part-2*

Calculation of enhanced kVA based on ERDA test results, as per IS 2026 Part-2

Check of temperature rise at approx. 10% enhanced continuous KVA

FACTORS IS 2026	CALC MF	PARTICULRS	ERDA RESULTS	AT ENHANCED KVA	LIMITS- IS 2026
		KVA	100	109	
+ 10%(1.1 TIMES)	1.09	LOAD/LV AMP	133.34	145.3406	
+ 20%(1.2 TIMES)	1.1881	LOAD LOSS	1168.01	1387.712681	
		NO LOAD LOSS	295.51	295.51	
		TOTAL LOSS	1463.52	1683.222681	
0.8	1.118392717	OIL TEMP RISE	31.4	**35.11753131**	50
1.6	1.147842753	WNDG T RISE	44.6	**51.19378679**	55
	1.09	% IMPEDANCE	4.21	4.5889	

6.1.4. Cost-Benefit Analysis

For cost-benefit analysis, ERDA results are preferred over MTRU results.

6.1.4.1. Top Results

Summary of Cost Benefit Analysis (CBA) is indicated below. The detailed CBA and assumptions are attached separately.

Rating of Transformer	Yearly units saved over baseline (kWh/year)	Money saved in 10 years (INR)	Incremental repair costs over normal repairs (INR)	Payback (years)
100 KVA (Name Plate)	4779.3	4,76,063	86,789	3.18
86 KVA (Actual observed Pre-repair)	4779.3	4,76,063	86,789	1.66

Some key assumptions made for payback calculations:

1. DT loading – 70%
2. Average Cost of Supply (ACoS) of 6.25 Rs. /kWh
3. 10% CAGR assumed for Average Cost of Supply
4. Normal As-Is repair cost for 100 KVA DT is INR 11,520 and for 200 KVA is INR 20,183

5. Incremental repair cost over and above normal repair is used for payback calculation. (The labor rates for repair remains similar to that of Normal repair)
6. 70% term loan assumed with 9.93% rate of interest

6.1.4.2. Scenario Analysis (considering actual 86kVA)

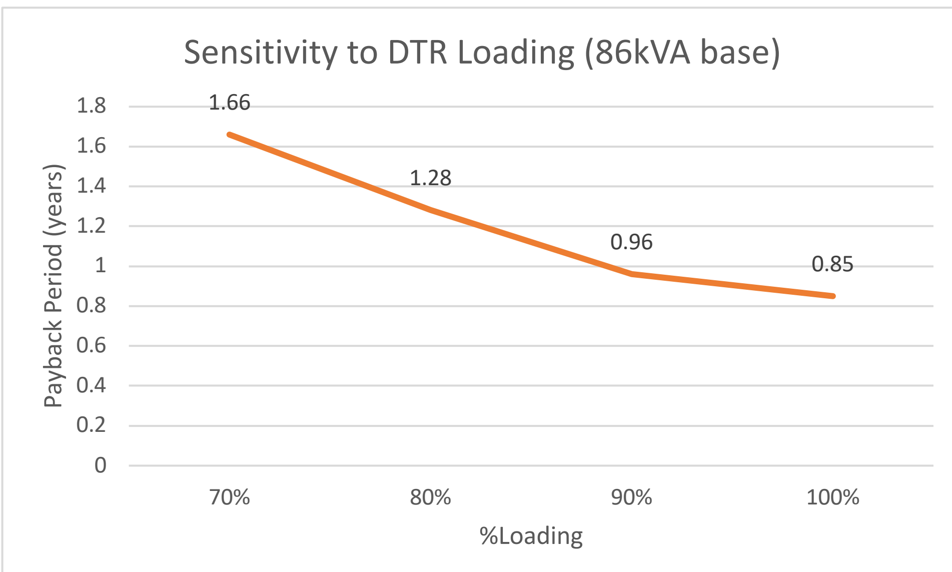
Sensitivity to **CAGR of Avg. Cost of Supply**

Solution	Payback period (years)		
	For 0% CAGR	**For 5% CAGR**	**For 10% CAGR**
	1.73	1.69	**1.66**

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**
	1.66	1.28	0.96	0.85



Sensitivity to **increased kVA capacity**

If an additional benefit of increased kVA capacity (109kVA from 86kVA) is considered, then payback will reduce further.

Solution	Payback period (years)	
	Increase in kVA capacity not considered	**Considering Increase in kVA capacity**
	3.18	**1.66**

6.1.4.3. Scenario Analysis (100kVA as per base nameplate)

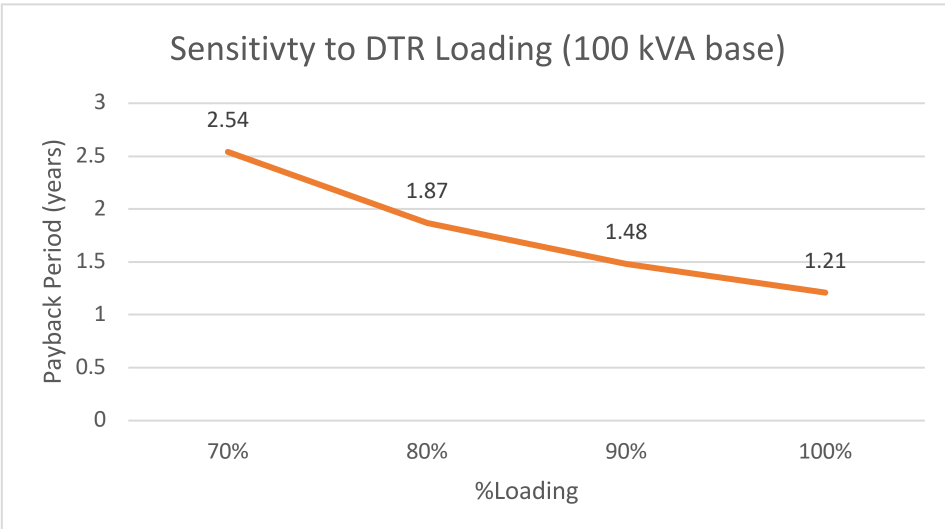
Sensitivity to **CAGR of Avg. Cost of Supply**

Solution	**Payback period (years)**		
	For 0% CAGR	**For 5% CAGR**	**For 10% CAGR**
	2.75	2.64	**2.54**

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**
	2.54	1.87	1.48	1.21



Sensitivity to **increased kVA capacity**

If an additional benefit of increased kVA capacity (109kVA from 100kVA) is considered, then payback will reduce further.

Solution	**Payback period (years)**	
	Increase in kVA capacity not considered	**Considering Increase in kVA capacity**
	3.18	**2.54**

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)

	Project IRR (%) with Cu Salvage value
@ACoS 6.25 Rs. /kWh	
86kVA	60.85
100kVA	49.66

6.2. Option-1(B): Improvement for Best Performance – 200 KVA

This option envisages to achieve lowest losses and kVA capacity enhancement of existing failed DT. The focus is on reduction of full load losses & thereby getting maximum possible efficiency, as well as the capability to perform under overloading conditions. Design of existing LV & HV both have been altered along with use of copper in place of existing aluminum, as winding material

6.2.1. 'As-Is' measurement

The failed transformer was allotted from old purchase orders before the enforcement of IS:1180 P-1-2014 where 50% and 100% load losses were mentioned. Hence, the 'As-Is' losses were assumed as per the GTP of the failed transformers, as per the relevant PO's where No Load Loss were 500W (for 200 KVA) and full load loss value is assumed to be the maximum expected values after repairs.

Parameters	Unit	'As-Is' Value	% Deviation from ideal values*
Capacity	KVA	200	-
Make		Electron Indore	-
Year of Mfg.		NA	-
Sr. No.		99651	-
Flux Density	Tesla	1.55	-
LV winding material		DPC Al	-
No. of turns (LV winding)	#	42	-
HV winding material		DPC Al	-
No. of turns (HV winding)	#	1848	-
Total loss	Watts	3850	-
Impedance	%	4.5	-
Total Winding Weight	kg	86.19	-

Table 4. Key Baseline Parameters of Distribution Transformer-200kVA

**1-star as per old BIS standard: Total Loss 3500 Watts*

6.2.2. Solution Design

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

Rating	Solution Design	Core unchanged	Designed LV winding (Material, # of turns, ID, OD, Height)	Designed HV winding (Material, # of turns, ID, OD, Height)	Estimated Total Loss as per design (Watts)
200 kVA	LV & HV Copper with same no. of turns (Reduced Full-Load; increased kVA)	Yes	DPC Copper, 42, 165, 220, 405	DPC Copper, 1848, 240, 311, 56	2261

Table 5 Design Solution for Repair-200kVA

6.2.3. Repair Execution

After conducting all tests, results were obtained for various parameters in reference to the baseline measurements. Post-repair technical loss reduction was validated by ERDA by conducting loss and impedance measurement tests. Following are the results obtained:

Key Design Parameters	Unit	Specification	Baseline (As-Is)	Actual Post repair results (measured at MTRU)	Actual Post repair results (measured at ERDA)
Capacity	kVA	200	200	200	200
Year of Manufacturing		-	2004	-	-
Flux Density	Tesla	1.55	-	-	-
LV Winding Material		-	DPC Al	DPC Cu	DPC Cu
# of LV Turns	#	-	42	42	42
HV Winding Material		-	DPC Al	DPC Cu	DPC Cu
# of HV Turns	#	-	1848	1848	1848
Total Loss	Watt	3000	3850	2319	2297
Impedance	%	4.5	-	4.36	4.42
Total Winding Weight	Kg	-	86.19	297.45	297.45

Table 6 Baseline v/s Actual results as per design specifications for 200kVA

Calculation of enhanced kVA based on ERDA test results, as per IS 2026 Part-2

Check of temperature rise at approx. 10% enhanced continuous KVA

FACTORS IS 2026	CALC MF	PARTICULRS	ERDA RESULTS	AT ENHANCED KVA	LIMITS- IS 2026
		KVA	200	**219**	
+ 10%(1.1 TIMES)	1.095	LOAD/LV AMP	266.67	292.00365	
+ 20%(1.2 TIMES)	1.199025	LOAD LOSS	1729.69	2073.941552	
		NO LOAD LOSS	567.79	567.79	
		TOTAL LOSS	2297.48	2641.731552	
0.8	1.118174426	OIL TEMP RISE	30.5	**34.10431999**	50
1.6	1.156278874	WNDG T RISE	47.3	**54.69199072**	55
	1.095	% IMPEDANCE	4.42	4.8399	

6.2.4. Cost Benefit Analysis

Summary of Cost Benefit Analysis (CBA) is indicated below.

