# Development of Distribution of Transformer Fleet Management Capability Framework and Application

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**ABSTRACT**

This paper will deliberate on Distribution Transformer Fleet Management Capability Framework (TFCF) and critical steps encompassing transformer fleet screening, transformer condition assessment (TCA) methodology, asset health management and risk-based strategic life cycle planning. Sample outcomes of transformer fleet management (TFM) outcomes and values are also illustrated. Typical gaps, barriers in moving advancing TFM and supportive risk-based asset management (RBAM) capability towards higher maturity and impact will also be discussed as part of learning lessons.

The risk-based asset management approach is highly data-driven and requires enhanced capability areas covering demographics analysis, outage management, failure and reliability analysis, condition assessment, risk assessment and cost management. Deficiency in any key areas may affect effectiveness and efficiency of fleet management outcomes which deal with asset life strategies and optimized transformer life cycle plan covering maintenance, renewal and replacement. The solutions lie in understanding scope of depth of data and information requirements, supportive processes, methods, OT/IT system, analytics in developing and integrating fleet management as core capability in risk-based asset management (RBAM).

***Keywords***- *risk-based asset management, transformer fleet management, reliability analysis, transformer fleet screening, condition assessment, risk assessment, cost management,*

## 1.0 Introduction:

Effective asset management is all about achieving the appropriate balance between cost, risk and performance. Focus was to provide results that could be used to manage transformer related risks now, as well as providing a roadmap for asset management process improvement in the future. Given the large capital value and long lead times, it is important that only units which are identified as high risk and detoriated condition are replaced.

For many distribution utilities that have made strategic move into risk-based transformer fleet management, the transition towards full maturity may take few years of structured set of to be the initiatives in closing capability gaps is essential after initial round of effort in developing and implementing risk-based transformer fleet management (RBTFM). A typical development roadmap will be discussed. However, early gains or benefits and values from implementation of RBTFM will come from greater understanding of fleet performance- reliability, cost, condition-based health index and risk and criticality mapping of entire fleet population.

## 2.0 Transformer Fleet Management Capability Framework:

Fig.1 shows the high level view of strategic transformer fleet management framework that embodies key elements in the development and implementation strategic or risk-based transformer fleet management. All of the elements of TFMC framework will have to be consistently managed towards ensuring successful development and implementation of risk-based transformer fleet management.

