Technical Loss Reduction through Active Repair of Distribution Transformers

Abstract— The high monetary value of a transformer has placed the transformer life-time optimization into the focus of asset management. Distribution Transformers (DTs) are key assets for any distribution network. Their reliable and efficient operations is important for strong economic standing of the DISCOMs. Many DISCOMs follow DT energy audit, but that focuses on AT&C losses external to the DT. This paper focuses on Technical losses internal to the DTs and how best it can be reduced. DT technical losses usually gets measured only at the repair facility during the breakdown event. In old legacy DTs, these technical losses stand highly deviated from original manufacturing specs, adding to the financial losses of the DISCOMs. This paper presents a technical loss reduction technique called 'active repair' using winding compensation only, with no change to the core. Active repair was conducted on two Aluminum wound legacy DTs with high technical losses, one failed DT of 100 kVA and other functional DT of 200 kVA, with winding compensation carried out through copper winding replacement. Results demonstrated significant technical loss reduction to near manufacturing specs, with business viability to the DISCOMs. Active repair can be further developed as an easy replicable DT repair technique, and DISCOMs can selectively apply it to high technical loss making legacy DTs that will yield shorter payback period. Existing DT repairers can be incentivized to undertake active repairs through performance tied improved repair contract or service level agreements (SLAs) with further extension to provide integrated DT managed services for improved reliability and life cycle management.

1. Current Scenario of Distribution Transformer and its losses in India

In India, power distribution companies (DISCOMs) are having high 24.96% Aggregate Technical & Commercial (AT&C) losses, with high 22% T&D losses [1]. Of these, the Technical losses are estimated to be around 9-12%. These losses are fairly high as compared to other countries and continue pressing financial sustenance of the

DISCOMs. Distribution Transformer (DT) forms one of the important and high capex asset for DISCOMs. It is estimated that the average overall technical losses in DTs with these DISCOMs could be as high as 3%, compared to 0.5% ideal value. This makes DT one of the key intervention areas for the DISCOMs to bring down their overall network Technical losses.

There are many reform programs initiated by the Government of India to modernize and improve the distribution network, utility processes and overall financial sustenance of DISCOMs. These programs have yielded some positive results in distribution loss reduction but at lower speed.

Challenges of measuring technical losses:

One major challenge with DTs is inherent difficulty in measurement of the Technical losses within while the DT is functional on the network. Usually DTs have secondary side meters for energy auditing. For measurement of technical losses, it will require to have metering also on the primary high side of the DT, which in turn will require mounting new CTs and PTs with right accuracy levels in sync with meters deployed, and that will be sizeable investment at each DT level. Alternatively, there can be a custom-made setup mounted on a mobile van, and this can be used to measure Technical losses in a DT. This will however require taking shutdown time at each DT level, and pose its own practical challenges.

2. About the pilot

The pilot focuses on developing a mass replicable proactive approach to undertaking repairs (hereinafter mentioned as Active Repair) of DTs in service and bring down the technical losses. Active repair of DTs is a method that primarily focus on technical loss reduction in DTs through winding compensation, including any change in winding material. The core, if not beyond a certain level of degradation, is left unchanged as different makes of DTs will require different laminates design and cuts and that would not be an easy and replicable repair methodology. Active repair can be carried on both the breakdown as well as functional legacy DTs, though usually it shall be selectively applied to high loss DTs.

3. Active Repair Methodology

Below is a step-wise approach that was adopted for undertaking active repair on two sample DTs:

DT Selection	• A 100kVA failed DT and another 200kVA functional DT was requisitioned from different DISCOMs based on key parameters like DT Make, No-load loss, Full load loss, ageing and number of repairs already made.
Pre-repair testing	• The selected sample DTs were tested at repairer's lab to determine its condition and measure the 'As-is' No-load and Full-load losses as per IS 2026. As the 100 kVA was a failed DT, its No-load loss was measured by supplying rated voltage at LV winding and keeping the HV winding open as per IS 2026. Its Full-load loss was calculated based on empirical formula. For 200KVA on-service DT, the no-load loss and full load loss was measured as per IS 2026.
Design options	• The designs were prepared with both the LV & HV windings being replaced with the copper windings with increased no. of turns and optimally using the window space.
Active Repair Execution	• Core laminations were unstacked and restacked tightly to reduce air gap between laminations. LV and HV winding were placed as per design. Transformer was oven dried and final assembly was placed back in the tank
Post Repair Testing	• After active repair execution both the DTs were tested for post repair loss levels by conducting routine and type tests as per IS 2026.

4. Pilot Results

A. *Case 1:100 kVA failed DT:* After Active Repair, it was observed that No-load loss was reduced to 13% from 65% and Full-load losses to -3% from 13% before active repair. Below post repair results in comparison with baseline measurements and manufacturing specifications shown in Table-1.