6.2.4.1. Top Results

200 KVA	**Yearly units saved over baseline (kWh/year)**	**Money saved in 10 years (INR)**	**Incremental repair costs over normal repairs (INR)**	**Payback (years)**
	4858.84	3,03,677.5	1,31,529.25	**3.55**

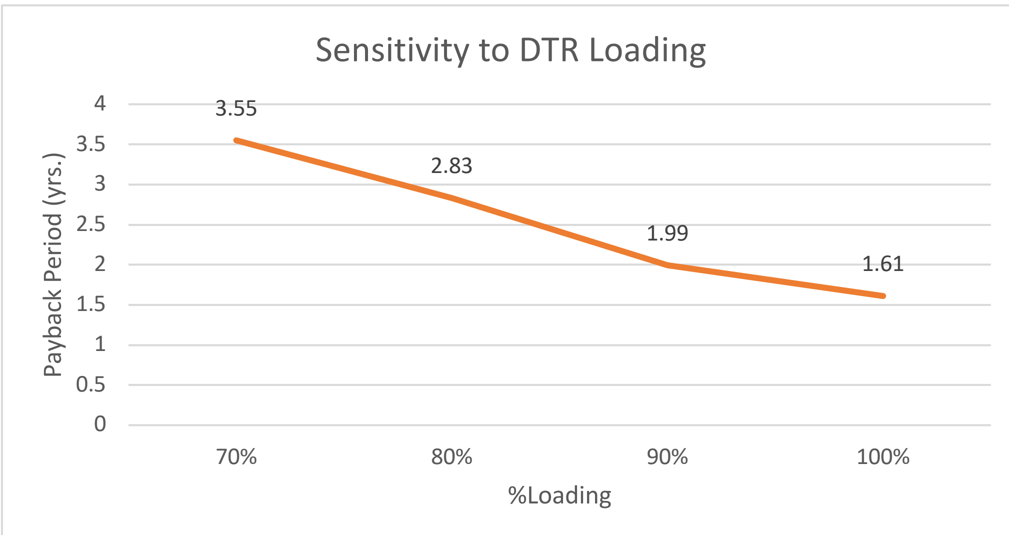
6.2.5. Scenario Analysis

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

Solution	Payback period (years)		
	For 0% CAGR	For 5% CAGR	For 10% CAGR
	4.21	3.77	**3.55**

Sensitivity to **DTR Loading**

Solution	Payback period (years)			
	70% DTR Load	80% DTR Load	90% DTR Load	100% DTR Load
	3.55	2.83	1.99	1.61



Sensitivity to **increased kVA capacity**

If an additional benefit of increased kVA capacity (**219kVA**) is considered, then payback will reduce further.

Solution	Payback period (years)	
	Increase in kVA capacity not considered	Considering Increase in kVA capacity
	4.56	**3.55**

Sensitivity to **Salvage value of Cu at the end of life**

The salvage value of Cu does not impact the payback but improves the Project IRR (Internal Rate of Return)

	Project IRR (%) with Cu Salvage value
@ACoS 6.25 Rs. /kWh	
200kVA	37.13

6.3. Option-2: Improvement for Cost-effective Capacity Enhancement

This option envisages cost-effective efficiency improvement along with KVA enhancement. With an optimum initial cost, The focus is on capability to perform under overloading conditions, reduction of full load losses & thereby getting improved efficiency, Design of existing LV & HV both have been altered along with use of copper for HV & Aluminum for LV, in place of existing aluminum in both , as winding material

6.3.1. 'As-Is' Measurement

The below table summarizes key baseline parameters of acquired failed 100kVA DT and its related details:

Parameters	Unit	'As-Is' Value	% Deviation from ideal values*
Capacity	KVA	200	-
Make		-	-
Year of Mfg.		-	-
Sr. No.		-	-
Flux Density	Tesla	-	-
LV winding material		DPC Al	-
No. of turns (LV winding)	#	42	-
HV winding material		DPC Al	-
No. of turns (HV winding)	#	1848	-
Total Winding Weight	kg	100.3	-
Impedance	%	4.5	-
Total Loss	Watts	3865*	-

**Could not measure total loss hence assumed spec + allowed total loss deviation (10%) for a 200kVA 1-star DT*

6.3.2. Solution Design

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

Rating	Solution Design	Core unchanged	Designed LV winding (Material, # of turns, ID, OD, Height)	Designed HV winding (Material, # of turns, ID, OD, Height)	Estimated Total Loss as per design (Watts)
200 kVA	LV Aluminum & HV Copper with same no. of turns	Yes	DPC Aluminum, 42, 167, 221, 400	DPC Copper, 1848, 243, 310, 55	2418

6.3.3. Repair Execution

After conducting all tests, results were obtained for various parameters in reference to the baseline measurements. Post-repair technical loss reduction was validated by ERDA. Following are the results obtained:

Key Design Parameters	Unit	Specification	Baseline (As-Is)	Actual Post repair results (measured at ERDA)
Capacity	kVA	200	200	200
Year of Manufacturing		-	-	-
Flux Density	Tesla	1.55	-	-
LV Winding Material		-	DPC Al	DPC Al
# of LV Turns	#	-	42	42
HV Winding Material		-	DPC Al	DPC Cu
# of HV Turns	#	-	1848	1848
Total Loss	Watt	3500	3850	3029
Impedance	%	4.5	-	4.2
Total Winding Weight	kg	-	100.50	178

Table 7. Baseline v/s Actual results as per design specifications for 200kVA (HV-Cu; LV-Al)

Some images of repair execution

Figure 13. Acquired failed DT

Figure 14. Pre-repair testing

Figure 15. Acquired failed DT core

Figure 16. DT Nameplate

6.3.4. Cost Benefit Analysis

Summary of Cost Benefit Analysis (CBA) is indicated below.

6.3.4.1. Top Results

200 KVA	Yearly units saved over baseline (kWh/year)	Money saved in 10 years (INR)	Incremental repair costs over normal repairs (INR)	Payback (years)
	8,927	8,89,240	77,917	**1.13**

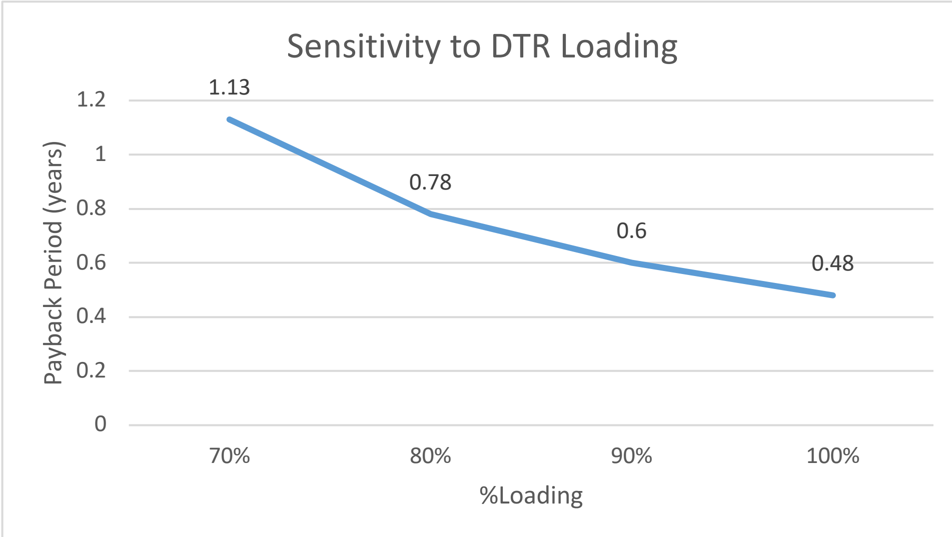
6.3.5. Scenario Analysis

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

Solution	Payback period (years)		
	For 0% CAGR	For 5% CAGR	For 10% CAGR
	1.14	1.13	**1.13**

Sensitivity to **DTR Loading**

Solution	Payback period (years)			
	70% DTR Load	80% DTR Load	90% DTR Load	100% DTR Load
	1.13	0.78	0.60	0.48



Sensitivity to **increased kVA capacity**

If an additional benefit of increased kVA capacity (**228 kVA**) is considered, then payback will reduce further.