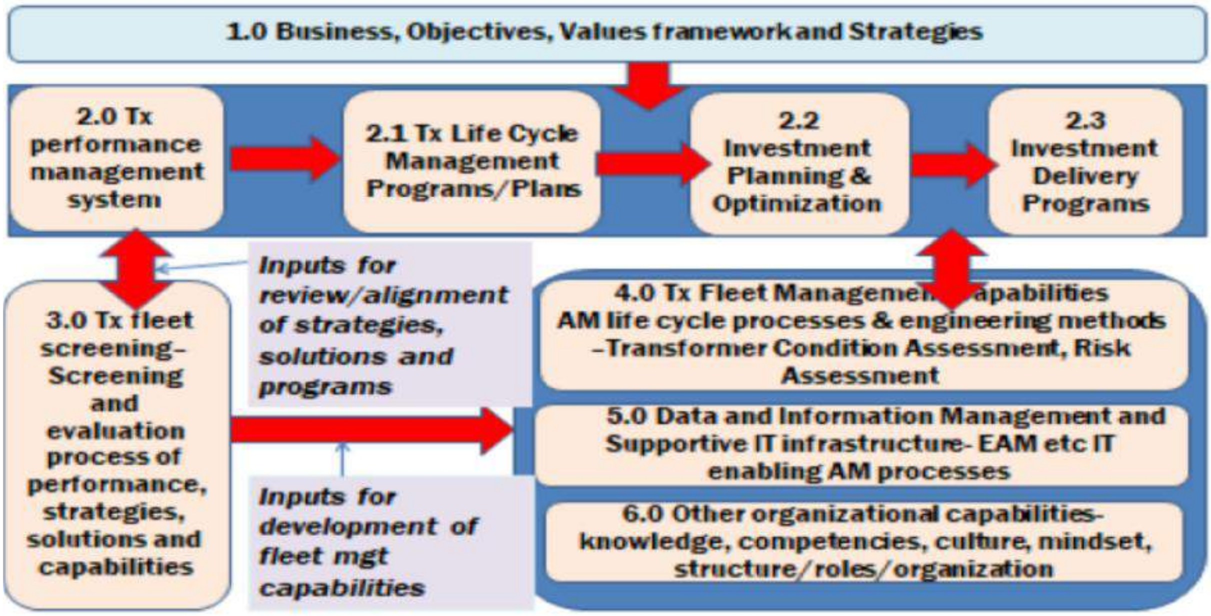



**Fig.1 Overview of strategic transformer fleet management framework**

## 3.0 Transformer Fleet Management Process & Methodology:

Major blocks of capability areas constituting key processes supporting transformer life cycle processes are summarized in fig.2.0 below.

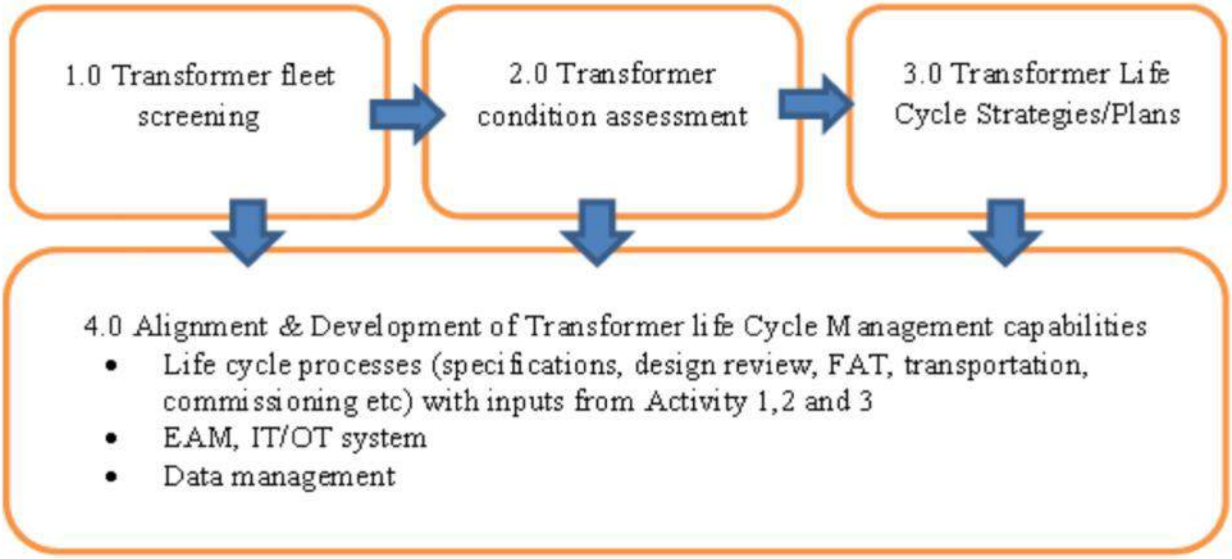



**Fig 2.0: Integrated process for Transformer Fleet Management**

**Table 1- TFM & Key Supporting process**

| Process/method | Key tasks | Process output/outcomes |
|---|---|---|
| Transformer fleet screening | • Asset databases development to support demographic, failure and reliability, TCO analysis<br>• Assessment of failure and reliability trends and root causes<br>• Assessment of asset health and criticality based on historical records | • Assessment of latest capability areas in TFM<br>• Risk and criticality assessment of transformer fleet based on historical and latest inputs<br>• Prioritized actions on transformer condition and risk assessment |
| Transformer condition assessment | • Conduct of extended on more complete condition parameters for critical transformer<br>• Application of new test procedures and application | • Conduct of complete tests to verify transformer condition and risk<br>• Advanced diagnostic tests on selected transformers |
| Transformer Life Cycle Strategies | • Asset maintenance and CBM methods<br>• Asset replacement | • Aligned strategies and diagnostic methods<br>• Risk based asset replacement strategies and methods |
| Alignment and development of asset life cycle management capabilities | Alignment of complete transformer life cycle management from design and specifications, construction, operations, outage management, risk management , performance management and data management | • Assessment and alignment of complete life cycle management objectives, strategies , plans and capabilities |