Key Design Parameters	***Utility Spec***	***Baseline (As-is)***	***Actual Post Repair Results***
Capacity (kVA)	100	100	110
Flux Density (Tesla)	1.55	1.55	1.35
LV Winding Material	-	DPC Al	DPC Copper
LV Winding No. of turns,	-	75, 123,	86, 123, 156
ID(mm), OD(mm)		159	
HV Winding Material,	-	DPC Al	DPC Copper
HV Winding No. of turns,		3300,	3784, 176, 241
ID(mm), OD(mm)		179, 260	
No-Load Loss (W)	260	426	295
Full-Load Loss (W) @ 134A	1760	1815	1654
rated current			
Impedance (%)	4.90 - 5.10	4.50	5.19
Total Winding Weight (kg)	-	57	174

Table 1. Design and Results for active repair with reference to the baseline measurements and utility specs

Post-repair heat-run test was undertaken and temperature rise of the winding and the top oil were found within the permissible limits as defined in IS 2026.

	Permissible Limits	***Results Obtained***
Winding Temperature Rise	55^0C	45.4^0C
Top Oil Temperature Rise	50^0 C	38^0C

Table 2. Post repair heat run test results

The DT loading was assumed to be 70% with average cost of supply of 6.03 Rs./kWh and 10% inflation. Active repair yields a sum total savings of 1838 kWh/year compared to baseline losses, and simple payback of around 6 years. The payback period further improves with increase in DT loading or cost of supply.

As it was a failed DT, its kVA capacity was assumed to be same as the name plate rating of 100 kVA. However, based on the post repair temperature rise test, it was observed that the kVA capacity was enhanced by 9% after the active repair, which can allow DT taking up more load with higher reliability. Additionally, this overhauled and upgraded DT can give full new life cycle similar to any new DT.

B. *Case 2: 200 kVA functional DT:* 'As-Is' No-load loss and Full-load loss was decreased from 79% and 26% to 2% and 9% consecutively. Below post repair results in comparison with baseline measurements and manufacturing specifications are as shown in Table 3

Key Design Parameters	***Utility Spec***	***Baseline (As-Is)***	***Actual Post Repair Results***
Capacity (kVA)	200	200	209
Flux Density (Tesla)	-	1.68	1.42
LV Winding No. of turns		48, 150,	56, 146, 185
(LV), ID(mm), OD(mm)		200	
HV Winding Material	-	DPC Al	DPC Copper
HV Winding No. of turns	-	2112, 220,	2646, 205,
(HV), ID(mm), OD(mm)		285	273
No-Load Loss (W)	500	894	486
Full-Load Loss (W) @ 268A	3000	3772	3272
rated current			
Impedance (%)	4.5 - 5.5	4.89	6.23
Total Winding Weight (kg)	-	95	215

Table 3. Design and Results for active repair with reference to the baseline measurements and utility specs

Post-repair heat-run test was undertaken and temperature rise of the winding and the top oil were found within the permissible limits as defined in IS 2026.

	Permissible Limits	*Results Obtained*
Winding Temperature Rise	55^0C	49.16^0C
Top Oil Temperature Rise	50^0C	37.6^0C

Table 4. Post repair heat run test results

The cost benefit analysis was prepared based on the factual data points obtained from the supporting DISCOM. The DT loading was assumed to be 70% with average cost of supply of 5.90 Rs./kWh and 10% inflation. Active repair yields a sum total savings of 5476 kWh/year compared to baseline losses, and simple payback of 3.97 years. The payback period further improves with increase in DT loading or cost of supply.