Solution	**Payback period (years)**	
	Increase in kVA capacity not considered	**Considering Increase in kVA capacity**
	1.52	**1.13**

Sensitivity to **Salvage value of Cu at end of life**

The salvage value of Cu does not impact the payback but improves the Project IRR (Internal Rate of Return)

	Project IRR (%) with Cu Salvage value
@ACoS 6.25 Rs. /kWh	
200kVA	86.51%

7. Post Repair Monitoring of DTs

Post Repair metering was done on both sides of the DTs (both 100 kVA and 200 kVA) with MPPKVVCL team. The metering will help monitor the performance of Repaired DTs.

Figure 17. Metering on Repaired 200 kVA DT

Figure 18. Metering on Repaired 100 kVA DT

8. 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

	100 KVA	200 KVA	200 KVA (HV-Cu; LV-Al)
Total loss	+30%	-	+34%

2. Repair does help in technical loss reduction (compared to spec + allowed deviation values).

	100 KVA	200 KVA	200 KVA (HV-Cu; LV-Al)
Total Loss	-34%	-40%	-21%

3. Actual Repair results were close to the estimations (in 100kVA DT results were better than estimations).

	Assumed Designed values	Actual observed (at MTRU)	Actual observed (at ERDA)
For 100 KVA			
Total Loss (W)	1469	1461	1463
For 200 KVA			
Total Loss (W)	2261	2319	2297
For 200 KVA (HV-Cu; LV-Al)			
Total Loss (W)	2418	Not Measured	3029

4. Cost Benefit Analysis is as follows

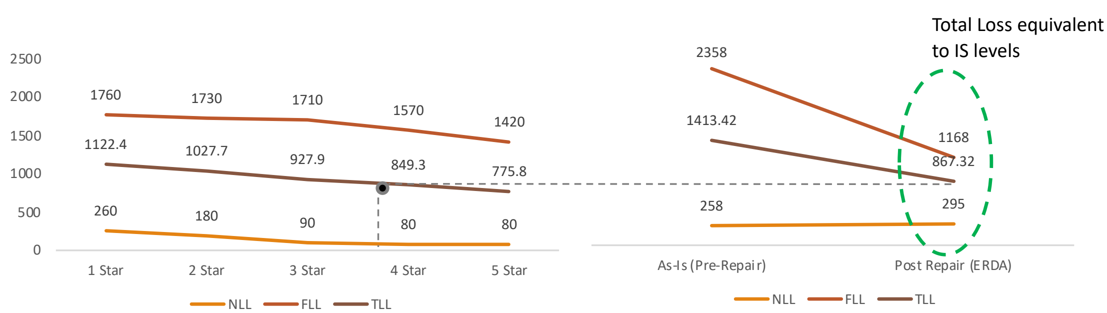
Payback Period (Yrs.)	86 KVA	100 KVA	200 KVA	200 KVA (Cost effective design)
Without KVA Enhancement	3.18	3.18	4.56	1.52
With KVA Enhancement	1.66	2.54	3.55	1.13

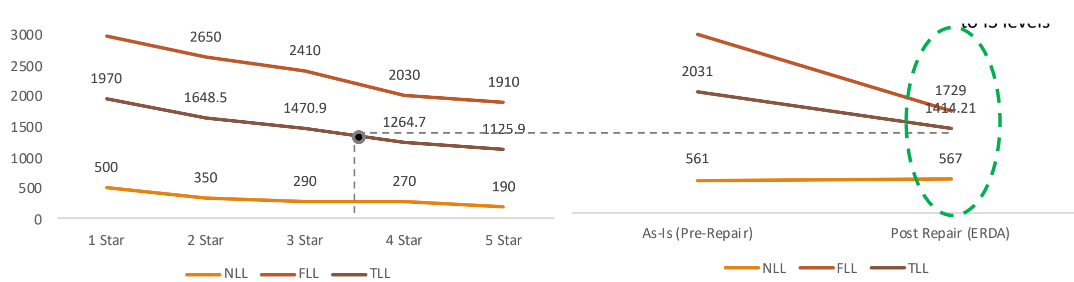
   4.1. Additional substantiated sensitivity analysis brings **2-5 years' payback period** for real life assumptions, indicating high potential opportunity and requiring deeper exploration.

5. It is evident from the Post repair test results that, in addition to the increased efficiency the continuous loading ability/capacity of both 100 & 200 KVA Transformers is increased to 109 KVA & 219 KVA respectively without affecting the Temperature Rise limits & Impedance Parameters of IS 2026. The KVA benefit is even more on comparing 109 KVA with 86.41 KVA. The third model (LV=Al; HV=Cu) shows even better results with payback period in 1.5 year.

6. As the design values are fairly close to actual achieved loss reduction, it can be inferred that DTs can have a baseline for technical losses at on-site then 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.

7. **Upgradation of old DTs**: Repair enhances the performance of the old DT to a level of Energy Efficiency stipulated as per IS 1180 specially at higher loading conditions





**Total Losses values are calculated at 70% DTR loading*

9. Key Recommendations

1. **Modify existing in-house DT repair process:** DTs being repaired in-house must go through a process change due to inefficient existing repair practices (e.g. poor design, workmanship, sub-standard material etc.). Some suggested changes are:
   a. Pre-repair testing of DTs to be done to check the loss levels
   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. Post repair testing to be conducted to measure losses and at times temperature rise test to be conducted to check capacity enhancement
   f. On a sample basis, repaired DTs to be tested at accredited lab (e.g. CPRI/ERDA)

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):** 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.

10. Applicability to broader MPPKVVCL utility

1. MPPKVVCL is the large power distribution company in India with total DTs count 2,25,296. The AT&C losses is around 29% as per performance indicator of MPPKVVCL.
2. The above concept has been explored for two sample DT only. However, depending on the condition of 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 2-5 years.
5. Base on the estimation of loss deviations of Discom data and representing at MPPKVVCL level, it is observed that DTs contribute ~5% of technical losses at overall utility level, resulting in ~1302.92 MU loss (assuming avg. cost of power supply as 6.25 kWh/unit).

	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 Repaired)
%loading	50%	50%	50%	50%
%deviation of No-load loss	0%	15%	15%	+10%
%deviation of Full load loss	0%	15%	30%	-30%
Estimated total losses (MUs/year)	1,048	1,206	1,302	896
% Total losses with respect to energy input	4.51%	5.19%	**5.61%**	**3.86%**
Total DT technical losses (Cr.)	655.59	753.93	814.32	560.10

Assumptions		
Total Transformers	#	2,25,296
Avg. Loading	%	50%
Avg. Cost of power supply	kWh/unit	6.25
Total revenue of MPPKVVCL (as per ARR 2017-18)	Cr.	11,364
Energy Input (as per ARR 2017-18)	MU/year	23,242

6. If 5% technical loss can be brought down to 3% (based on best performing utility's standard) through effective & DT repair & maintenance, it can save nearly INR 254 Cr. per year (approx. 3.83% of Avg. revenue)

6.1. Even if 71% of MVA capacity (less than 200kVA) is Repaired it can save nearly 180 Cr./year

- **Old DTs have potentially higher technical losses than being thought (i.e. ~5%) causing loss of INR 814 Cr. annually.**
- **Repair has the potential to reduce the technical losses and upgrade the DTs performance equivalent to Energy Efficiency levels as specified by IS 1180. It can save nearly INR 254 Cr. per year (approx. 3.83% of Avg. revenue)**