Distribution Transformer asset management program consists of following steps of action:

- Condition based maintenance (CBM) scheduling with updated maintenance processes and procedures,
- On line monitoring , Inspection and Testing schedule,
- Quality audits and inspections, spares management, emergency standby transformer,
- Risk based Transformer replacement / Refurbishment program.

CBM involves four sequential steps. Firstly, define asset condition by deriving ‘heath indices’ for individual assets and build health index profiles for asset groups. Secondly, link current condition to performance by calibrating the health index against relative probability of failure (POF) as shown in Figure 1.

The health index profile is matched with current failure rate to determine health index/POF relationship. Thirdly estimate future condition and performance by using knowledge of degradation processes to ‘age’ health indices, ageing rates dependent on initial health index and operating conditions. Lastly evaluate potential interventions in terms of POF and failure rates by factoring in the effect of potential replacement, refurbishment or changes to maintenance regimes, modify future health index profiles and recalculate future failure rates.

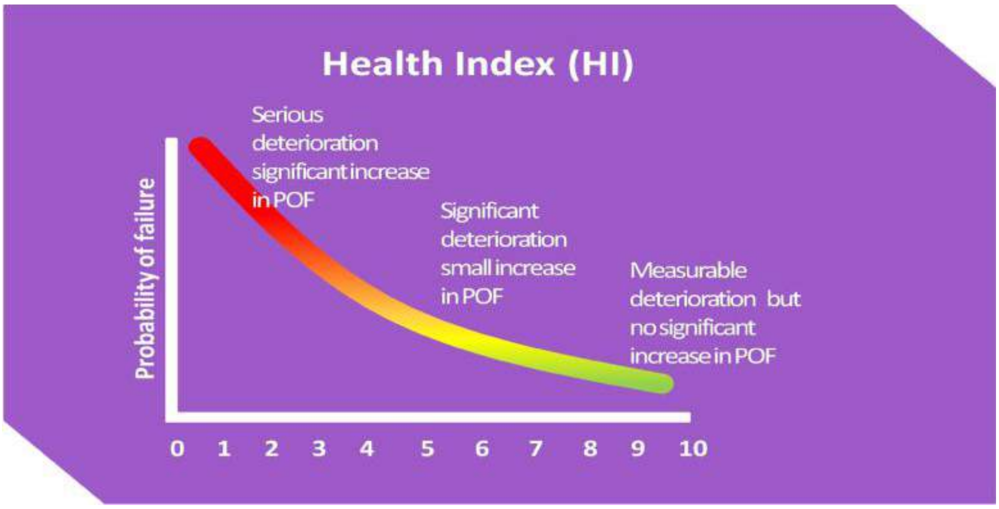



**Figure 3: The relationship between Health Index and POF**

**Relevance to health index number:**

To provide more clarity to health index number and its relevance a specific condition is suggested to each number as follows:

**Table 2- Summary of Transformer Health Index**

| Health index | Key word | Condition | Suggested action |
|---|---|---|---|
| 10 -8 | Good | All parameters are good | Routine monitoring |
| 7-6 | Average | Moderate degradation | Increase frequency |
| 5 | Poor | High degradation | Online monitoring |
| 4 | Bad | Moderate criticality suspected | Identify fault |
| 3 | | Higher criticality found | Quantify fault |
| 2 | Critical | High criticality found | Corrective measure |
| 1 | | Very critical | Replacement/ Refurbishment |

Above Table 2, provides a broad idea about usefulness of each health index number. Utility can take first step based on the health index then later on experts can go in detail, if needed.

## 4.0 Transformer Fleet Management – Case Study:

In this study 72 Distribution Transformers of various make, voltage class, rating and age & located in one industrial premise are selected. These transformers are operated and maintained by the owner industry since commissioning.