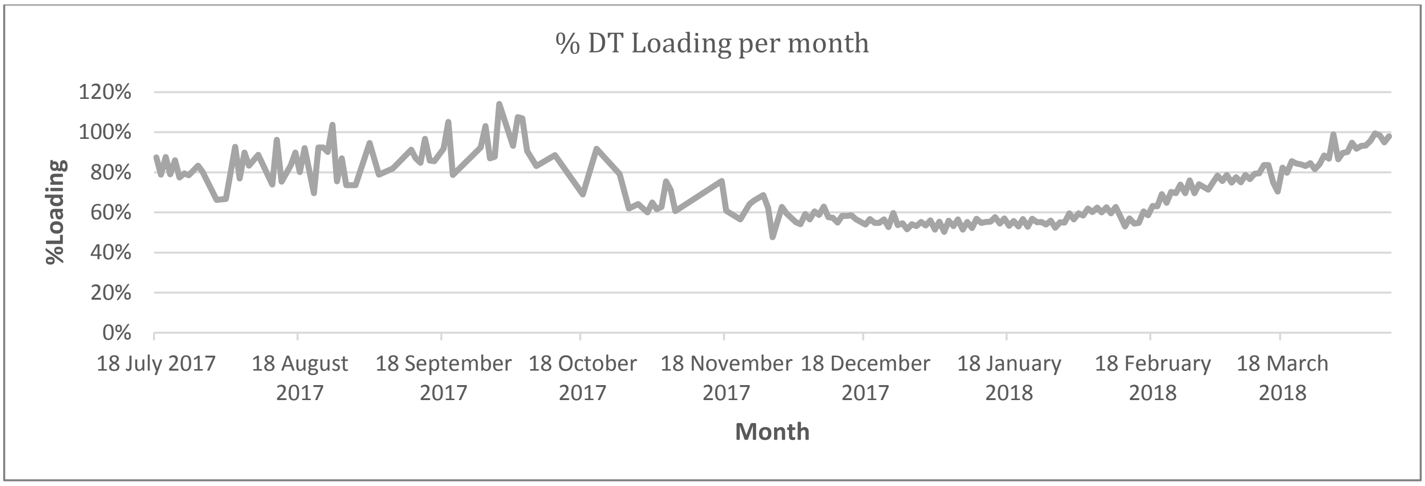
Based on the post repair temperature rise test, it was observed that the kVA capacity was enhanced by 5% after the active repair. Additionally, this upgraded DT can give additional full new life cycle similar to an equivalent new DT.