Annexures

Annexure A: Snapshot of Post Repair Reports for 100kVA and 200kVA DT

Project: Active Repair of Distribution Transformer at MTRU Indore MP									
OFFICE OF THE E.E. (MTRU), M.P.P.K.V.V.Co.Ltd., INDORE									
TRANSFORMER ROUTINE TEST REPORT		(Post Repair)				Test Sr. No.		Test Date	03-05-2018
G.P.No. & Dt.:		Date		Name of A/S	INDORE			Time: 4.00 pm	
MFD. By:	swastik copper ltd jaipur			HV VOLT :	11000		% IMP :	4.5	
KVA:	100			LV VOLT :	433		CONNECTION:	Delta/Star	
Sr. No.:	MR NO-8973 SC/119243 id code-13-37609-9			HV AMP:	5.25		VECTOR GR :	Dy 11	
Winding:	Cu			LV AMP:	133.34		COOLING :	ONAN	
1. TURN RATIO & POLARITY TEST									
TAP NO.	POLARITY	STD> VALUE		RATIO PH U		RATIO PH V		RATIO PH W	
NORMAL	OK	44.00		44.05		44.05		44.00	
2. INSULATION RESISTANCE TEST									
AMB. TEMP(°C)		MEGGER VOLTS		LV - HV(M-OHMS)		HV -E(M-OHMS)		LV -E(M-OHMS)	
36.9		1000		> 2000		> 2000		> 2000	
3. POWER FREQUENCY HV WITHSTAND TEST									
HV WINDINGS (KV/MIN.)			RESULTS		LV WINDINGS (KV/MIN.)			RESULTS	
28			WITHSTOOD		3			WITHSTOOD	
4. INDUCED OVER VOLTAGE WITHSTAND TEST									
VOLTS ON HV SIDE(KV)			FREQUENCY(HZ)		TIME (MIN.)		RESULTS		
22			100		1		WITHSTOOD		
5. NO LOAD LOSS MEASURMENT									
CTR ›	1	PTR ›	1	WMF ›	1	FREQUENCY ›		50	HZ
V1(PH-PH)	V2(PH-PH)	V3(PH-PH)	A1	A2	A3	W1	W2	W3	SUM(W)
426.73	442.02	430.25	3.130	3.081	3.29	39.6	116.70	136.6	292.9
AVG.VOLTS FED. ›		433.00	AVG. N.L.AMP. ›		3.167	NO LOAD LOSS(WATTS) ›			293
6. WINDING RESISTANCE MEASURMENT									
AMB. TEMP(°C)		HV WINDINGS- NORMAL TAP (Ω)				LV WINDINGS- (mili Ω)			
36.9		UV	VW	WU	AVERAGE	UV	VW	WU	AVERAGE
		14.5	14.50	14.48	14.49	14.49	15.24	14.75	14.83
7. LOAD LOSS MEASURMENT AT 50% LOAD									
AMB. TEMP(°C) ›		36.9							
CTR ›	1	PTR ›	1	WMF ›	1	FREQUENCY ›		50	HZ
A1	A2	A3	V1(PH-PH)	V2(PH-PH)	V3(PH-PH)	W1	W2	W3	SUM(W)
2.572	2.725	2.577	222.77	231.60	225.11	81.54	89.77	86.59	257.9
AVG. TEST AMP. FED ›		2.6247	AVG. IMP. VOLTS AT TEST ›		226.49	LOAD LOSS @ TEST AMP (WATTS) ›			258
		% IMPEDENCE @ RATED AMP. @ 75°C ›			NA	LOAD LOSS @ RATED AMP (WATTS) @ 75°C ›			291.61
CALCULATION LOAD LOSSES & % IMPEDENCE					TEMP. CORRECTION CO-EFFICIENT ›			235	Cu
AT LOSS TEST TEMP. ›			36.9 °C		AT PERFORMANCE TEMP. ›			75 °C	
a.	I^2R (HV)		149.80		a.	I^2R (HV)		170.79	
b.	I^2R (LV)		98.85		b.	I^2R (LV)		112.71	
c.	I^2R TOTAL		248.66		c.	I^2R TOTAL		283.50	
d.	STRAY LOSS		9.24		d.	STRAY LOSS		8.11	
e.	LOAD LOSS @ RATED AMP.		258		e.	LOAD LOSS @ RATED AMP.		291.61	
8. TOTAL LOSS AT 50% LOAD ›			292.90	+	291.61	=		584.51 WATT	
9. LOAD LOSS MEASURMENT AT 100% LOAD									
AMB. TEMP(°C) ›		36.9							
CTR ›	1	PTR ›	1	WMF ›	1	FREQUENCY ›		50	HZ
A1	A2	A3	V1(PH-PH)	V2(PH-PH)	V3(PH-PH)	W1	W2	W3	SUM(W)
5.179	5.41	5.16	448.93	460.23	451.22	331.70	354.10	347.90	1033.7
AVG. TEST AMP. FED ›		5.250	AVG. IMP. VOLTS AT TEST ›		453.46	LOAD LOSS @ TEST AMP (WATTS) ›			1034
		% IMPEDENCE @ RATED AMP. @ 75°C ›			4.158	LOAD LOSS @ RATED AMP (WATTS) @ 75°C ›			1168.27
CALCULATION LOAD LOSSES & % IMPEDENCE					TEMP. CORRECTION CO-EFFICIENT ›			235	Cu
AT LOSS TEST TEMP. ›			36.9 °C		AT PERFORMANCE TEMP. ›			75 °C	
a.	I^2R (HV)		599.21		a.	I^2R (HV)		683.17	
b.	I^2R (LV)		395.42		b.	I^2R (LV)		450.83	
c.	I^2R TOTAL		994.63		c.	I^2R TOTAL		1134.00	
d.	STRAY LOSS		39.07		d.	STRAY LOSS		34.27	
e.	LOAD LOSS @ RATED AMP.		1034		e.	LOAD LOSS @ RATED AMP.		1168.27	
f.	% R		1.0337		f.	% R		1.168	
g.	% X		3.991		g.	% X		3.991	
h.	% Z @ RATED AMP.		4.12		h.	% Z @ RATED AMP.		4.158	
10. TOTAL LOSS AT 100% LOAD ›			292.90	+	1168.27	=		1461.17 WATT	
ICA India		Design Expert (Tristar Technocrates)			J.E./A.E.(MTRU)			E.E.(MTRU) C/S	

Project: Active Repair of Distribution Transformer at MTRU Indore MP

OFFICE OF THE E.E. (MTRU), M.P.P.K.V.V.Co.Ltd., INDORE

TRANSFORMER ROUTINE TEST REPORT (Post Repair)

G.P.No. & Dt.:		Test Sr. No.		Test Date	03-05-2018
MFD. By:	Date ELECTRONS INDORE	Name of A/S	INDORE	Time: 4.00 pm	
KVA:	200	HV VOLT :	11000	% IMP :	4.5
Sr. No.:	MR NO-8974 SR NO-99651 id code-04-14890-4	LV VOLT :	433	CONNECTION:	Delta/Star
Winding:	Cu	HV AMP:	10.5	VECTOR GR :	Dy 11
		LV AMP:	266.67	COOLING :	ONAN

1. TURN RATIO & POLARITY TEST

TAP NO.	POLARITY	STD> VALUE	RATIO PH U	RATIO PH V	RATIO PH W
NORMAL	OK	44.00	43.88	43.96	43.85

2. INSULATION RESISTANCE TEST

AMB. TEMP(°C)	MEGGER VOLTS	LV - HV(M-OHMS)	HV -E(M-OHMS)	LV -E(M-OHMS)
44.7	1000	> 2000	> 2000	> 2000

3. POWER FREQUENCY HV WITHSTAND TEST

HV WINDINGS (KV/MIN.)	RESULTS	LV WINDINGS (KV/MIN.)	RESULTS
28	WITHSTOOD	3	WITHSTOOD

4. INDUCED OVER VOLTAGE WITHSTAND TEST

VOLTS ON HV SIDE(KV)	FREQUENCY(HZ)	TIME (MIN.)	RESULTS
22	100	1	WITHSTOOD

5. NO LOAD LOSS MEASURMENT

CTR ›	1	PTR ›	1	WMF ›	1	FREQUENCY ›		50	HZ
V1(PH-PH)	V2(PH-PH)	V3(PH-PH)	A1	A2	A3	W1	W2	W3	SUM(W)
426.44	442.98	429.71	4.253	3.377	4.201	51.9	150.30	358.9	561.1
AVG.VOLTS FED. ›		433.04	AVG. N.L.AMP. ›		3.944	NO LOAD LOSS(WATTS) ›			561

6. WINDING RESISTANCE MEASURMENT

AMB. TEMP(°C)	HV WINDINGS- NORMAL TAP (Ω)				LV WINDINGS- (mili Ω)			
	UV	VW	WU	AVERAGE	uv	vw	wu	AVERAGE
44.7	5.29	5.28	5.27	5.28	5.38	5.16	5.10	5.21

7. LOAD LOSS MEASURMENT AT 50% LOAD

AMB. TEMP(°C) ›		44.7							
CTR ›	1	PTR ›	1	WMF ›	1	FREQUENCY ›		50	HZ
A1	A2	A3	V1(PH-PH)	V2(PH-PH)	V3(PH-PH)	W1	W2	W3	SUM(W)
5.148	5.411	5.194	237.04	243.78	238.29	125.39	144.30	138.43	408.1
AVG. TEST AMP. FED ›		5.2510	AVG. IMP. VOLTS AT TEST ›		239.70	LOAD LOSS @ TEST AMP (WATTS) ›			408
		% IMPEDENCE @ RATED AMP. @ 75°C ›			NA	LOAD LOSS @ RATED AMP (WATTS) @ 75°C ›			441.86

CALCULATION LOAD LOSSES & % IMPEDENCE			TEMP. CORRECTION CO-EFFICIENT ›		235	Cu
AT LOSS TEST TEMP. ›		44.7 °C	AT PERFORMANCE TEMP. ›		75 °C	
a.	I^2R (HV)	218.30	a.	I^2R (HV)	241.94	
b.	I^2R (LV)	139.03	b.	I^2R (LV)	154.09	
c.	I^2R TOTAL	357.32	c.	I^2R TOTAL	396.03	
d.	STRAY LOSS	50.80	d.	STRAY LOSS	45.83	
e.	LOAD LOSS @ RATED AMP.	408	e.	LOAD LOSS @ RATED AMP.	441.86	

8. TOTAL LOSS AT 50% LOAD › 561.10 + 441.86 = 1002.96 WATT

9. LOAD LOSS MEASURMENT AT 100% LOAD

AMB. TEMP(°C) ›		44.7							
CTR ›	1	PTR ›	1	WMF ›	1	FREQUENCY ›		50	HZ
A1	A2	A3	V1(PH-PH)	V2(PH-PH)	V3(PH-PH)	W1	W2	W3	SUM(W)
10.331	10.808	10.371	476.13	486.71	476.80	505.80	569.70	547.00	1622.5
AVG. TEST AMP. FED ›		10.503	AVG. IMP. VOLTS AT TEST ›		479.88	LOAD LOSS @ TEST AMP (WATTS) ›			1623
		% IMPEDENCE @ RATED AMP. @ 75°C ›			4.376	LOAD LOSS @ RATED AMP (WATTS) @ 75°C ›			1758.45

CALCULATION LOAD LOSSES & % IMPEDENCE			TEMP. CORRECTION CO-EFFICIENT ›		235	Cu
AT LOSS TEST TEMP. ›		44.7 °C	AT PERFORMANCE TEMP. ›		75 °C	
a.	I^2R (HV)	873.18	a.	I^2R (HV)	967.77	
b.	I^2R (LV)	556.10	b.	I^2R (LV)	616.35	
c.	I^2R TOTAL	1429.28	c.	I^2R TOTAL	1584.12	
d.	STRAY LOSS	193.22	d.	STRAY LOSS	174.33	
e.	LOAD LOSS @ RATED AMP.	1623	e.	LOAD LOSS @ RATED AMP.	1758.45	
f.	% R	0.81125	f.	% R	0.879	
g.	% X	4.286	g.	% X	4.286	
h.	% Z @ RATED AMP.	4.36	h.	% Z @ RATED AMP.	4.376	