**Historical Record of Transformer:**

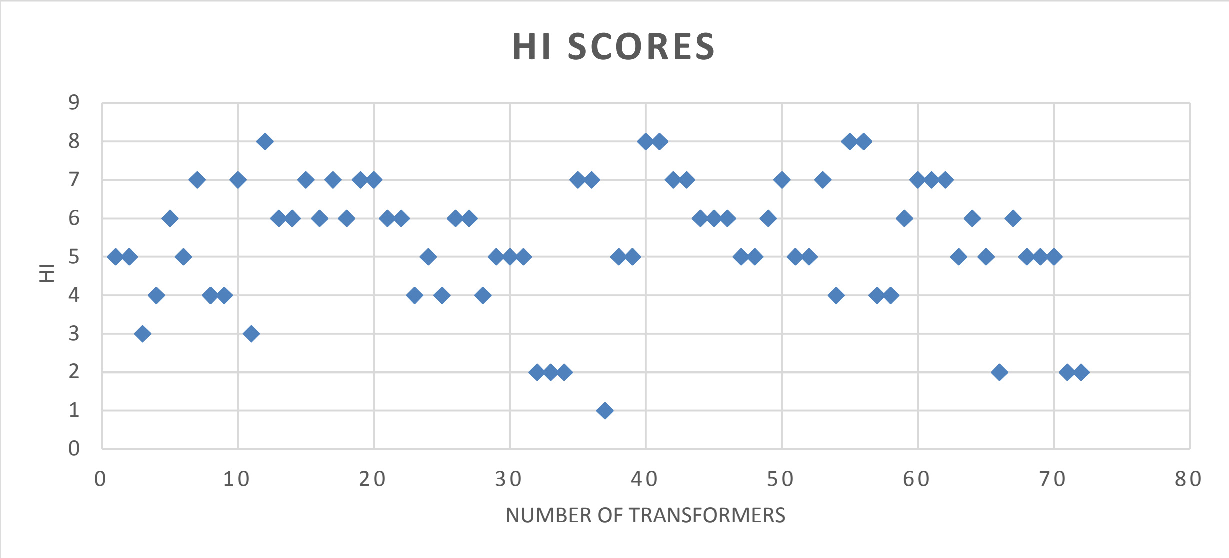
Utility owns and operates about 200 transformers with a high side voltage upto 220 kV and numerous bushing & OLTC failures in the transformers have been recorded in recent years, mostly independent of age.

According to historical operation/maintenance records, the transformers have not been overloaded in service. It is having a fleet of transformers, many loaded upto 50 percent capacity and the present age of many units is approaching the expected design life. The age of the unit is sometimes a useful indicator of the condition of the insulation and of the number of faults a transformer may have seen. In this case, 95 % of Population is having average age of 30 years and it is critical period for asset fleet management and advance planning fleet replacement.

**Health Index Estimation of Transformer:**

Table 3 presents the overall performance of Transformer based on Health Index Analysis. HI indicates 19 nos.(25 % of overall population) of Transformer having HI in the range of (8-7) indicating normal condition . As can be seen from Table 3, there are many units of significant age (30 years) , but in relatively good condition indicating good design, quality of Transformer.

**Table 3- Summary of Health Index Score**




The balance 75 % of fleet of transformers is beyond normal aging condition & targeted for strategic replacement/refurbishment/maintenance action plan as Indicated in Table 4 .