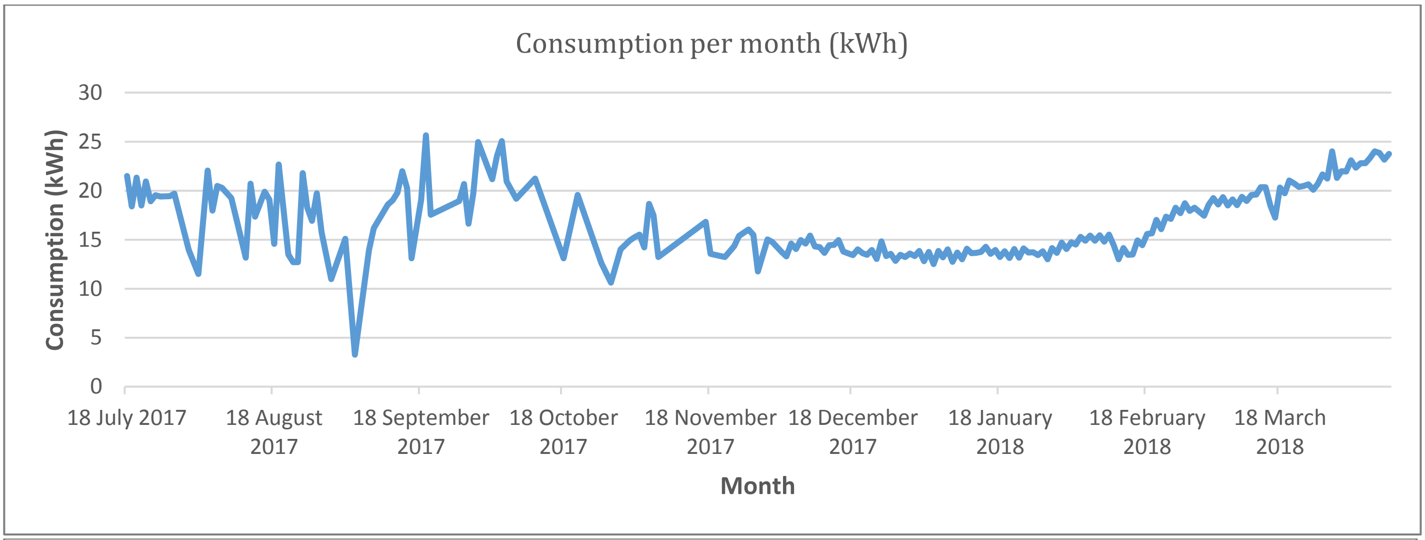
5. Post Repair Monitoring

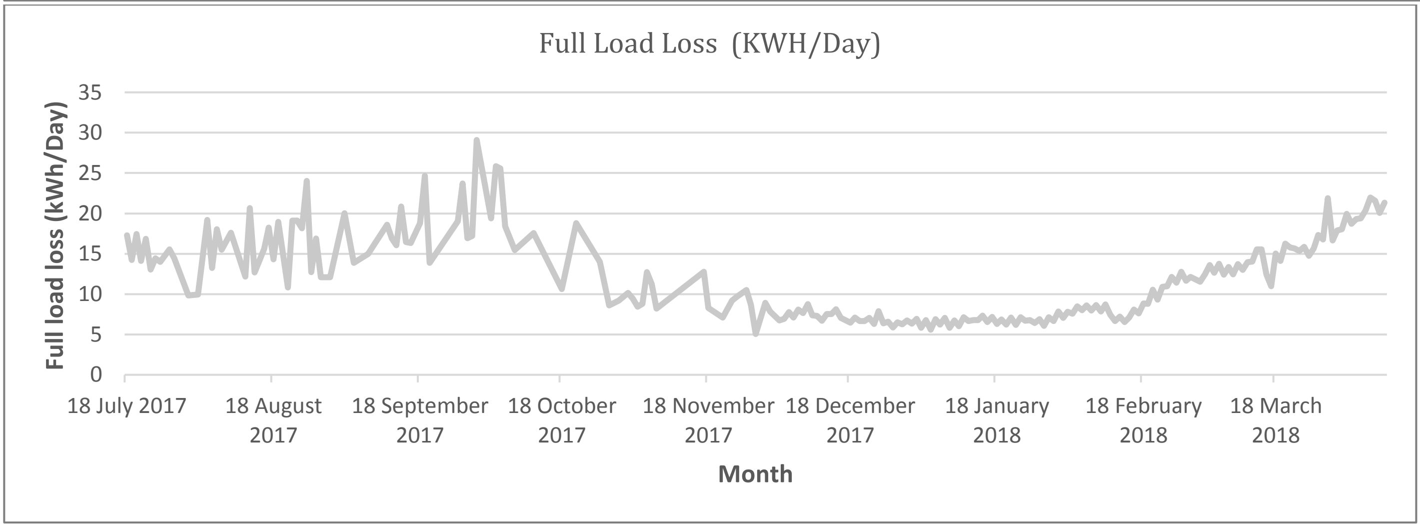
Post field installation of active repaired DT, Transformer Monitoring Unit (TMU) was installed to capture continuous performance of the repaired 100kVA DT. TMU includes Energy Monitoring Unit (LT side) and a temperature monitoring unit for transformer. Energy Monitoring Unit consists of an energy meter connected to CTs on LT side. A GPRS modem connected to the energy meters communicate with server for the transmission of data.

Figure 1. Transformer Monitoring unit

Below is observation based on daily data extracted from TMU:







At 70% loading			
Parameters	**Pre-Repair**	**Post Repair (Actual)**	**Post Repair (On-site)**
NLL (W)	426	295	295
FLL (W)	907	826	463
TL (W)	1,333	1,121	758
NLL (KWH)	10.22	7.08	7.08
FLL (KWH)	21.77	19.82	11.12

TL(KWH)	31.99	26.90	18.20
Lost units	NA	2,154.76	2,080.26
Savings (Rs. /Yr.)	NA	12,993.20	12,543.97
Monthly	NA	1,082.77	1,045.33

It is observed that post repair under highly loaded condition the on-site performance of Active Repaired transformer is efficient and surpassed levels expected during design optimization. It is further reported that even during summer months when the ambient temperature remained 40 degree Centigrade and above the performance of the Active Repaired DT remained reliable.

6. Conclusion

As power distribution systems continues to grow in size and complexity, technical loss reduction will form greater priority. Added with the efficiency drive the utilities are looking at reliable supply to consumers. Active repair with only winding compensation provides an opportunity for sizeable technical loss reduction at reduced costs over replacement with new DT incurring heavy CAPEX. In addition the reliability improvement assures of lesser downtime. Both the active repair cases demonstrated significant deviation of No-load and Full-load losses from the specification values, and that active repair offers business case for sizable loss reduction. Leveraging the breakdown repair window opportunity for legacy DTs, active repair can be applied to selective high losses DTs that can yield attractive payback period. It can also be applied to selective functional DTs based on loss data if tracked well from previous conventional repairs. This was demonstrated on one 100kVA failed DT and another 200kVA functional DT, with additional benefits accruing from increased kVA capacity, higher reliability (i.e. reduced failure rate) and increased asset life. Further DISCOMs can develop new business models and contracting for DT repairing that encourage performance tied SLAs, including technical loss reduction and possibly some combination of managed services around DTs for effective life cycle asset management.

References

[1] Government of India, Ministry of Power, Central Electricity Authority, New Delhi- Power Sector, April 2017

[2] "Innovative Business Model for Refurbishment of Distribution Transformers" by Idam infrastructure Advisory Pvt. Ltd, 8th Annual Conference on "Power Distribution in India" Issues & Challenges; Strategies & Solutions

[3] "Reduction of losses" by Electrical India, July 5, 2016

[4] "Determination of Capitalization Values for No Load Loss and Load Loss in Distribution Transformers" by W.D.A.S. Wijayapala, S.R.K. Gamage and H.M.S.L.G. Bandara, ol. XLIX, No. 03, pp. [11-20], 2016, The Institution of Engineers, Sri Lanka

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