10. TOTAL LOSS AT 100% LOAD › 561.10 + 1758.45 = 2319.55 WATT

ICA India 4/5	Design Expert (Tristar Technocrates) 4/5/18	J.E./ A.E.(MTRU)	C/S E.E.(MTRU)

Annexure B: Snapshot of Losses Chart from recent TS-1116

S N	Rating in KVA	Max. Losses in Watts at 75°C			
		No load losses(Watts)		Load losses (Watts)	
		Max. permissible guaranteed No load Losses for transformers	Max. limit of permissible No load Losses beyond this the red strip will be marked	Max. permissible guaranteed load Losses.	Tolerance
1	2	3	4	5	6
1	16	80	120	475	10 %
2	25	100	150	685	10 %
3	63	180	270	1235	10 %
4	100	260	390	1760	10 %
5	200	500	750	3000	10 %

Annexure C: Snapshot of ERDA Test Result 100kVA

ELECTRICAL RESEARCH AND DEVELOPMENT ASSOCIATION
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Fax : +91 (0265) 2638382
E-mail : erda@erda.org
Web : http://www.erda.org

Certificate No. : TC-5389

TEST REPORT Sheet : 1 of 6

NAME AND ADDRESS OF CUSTOMER M/s. M.P.PASHCHIM KSHETRA VIDYUT VITARAN CO.LTD. OFFICE OF THE EXECUTIVE ENGINEER (MTRU) GPH COMPOUND,POLOGROUND, INDORE (M.P.)-452001.	**REPORT NO.:** RP-1819-015362 **DATE** : 21.07.2018	
	CUSTOMER REF. NO.	**DATE**
	NO.242/EE/MTRU/18-19/ INDORE	24.05.2018
	DATE OF SAMPLE RECEIPT	**DATE OF TESTING**
	13.06.2018	11.07.2018 & 12.07.2018

SAMPLE DESCRIPTION
DISTRIBUTION TRANSFORMER
Manufactured by: SWASTIK COPPER P. LTD.
Rating : 100 kVA
Volts : 11000/433 V (at no-load)
Current : 5.25/133.3 Amps
Phases : 3/3 ; %Impedance : 4.5 %
Vector group : Dyn11 ; Frequency : 50 Hz
Winding : Copper
Cooling : ONAN
Losses as specified by customer :
1.Guaranteed no load loss : 260 W +(IS Tol.)
2.Guaranteed load loss at 75 °C:
1760 W +(IS Tol.)
Guaranteed maximum temperature-rise in oil/winding :45/50°C(as specified by customer)

SAMPLE IDENTIFICATION
ERDA sample code number : ERDA-00263644
Manufacturer serial no. : SC/119243
Customer: Madhya Pradesh Paschim Kshetra Vidyut Vitaran company ltd.
Year of manufacture :2013

Enclosed drawing numbers :
1) ICA/SC/100.11/02
2) ICA/SC/100.11/01

TEST DETAILS
As per sheet 2 of 6.

TEST SPECIFICATION
As per sheet 2 of 6.

TEST RESULTS : As per sheets from 3 of 6 to 5 of 6.

ENCLOSURE : Photographs of test sample – As per sheet 6 of 6.

TESTS WITNESSED BY : 1) Mr.Sunil Patel (E.E.,M/s.MPPKVVCL-INDORE)
2) Mr.Ashish Pandit (Project associate, M/s. International Copper Association, India)

REMARKS : 1)The transformer **conforms** to the guaranteed requirement as per above mentioned test specification for above mentioned test nos. 2 to 4.
2) Criteria limit has not been specified for test no.1.

PREPARED BY **CHECKED BY** **APPROVED BY** (Kapil J. Sharma)

Note : 1. This report relates only to the particular sample received for testing in good condition at E.R.D.A.
2. This report cannot be reproduced in part under any circumstances.
3. Publication of this report requires prior permission in writing from Director, E.R.D.A.
4. Only the tests asked for by the customer have been carried out.
5. In case of any dispute, Vadodara will be the exclusive jurisdiction & shall be construed as where the cause has arised.

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TC 2572944

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Web : http://www.erda.org

REPORT NO.: RP-1819-015362 **Sheet :** 2 of 6
DATE : 21.07.2018

	TEST DETAILS	TEST SPECIFICATION
1.	Measurement of winding resistance	As per cl.no.10.2 of IS 2026 (Part 1) : 2011
2.	Measurement of short-circuit impedance and load loss.	As per customer's requirement, testing procedure followed as per cl.no.10.4 of IS 2026 (Part 1) : 2011
3.	Measurement of no-load loss and current	As per customer's requirement, testing procedure followed as per cl.no.10.5 of IS 2026 (Part 1) : 2011
4.	Temperature-rise test	As per customer's requirement testing procedure followed as per cl.no.5 of IS 2026 (Part 2) : 2010

PREPARED BY **CHECKED BY**

TC 2572943

Certificate No. : TC-5389

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Web : http://www.erda.org

REPORT NO.: RP-1819-015362 **Sheet :** 3 of 6
DATE : 21.07.2018

Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
1.	**Measurement of winding resistance :** (As per cl.no.10.2 of IS 2026 (Part 1) : 2011) Top oil temperature: 30.4°C			---
	HV Winding			
	1U – 1V:	--	14.152 Ω	
	1V – 1W:	--	14.146 Ω	
	1U – 1W:	--	14.152 Ω	
	Average:	--	14.150 Ω	
	LV Winding			
	2u – 2v:	--	14.047 mΩ	
	2v – 2w:	--	14.141 mΩ	
	2u – 2w:	--	14.193 mΩ	
	Average:	--	14.127 mΩ	

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REPORT NO.: RP-1819-015362 **Sheet :** 4 of 6
DATE : 21.07.2018

Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
2.	**Measurement of short-circuit impedance and load loss :** (As per customer's requirement, testing procedure followed as per cl.no.10.4 of IS 2026 (Part 1) : 2011) Tested with **5.2517** Amps (on HV side) Frequency : **50.013** Hz Top oil temperature : **31.7**°C			Conforms
	Test current (Amps)		5.2517	
	Impedance voltage (Volts)		459.38	
	Measured load loss (Watts)		1019.0	
	Impedance voltage (%) (Computed to 100% load)			
	At 31.7 °C		4.17	
	At 75 °C	4.50 (± 10%) (As specified by customer)	4.21	
	Load loss (Watts) (Computed to 100% load)			
	At 31.7 °C		1018.34	
	At 75 °C	1760 +(IS Tol.) (As specified by customer)	1168.01	
3.	**Measurement of no-load loss and current :** (As per customer's requirement, testing procedure followed as per cl.no.10.5 of IS 2026 (Part 1) :2011) Tested with average **432.46** volts (on LV side) Frequency : **49.932** Hz			Conforms
	RMS Voltage (Volts)		432.60	
	No load current (Amps)		3.1583	
	Measured No load loss (Watts)		295.60	
	Corrected No load loss (Watts)	260 +(IS Tol.) (As specified by customer)	295.51	

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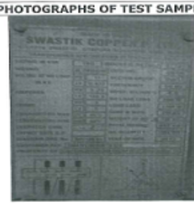
REPORT NO.: RP-1819-015362 **Sheet :** 6 of 6
DATE : 21.07.2018

PHOTOGRAPHS OF TEST SAMPLE



ERDA-00263644
PSMPIW-1819-003872

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Annexure D: Snapshot of ERDA Test Result 200kVA

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TEST REPORT Sheet : 1 of 6

NAME AND ADDRESS OF CUSTOMER
M/s. M.P.PASHCHIM KSHETRA VIDYUT VITARAN CO.LTD.
OFFICE OF THE EXECUTIVE ENGINEER (MTRU)
GPH COMPOUND,POLOGROUND,
INDORE (M.P.)-452001.

REPORT NO.: RP-1819-015363
DATE : 21.07.2018

CUSTOMER REF. NO.	DATE
NO.242/EE/MTRU/18-19/ INDORE	24.05.2018
DATE OF SAMPLE RECEIPT	**DATE OF TESTING**
13.06.2018	11.07.2018 & 12.07.2018

SAMPLE DESCRIPTION
DISTRIBUTION TRANSFORMER
Manufactured by: ELECTRANS
Rating : 200 kVA
Volts : 11000/433 V (at no-load)
Current : 10.5/266.67 Amps
Phases : 3/3 ; %Impedance : 4.5 %
Vector group : Dyn11 ; Frequency : 50 Hz
Winding : Copper
Cooling : ONAN
Losses as specified by customer :
1.Guaranteed no load loss : 500 W +(IS Tol.)
2.Guaranteed load loss at 75 °C: 3000 W +(IS Tol.)
Guaranteed maximum temperature-rise in oil/winding :45/50°C(as specified by customer)

SAMPLE IDENTIFICATION
ERDA sample code number : ERDA-00263645
Manufacturer serial no. : 99651
Customer: MPPKVVCL-INDORE
Year of manufacture :1999

Enclosed drawing numbers :
1) ICA/EL/200.11/02
2) ICA/EL/200.11/01

TEST DETAILS
As per sheet 2 of 6.