Table 4- Summary of Failure Mode and Action plan

| No | Failure mode | Maintenance action | Number of transformers |
|---|---|---|---|
| 1 | Leads & Insulation (Failure mode- High level of Partial Discharge Observed) | On -line PD Monitoring on half yearly basis | 5 |
| 2 | Winding (Failure mode-Mechanical Weakness of Winding) | Rewinding & Factory Repair | 3 |
| 3 | Solid insulation (Failure mode- Excessive Moisture) | Rewinding & Factory Dryout | 9 |
| 4 | Solid insulation (Failure mode- High Tandelta value ) | Tan-delta Monitoring of Winding on yearly basis | 11 |
| 5 | Bushing( Failure mode-Increasing trend Tandelta) | Tan-delta Monitoring of Bushing on yearly basis | 2 |
| 6 | Tank ( Failure mode-Leakage) | On line leakage arrest | 9 |
| 7 | OLTC( Failure mode-DCRM data indicate selector contact aging) | OLTC Overhauling | 1 |
| 8 | OCTC (Failure mode- Contact misalignment & Carbon deposits) | OCTC Replacement | 1 |
| 9 | Oil ( Failure mode-DGA High content of C2H4 & C2H6) | On -line DGA monitoring | 5 |
| 10 | Oil ( Failure mode-High Resistivity & aging) | Oil Replacement | 6 |
| 11 | Solid Insulation( Failure mode- accelerated aging ) | Scrap | 1 |
| 12 | Core-( Failure mode-accelerated aging & Stray gassing ) | Scrap | 1 |

## 2.1 Transformer Criticality factor & Findings

Recommendations for short and long term improvements were prioritized using Health index and risk analysis approach so that the tangible business benefits of each investment were clearly understood as described in Table 5 for some Critical Transformer.

For all units Risk is calculated based on transformer condition and criticality as indicated in Table 3. The process is iterative and makes best use of condition data and expert opinion, combined with consequence of unplanned unavailability.

These risk based analytics can be applied too minimize equipment lifecycle costs of replacement and maintenance including failure costs. Numerous utilities have used this approach to focus limited resources on the right equipment, thus reducing risk and maintaining power system reliability in a cost-effective manner.

Table 5- Summary of Some Critical Transformer with Risk

| Sr. no. | TF ID | Rating (MVA) | Voltage (kV) | Year | Final Recommendation | Maintenace Action | HI | Risk |
|---|---|---|---|---|---|---|---|---|
| **1** | **CPP-1** | **5** | **11/6.9** | **1988** | DGA on half yearly basis(High content of C2H6 & C2H4, indicate excessive localised heating | **Monitoring** | **5** | **Medium** |
| **3** | **CPP-3** | **2** | **11/0.433** | **1988** | High Tan delta value (8.9%) & Moisure content. Factory dry out of transformer. | **Replacemnet** | **3** | **High** |
| **4** | **CPP-4** | **2** | **11/0.433** | **1988** | High Tan delta value (6.0%) & Furan . Rewinding of transformer. | **Replacemnet** | **4** | **High** |
| **6** | **CPP-6** | **6.6 MVAr** | **11** | **1989** | Oil replacement needed (Low Resistivity) | **Oil Replacement** | **5** | **Medium** |
| **8** | **CT1-1** | **1.6** | **11/0.433** | **1987** | High Tan delta value (6.5%) & Moisure content. Factory dry out of transformer | **Replacemnet** | **4** | **High** |
| **23** | **GC-ISBL-7** | **1** | **11/0.433** | **1987** | Oil replacement needed (Low Resistivity) | **Oil Replacemnet** | **4** | **High** |
| **24** | **GC-ISBL-8** | **2** | **11/0.433** | **1987** | Low BDV & High PPM oil | **Monitoring** | **5** | **Medium** |
| **29** | **GC-OSBL-5** | **5** | **11/6.9** | **2008** | **Need DGA trending on half yearly basis as C2H6 is exceeding the limit** | **Monitoring** | **5** | **Medium** |
| **30** | **LDP-1** | **3.15** | **11/6.9** | **1987** | High Tan delta (2.9 %),low BDV & High PPM oil | **Monitoring** | **5** | **Medium** |
| **31** | **LDP-2** | **3.15** | **11/6.9** | **1987** | High Tan delta value (4.1%) | **Monitoring** | **5** | **Medium** |
| **37** | **LDP-8** | **1.6** | **11/0.433** | **1987** | Very High Tan delta value (17%) & Aging- Scrap. | **Replacemnet** | **1** | **High** |
| **38** | **LDP-9** | **2** | **11/1.9/1.9** | **2010** | Negative Tan delta observed, need to be repeated on yearly basis | **Monitoring** | **5** | **Medium** |
| **42** | **LLD-3** | **2** | **11/0.433** | **1989** | Online Acoustic PD on half yearly basis -High PD observed | **Monitoring** | **7** | **Medium** |
| **48** | **LLD-9** | **2** | **11/0.433** | **1997** | Oil replacement needed (Low Resistivity) & Online Acoustic PD on half yearly basis | **Monitoring & oil replacement** | **5** | **Medium** |
| **59** | **PP-3** | **0.5** | **11/0.433** | **1987** | High Tan delta value (3.8%) & Moisture. | **Monitoring** | **6** | **Medium** |
| **63** | **SS7-1** | **21** | **11/6.9** | **1989** | DGA on half yearly basis, High content of C2H6 & C2H4 gases, indicate excessive localised heating | **Monitoring** | **5** | **Medium** |
| **65** | **SS7-3** | **2** | **11/0.433** | **1987** | Oil low BDV & high tandelta (2.6 %) | **Monitoring** | **5** | **Medium** |
| **68** | **SS7-7** | **1** | **11/0.433** | **1987** | Oil Low Resistivity and high C2H2 need monitoring on 3 month basis. | **Monitoring** | **5** | **High** |
| **70** | **SWY-2** | **33** | **220/11** | **1988** | Oil replacement needed (Low Resistivity) ,Measure HV bushing Tan delta Yearly | **Oil replacement, Monitoring** | **5** | **High** |
| **72** | **R-PET-2** | **2** | **11/0.433** | **1989** | Very High Tan delta value (8.5%) & Aging-. | **Replacemnet** | **2** | **High** |