TEST SPECIFICATION
As per sheet 2 of 6.

TEST RESULTS : As per sheets from 3 of 6 to 5 of 6.

ENCLOSURE : Photographs of test sample – As per sheet 6 of 6.

TESTS WITNESSED BY : 1) Mr.Sunil Patel (E.E.,M/s.MPPKVVCL-INDORE)
2) Mr.Ashish Pandit (Project associate, M/s. International Copper Association, India)

REMARKS : 1)The transformer **conforms** to the guaranteed requirement as per above mentioned test specification for above mentioned test nos. 2 to 4.
2) Criteria limit has not been specified for test no.1.

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Note : 1. This report relates only to the particular sample received for testing in good condition at E.R.D.A.
2. This report cannot be reproduced in part under any circumstances.
3. Publication of this report requires prior permission in writing from Director, E.R.D.A.
4. Only the tests asked for by the customer have been carried out.
5. In case of any dispute, Vadodara will be the exclusive jurisdiction & shall be construed as where the cause has arised.

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REPORT NO.: RP-1819-015363 Sheet : 2 of 6
DATE : 21.07.2018

	TEST DETAILS	TEST SPECIFICATION
1.	Measurement of winding resistance	As per cl.no.10.2 of IS 2026 (Part 1) : 2011
2.	Measurement of short-circuit impedance and load loss.	As per customer's requirement, testing procedure followed as per cl.no.10.4 of IS 2026 (Part 1) : 2011
3.	Measurement of no-load loss and current	As per customer's requirement, testing procedure followed as per cl.no.10.5 of IS 2026 (Part 1) : 2011
4.	Temperature-rise test	As per customer's requirement testing procedure followed as per cl.no.5 of IS 2026 (Part 2) : 2010

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REPORT NO.: RP-1819-015363 **Sheet :** 3 of 6
DATE : 21.07.2018

Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
1.	**Measurement of winding resistance :** (As per cl.no.10.2 of IS 2026 (Part 1) : 2011) Top oil temperature: 31.2°C			---
	HV Winding			
	1U – 1V:	--	5.0495 Ω	
	1V – 1W:	--	5.0545 Ω	
	1U – 1W:	--	5.0515 Ω	
	Average:	--	5.0518 Ω	
	LV Winding			
	2u – 2v:	--	4.9224 mΩ	
	2v – 2w:	--	4.9214 mΩ	
	2u – 2w:	--	4.9668 mΩ	
	Average:	--	4.9369 mΩ	

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REPORT NO.: RP-1819-015363 **Sheet :** 4 of 6
DATE : 21.07.2018

Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
2.	**Measurement of short-circuit impedance and load loss :** (As per customer's requirement, testing procedure followed as per cl.no.10.4 of IS 2026 (Part 1) : 2011) Tested with **10.5012** Amps (on HV side) Frequency : **49.890** Hz Top oil temperature : **31.0**°C			Conforms
	Test current (Amps)		10.5012	
	Impedance voltage (Volts)		483.68	
	Measured load loss (Watts)		1528.63	
	Impedance voltage (%) (Computed to 100% load) At 31.0 °C		4.40	
	At 75 °C	4.50 (± 10%) (As specified by customer)	4.42	
	Load loss (Watts) (Computed to 100% load) At 31.0 °C		1528.28	
	At 75 °C	3000 +(IS Tol.) (As specified by customer)	1729.69	
3.	**Measurement of no-load loss and current :** (As per customer's requirement, testing procedure followed as per cl.no.10.5 of IS 2026 (Part 1) :2011) Tested with average **432.53** volts (on LV side) Frequency : **49.952** Hz			Conforms
	RMS Voltage (Volts)		433.23	
	No load current (Amps)		4.0502	
	Measured No load loss (Watts)		568.70	
	Corrected No load loss (Watts)	500 +(IS Tol.) (As specified by customer)	567.79	

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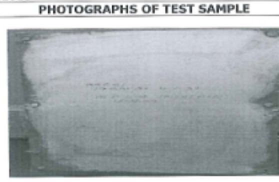
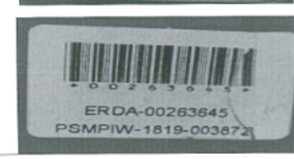
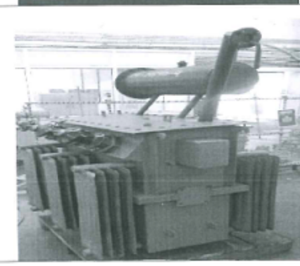
REPORT NO.: RP-1819-015363 **Sheet :** 6 of 6
DATE : 21.07.2018

PHOTOGRAPHS OF TEST SAMPLE







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Annexure E: Snapshot of ERDA Test Result 200kVA (HV-Cu; LV-Al)

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TEST REPORT

ULR-TC538919000022469F

Sheet : 1 of 9

NAME AND ADDRESS OF CUSTOMER MPPKVVCL (MTRU), INDORE GPH COMPOUND, POLOGROUND, INDORE (M.P.) – 452 001.	**REPORT NO.:** RP-1920-014933 **DATE** : 20.07.2019	
	CUSTOMER REF. NO.	**DATE**
	153/EE/MTRU/18-19	26.03.2019
	DATE OF SAMPLE RECEIPT	**DATE OF TESTING**
	11.04.2019	16.07.2019 & 17.07.2019
SAMPLE DESCRIPTION **DISTRIBUTION TRANSFORMER** Manufactured by : RELIABLE TRANSFORMERS Rating : 200 kVA Volts : 11000/433 V (at no-load) Current : 10.5/266.67 Amps Phases : 3/3 Vector group : Dyn11 Further details as per sheet no.2	**SAMPLE IDENTIFICATION** ERDA sample code number : ERDA-00321922 Manufacturer serial no.: RTR/2742 Year of manufacture : 2002 Customer : MPPKVVCL, INDORE (M.P.) Enclosed drawing numbers : 1) ICAI/RTR/200.11/02 2) ICAI/RTR/200.11/01	
TEST DETAILS As per sheet 3 of 9.	**TEST SPECIFICATION** As per sheet 3 of 9.	

TEST RESULTS : As per sheets from 4 of 9 to 8 of 9.

ENCLOSURE: Photographs of test sample - As per sheet 9 of 9.

REMARKS : As per customer's requirement & declared by customer :-

1) Testing was carried out as per IS 2026 (Part 1) : 2011, IS 2026 (Part 2) : 2010 & IS 2026 (Part 3) : 2009.
2) Winding material of HV winding is copper & LV winding is aluminium.
3) Only the test results as obtained during testing are reported.

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REPORT NO.: RP-1920-014933 Sheet : 2 of 9
DATE : 20.07.2019

TECHNICAL SPECIFICATIONS OF TEST OBJECT ASSIGNED BY CUSTOMER

1.	Name of Manufacturer	RELIABLE TRANSFORMERS
2.	Sr.No.	RTR/2742
3.	kVA rating	200
4.	Rated Voltage H.V.(Volts)	11000
5.	Rated Voltage L.V.(Volts)	433
6.	Rated Current H.V.(Amp.)	10.5
7.	Rated Current L.V.(Amp.)	266.67
8.	Number of phases	3
9.	Vector Group	Dyn11
10.	Winding Material : HV winding, LV winding	Copper, Aluminium
11.	Type of Cooling	ONAN
12.	Frequency (Hz)	50
13.	Guaranteed Percentage impedance (%)	4.5
14.	Guaranteed temperature rise of oil/winding	50/55°C
15.	Year of Manufacture	2002
16.	Standard no.	IS 2026 & customer's requirement

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REPORT NO.: RP-1920-014933 Sheet : 3 of 9
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SR. NO.	TEST DETAILS	TEST SPECIFICATION
1.	Measurement of winding resistance.	As per cl.no.10.2 of IS 2026 (Part 1):2011
2.	Measurement of voltage ratio and check of phase displacement	As per cl.no.10.3 of IS 2026 (Part 1):2011
3.	Measurement of short-circuit impedance and load loss at 70%, 100% & 120% load	As per customer's requirement, testing procedure followed as per cl.no.10.4 of IS 2026 (Part 1):2011
4.	Measurement of no-load loss and current.	As per cl.no.10.5 of IS 2026 (Part 1):2011
5.	Measurement of insulation resistance.	As per customer's requirement, testing procedure followed as per cl.no.10.1.3.j of IS 2026 (Part 1):2011
6.	Induced AC voltage tests.	As per cl.no.12 of IS 2026 (Part 3):2009
7.	Separate-source AC withstand voltage test	As per customer's requirement, testing procedure followed as per cl.no.11 of IS 2026 (Part 3):2009
8.	Temperature-rise test	As per customer's requirement, testing procedure followed as per cl.no.5.0 of IS 2026 (Part 2):2010

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REPORT NO.: RP-1920-014933 Sheet : 4 OF 9
DATE : 20.07.2019

Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
1.	**Measurement of winding resistance :** (As per cl.no.10.2 of IS 2026 (Part 1): 2011) Oil temperature : 30.7°C			---
	HV Winding			
	1U – 1V:	--	5.8185 Ω	
	1V – 1W:	--	5.8255 Ω	
	1U – 1W:	--	5.8250 Ω	
	Average:	--	5.8230 Ω	
	LV Winding			
	2u – 2v:	--	9.135 mΩ	
	2v – 2w:	--	9.104 mΩ	
	2u – 2w:	--	9.236 mΩ	
	Average:	--	9.158 mΩ	
2.	**Measurement of voltage ratio and check of phase displacement :** (As per cl.no.10.3 of IS 2026 (Part 1) : 2011)			---
	Measurement of voltage ratio			
	1U-1V and 2u-2n:	---	43.989	
	1V-1W and 2v-2n:	---	44.033	
	1W-1U and 2w-2n:	---	44.037	
	Vector Group :	---	Dyn11	

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REPORT NO.: RP-1920-014933 Sheet : 5 of 9
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Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
3.	**Measurement of short-circuit impedance and load loss at 70%, 100% & 120% load :** (As per customer's requirement, testing procedure followed as per cl.no.10.4 of IS 2026 (Part 1) : 2011)			---
	➢ At 70% load : Tested with 7.344 Amps (on HV side) Frequency : 50.052 Hz Oil temperature : 30.5°C			
	Test current (Amps)		7.344	
	Impedance voltage (Volts)		321.60	
	Measured load loss (Watts)		1011.0	
	Impedance voltage (%) (Computed to 70% load)			
	At 30.5°C		2.93	
	At 75°C	---	2.96	---
	Load loss (Watts) (Computed to 70% load)			
	At 30.5°C		1012.65	
	At 75°C	---	1168.76	---
	➢ At 100% load : Tested with 10.493 Amps (on HV side) Frequency : 50.040 Hz Oil temperature : 30.5°C			
	Test current (Amps)		10.493	
	Impedance voltage (Volts)		459.29	
	Measured load loss (Watts)		2054.3	
	Impedance voltage (%) (Computed to 100% load)			
	At 30.5°C		4.18	
	At 75°C	---	4.22	---
	Load loss (Watts) (Computed to 100% load)			
	At 30.5°C		2057.04	
	At 75°C	---	2377.05	---

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REPORT NO.: RP-1920-014933 Sheet : 6 of 9
DATE : 20.07.2019

Sr. No	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
	➢ At 120% load : Tested with 12.660 Amps (on HV side) Frequency : 50.000 Hz Oil temperature : 30.5°C			
	Test current (Amps)		12.660	
	Impedance voltage (Volts)		554.01	
	Measured load loss (Watts)		3002.3	
	Impedance voltage (%) (Computed to 120% load) At 30.5°C		5.01	
	At 75°C	---	5.06	---
	Load loss (Watts) (Computed to 120% load) At 30.5°C		2973.91	
	At 75°C	---	3433.00	---
	Note : As per customer's request, temperature co-efficient of aluminium material was considered while calculating short circuit impedance and load losses at 75°C.			
4.	**Measurement of no-load loss and current :** (As per cl.no.10.5 of IS 2026 (Part 1) : 2011) Tested with average 432.57 Volts (on LV side) Frequency : 50.022 Hz			---
	RMS voltage (Volts)		433.17	
	No-load current (Amps)		4.1073	
	Measured no-load loss (Watts)		652.0	
	Corrected no-load loss (Watts)	---	651.09	

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REPORT NO.: RP-1920-014933 Sheet : 7 OF 9
DATE : 20.07.2019

Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained Value	Remarks
5.	**Measurement of insulation resistance :** (As per customer's requirement, testing procedure followed as per cl.no.10.1.3.j of IS 2026 (Part 1) : 2011) Oil temperature : 34.7°C IR value measured between			---
	HV winding --- Earth at 2500 V DC	--	30.3 GΩ	
	LV winding --- Earth at 500 V DC	--	18.71 GΩ	
	HV winding --- LV winding at 2500 V DC	--	33.2 GΩ	
6.	**Induced AC voltage tests :** (As per cl.no.12 of IS 2026 (Part 3): 2009) The test voltage of 866 Volts, 3 – phase was applied to the LV winding of the transformer. The supply frequency was maintained at 150 Hz. The test voltage was applied for 40 seconds.	Transformer shall withstand 866 volts at 150 Hz frequency for 40 seconds.	Withstood	---
7.	**Separate-source AC withstand voltage test :** (As per customer's requirement, testing procedure followed as per cl.no.11 of IS 2026 (Part 3):2009) ➢ on HV winding: The test voltage of 28 kV ac, rms was applied between the HV winding and earth. The tank and LV winding were shorted together and earthed. The test voltage was applied for 60 seconds.	Transformer shall withstand power frequency voltage of 28 kV for 60 seconds.	Withstood	---
	➢ on LV winding: The test voltage of 3 kV ac, rms was applied between the LV winding and earth. The tank and HV winding were shorted together and earthed. The test voltage was applied for 60 seconds.	Transformer shall withstand power frequency voltage of 3 kV for 60 seconds.	Withstood	

PREPARED BY CHECKED BY

TC 2832227

ELECTRICAL RESEARCH AND DEVELOPMENT ASSOCIATION
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Certificate No. : TC-5389

ULR-TC538919000022469F

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Sr. No.	Particulars of test and Cl. No.	Requirement as per specification	Obtained value	Remarks
8.	**Temperature-rise test :** (As per customer's requirement, testing procedure followed as per cl.no.5.0 of IS 2026 (Part 2):2010) Before starting test, the dimensions of tank with radiators were measured & recorded. Size of tank : L-1010 mm, W-400 mm, H(Avg.)-1010 mm Size of fins : L-700 mm, W-230 mm Number of radiators : 5 Number of fins per radiator : 4 As requested by customer, total losses at 100% of load fed for temperature-rise test were 3028.14 Watts (Measured no-load loss : 651.09 Watts & load loss at 75°C : 2377.05 Watts) Measured losses were fed to the transformer (i.e. Supply was connected to HV winding and LV winding kept short-circuited) till steady state temperature-rise was attained. Top oil temperature was recorded hourly. After steady state condition, the losses were brought down in reference to the rated current one hour prior to shut down. At the shutdown, the hot windings resistance were measured and temperature-rise calculated.			---
	A) Top oil temperature-Rise :	---	37.1°C	
	B) Winding Temperature Rise (Resistance method)			
	1) HV Winding :	---	43.0°C	
	2) LV Winding :	---	42.3°C	
	C) Ambient temperature at shutdown :		34.9°C	
	D) Time of Shutdown (HRS) :		21:00	

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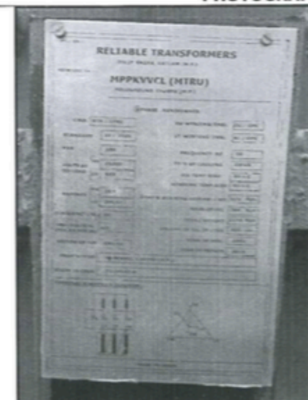
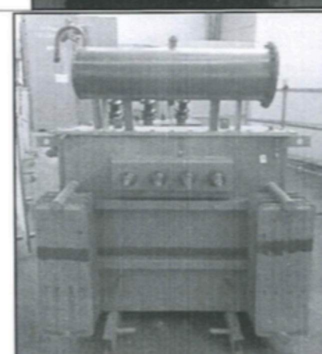
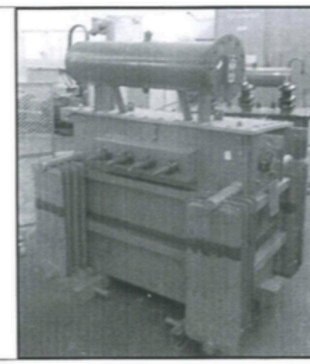
REPORT NO.: RP-1920-014933 Sheet : 9 of 9
DATE : 20.07.2019