## Summary:

The approach supports effective planning, maintenance, refurbishment and replacement decisions of transformer by providing the required knowledge about asset performance and the ability to predict future performance.

Key points to note is that TCA is highly dependent on matured processes in many areas of maintenance- inspections, preventive, breakdown maintenance and predictive/CBM maintenance as

TCA needs all related historical records of each transformer ID. The whole TCA process is data intensive and high emphasis is placed upon management of long—run data on transformer commission data, condition and failure data.

As summarized, it is critical for TCA and CBM processes to deliver the necessary outcomes :

- Transformer condition based on specific test and risk groups
- Global health index of transformer
- Aging and remaining life profiles
- Risk and criticality of Transformer and relative ranking
- Generation of asset and non-asset solutions for asset life cycle planning

In summary, data-driven and risk-based approach in life cycle management of entire transformer population could provide tangible strategic opportunities in unlocking trapped values across energy value chain. A wave of more deliberate efforts by many power utilities to develop and integrate TFM/RBAM is anticipated to be the emerging trend.

## Authors

**Dr. Aradhana Ray** from Laxmi Associates, Gujarat, India is Ph. D. in Electrical Engineering with 23 years' experience including 6 years with, Doble Engineering USA as consulting engineer and Omicron Energy Services, Austria as Services Manager and 10 years in Short Circuit Test Laboratory ERDA, Vadodara as Dy. Manager. She has done consulting, third party inspection and Asset management projects, specification & maintenance manual (third party) documentation related to EHV class power equipment in several countries such as India, Malaysia, Dubai, OMAN, North America, South Africa and Australia. She has conducted many Workshops worldwide over the last 9 years. Some 4,000 managers, engineers have attended her training courses and workshops. She has written more than 45 national and international publications. She was a recipient of **"Dr Vikram Sharabhai Young Scientist Award"** by Department of Science & Tech. India, for **"Development of fault current limiter"** in 2005. She has also served on technical committees of national and international conferences including IEC, IEEMA, CBIP,TIFAC, BIS, CIRED Malaysia Conferences. Currently she is working on **implementation of Asset Management project based on PASS 55 Standards** with various utiliites like Sarawak Energy Berhad (SEB), TNB & TAMAS Malaysia. Presently working as one of the **Principle member for Development of IEC- ETD 53 on Standardization of the management** of assets in power networks.