PHOTOGRAPHS OF TEST SAMPLE

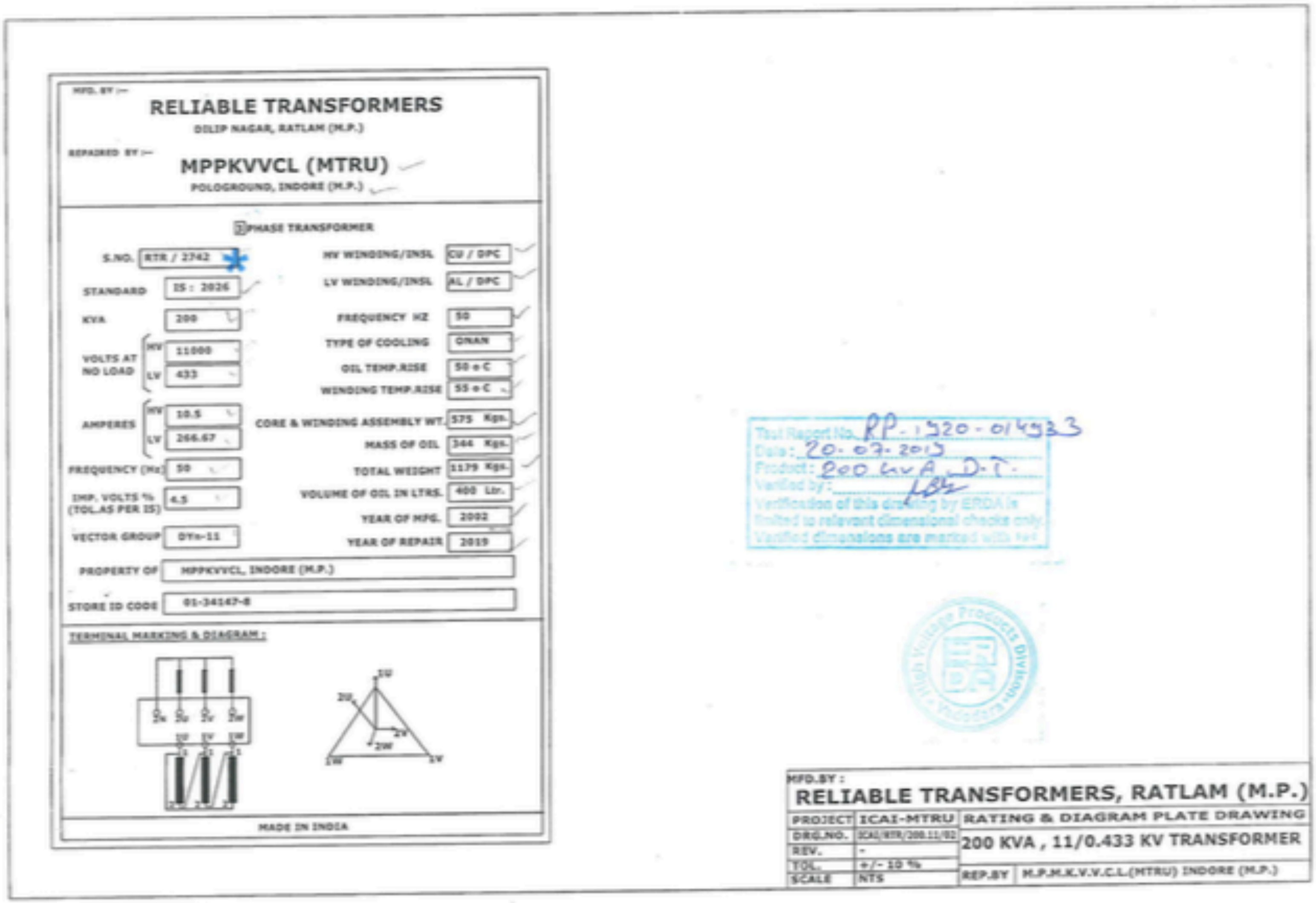


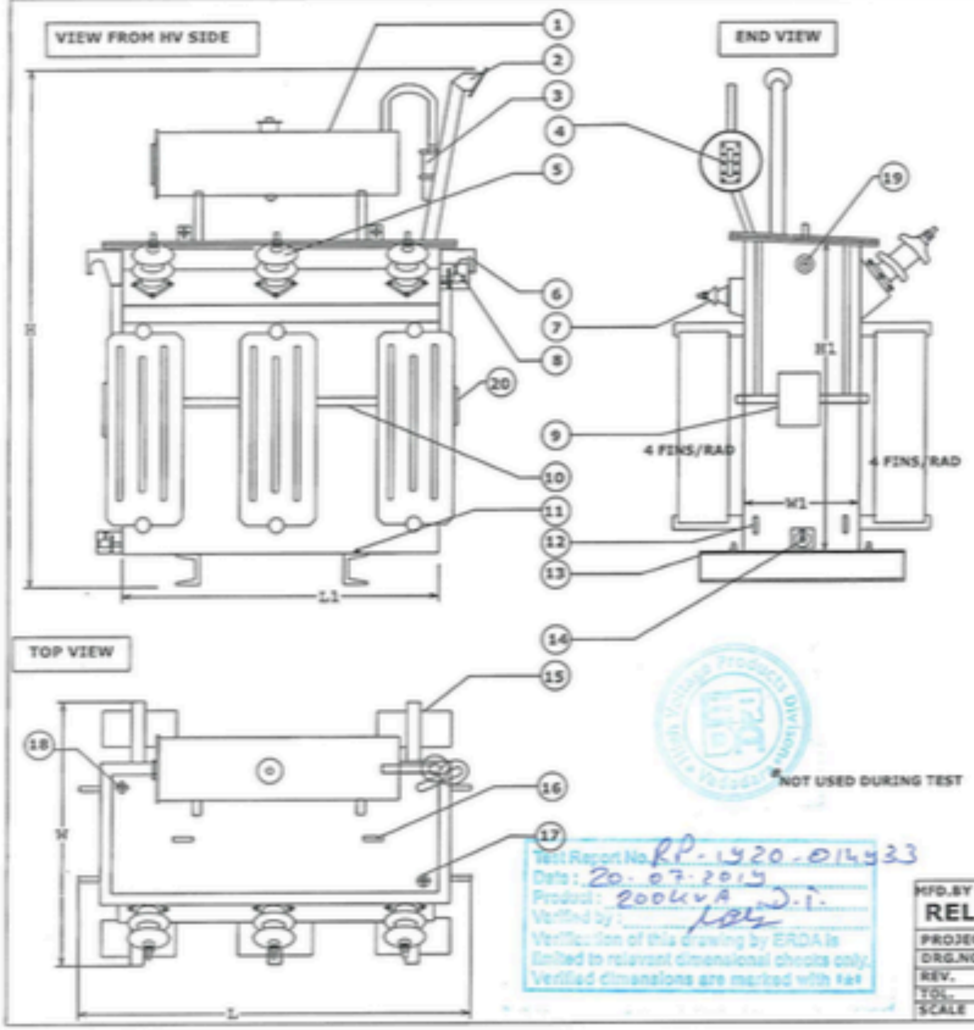




PREPARED BY CHECKED BY

TC 2820423


MFD. BY :-
RELIABLE TRANSFORMERS
DILIP NAGAR, RATLAM (M.P.)
REPAIRED BY :-
MPPKVVCL (MTRU)
POLOGROUND, INDORE (M.P.)
3 PHASE TRANSFORMER
S.NO. RTR / 2742
STANDARD IS : 2026
KVA 200
VOLTS AT NO LOAD HV 11000
LV 433
AMPERES HV 10.5
LV 266.67
FREQUENCY (Hz) 50
IMP. VOLTS % (TOL.AS PER IS) 4.5
VECTOR GROUP DYn-11
HV WINDING/INSL CU / DPC
LV WINDING/INSL AL / DPC
FREQUENCY HZ 50
TYPE OF COOLING ONAN
OIL TEMP.RISE 50 o C
WINDING TEMP.RISE 55 o C
CORE & WINDING ASSEMBLY WT. 575 Kgs.
MASS OF OIL 344 Kgs.
TOTAL WEIGHT 1179 Kgs.
VOLUME OF OIL IN LTRS. 400 Ltr.
YEAR OF MFG. 2002
YEAR OF REPAIR 2019
PROPERTY OF MPPKVVCL, INDORE (M.P.)
STORE ID CODE 01-34147-8
TERMINAL MARKING & DIAGRAM :
MADE IN INDIA
Test Report No. RP-1920-014933
Date: 20.07.2019
Product: 200 kVA D.T.
Verified by:
Verification of this drawing by ERDA is limited to relevant dimensional checks only. Verified dimensions are marked with tick
MFD.BY :
RELIABLE TRANSFORMERS, RATLAM (M.P.)
PROJECT ICAI-MTRU
RATING & DIAGRAM PLATE DRAWING
DRG.NO. ICAI/RTR/200.11/02
200 KVA , 11/0.433 KV TRANSFORMER
REV. -
TOL. +/- 10 %
SCALE NTS
REP.BY M.P.M.K.V.V.C.L.(MTRU) INDORE (M.P.)



ELECTRICAL CLEARANCES IN AIR IN MM (MIN)		
BETWEEN	HV	LV
PHASE TO PHASE	255	75
PHASE TO EARTH	140	40

DIMENSIONS(MM)	L1	W1	H1(Avg)
TANK (INSIDE)	1010 *	400 *	1010 *
OVERALL	L	W	H
	1300	975	1750

NOTE :- ALL DIMENSIONS IN MM UNLESS OTHERWISE STATED.

S.NO.	PARTICULARS	NOS./SET
1.	CONSERVATOR	1
2.	EXPLOSION VENT	1
3.*	SILICA GEL BREATHER	1
4.	OIL LEVEL GAUGE	1
5.	HV BUSHING WITH METAL PARTS	3
6.	LIFTING LUGS	4
7.	LV BUSHING WITH METAL PARTS	4
8.	FILTER VALVE (WITH METALIC COVER)	1
9.	RATING & DIAGRAM PLATE	1
10.	STIFFNER	1
11.	EARTHING TERMINALS	2
12.	PULLING LUGS	4
13.	PLATFORM MOUNTING CHANNEL	2
14.	DRAIN VALVE (WITH METALIC COVER	1
15.	PRESS-STEEL RADIATOR(700 X 230MM X 4FIN) *	5
16.	TOP COVER LIFTING LUGS	2
17.	AIR RELEASE PLUG	1
18.	THERMOMETER POCKET	1
19.*	OFF CKT TAP SWITCH	1
20.	IDENTITY PLATE (ID NO. 01-34147-8)	1

MFD.BY :

RELIABLE TRANSFORMERS, RATLAM (M.P.)

PROJECT	ICAI-MTRU	GENERAL ARRANGEMENT DRAWING
DRG.NO.	ICAI/RTR/200.11/01	200 KVA , 11/0.433 KV TRANSFORMER
REV.	-	
TOL.	+/- 10 % *	REF.BY M.P.M.K.V.V.C.L.(MTRU) INDORE (M.P.)
SCALE	NTS	

Acknowledgement

Madhya Pradesh Paschim Kshetra Vidyut Vitaran Company Limited	• CE, Commercial • SE, Stores • MTRU
International Copper Association India Copper Alliance	• Mr. Manas Kundu, Director, Energy Solutions • Mr. Mayur Karmarkar, Regional Director Sustainable Energy • Mr. Ashish Pandit, Associate • Mr. Rajesh Joshi, Transformer Design Expert, Tristar Technocrates
MANIFOLD BUSINESS SOLUTIONS	• Mr. Rahul Bagdia, Managing Director • Ms. Yamini Keche, Sr. Business Analyst