



Model Terms of Reference for Distribution Transformer Health Monitoring System

Noida Smart Distribution Project

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1. Introduction and General information

1.1 Introduction

Distribution transformer (DT) is one of the most vital assets in any electrical distribution network. DTs are present in large numbers across any distribution grid and spread across a wide area. Owing to high cost, DTs are not typically connected through SCADA systems. Physical/ manual monitoring and management of large number of DTs is difficult as well as an expensive exercise for any DISCOM. Therefore, DTs are often overlooked and hence are susceptible to overloading, faults, and frequent failures. Often, the repairs and maintenance happen only upon failure.

Distribution transformer health management (DTHM) is a strategic approach involving the constant monitoring and assessment of transformers within electrical networks. This system relies on sensors capturing real-time data of physical parameters like oil level, oil temperature, winding temperature, lug / palm temperature, outage etc. It also captures electrical parameters (through DT smart meter) such as instantaneous voltage, current, power factor, load profile etc. The collected data is transmitted to a central monitoring system, employing advanced analytics and machine learning for in-depth analysis and pre-emptive maintenance.

This process identifies patterns, anomalies, and trends crucial for assessing transformer health. By integrating this technology, DISCOMs benefit from reduced overloading, enhanced operational efficiency, extended equipment lifespan, and cost savings through proactive maintenance. Improved safety, enhanced grid resilience, informed decision-making via data insights, and compliance with regulatory standards further underline the advantages of this system. In essence, distribution transformer health management ensures a reliable, efficient, and secure power distribution infrastructure for companies in the energy sector.

1.2 Objectives

The implementation of Distribution Transformer Health Management (DTHM) is a potentially vital solution with which DISCOMs can gain the capability to continually monitor and proactively mitigate root causes for DT failures. DT health parameters can be directly routed to a standalone web-based analytic platform with a provision to help in carrying out preventive maintenance schedules.

Preventing transformer failures is instrumental in reducing maintenance costs and enhancing overall system reliability. Therefore, PVVNL proposes to demonstrate DTHM solution for 2,900 nos. out of its 4,488 nos. of DTs in Noida.

Distribution Transformer Health Monitoring solution shall provide the following features:

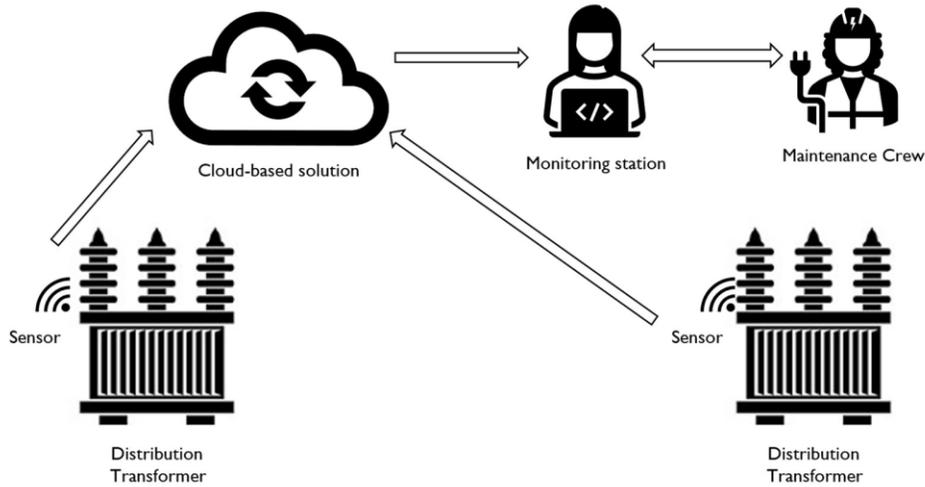
- Real-time outage alerts
- Critical sensor-based alerts such as oil temp, bushing temp, oil level to O&M team
- Real-time DT health critical parameters such as overloading, unbalancing, voltage
- DT condition monitoring tool for capturing physical anomalies
- Real-time DT health monitoring & downtime reduction leading to revenue enhancement

The following benefits are envisaged for PVVNL:

- Reduction in DT failure % and reduced system down-time
- DT failure analysis through AI/ML tool for predictive maintenance
- Reduction in ENS (Energy Not Served)

1.3 Schematic diagram

Schematic diagram of the Distribution Transformer Health Monitoring solution is as follows:



2. Scope of work

The bidder is required to provide an unpriced Bill of Quantity (BoQ) for the Distribution Transformer Health Monitoring (DTHM) platform. This unpriced BoQ must state all the line items influencing the development of the solution as defined in this scope of work. The selected bidder shall empanel a qualified and experienced Implementing agency with requisite skillsets, teams and technology stack complementing the requirements underlined in this Scope of Work.

The following sub-sections provide an overview of the Scope of Work for the DTHM solution:

2.1 Selection of DTs for pilot

The selected bidder / implementing agency shall assist PVVNL in formulating criteria of selecting 2,900 nos. of target distribution transformers for DT health monitoring solution. It is estimated that PVVNL has around 4,488 nos. of distribution transformers in Noida.

Post formulation of the selection criteria, PVVNL shall provide the required data enabling the selected bidder / implementing agency to generate a list of shortlisted DTs for pilot implementation of the DT health monitoring solution.

2.2 Kick-off and approvals

The selected bidder / implementing agency shall perform the following activities during the initial phase of the project:

Stage	Activities
Kick-off meeting	<ul style="list-style-type: none"> a. Presenting the approach and methodology to PVVNL during the kick-off meeting b. Develop inspection plan with timelines for shortlisted DTs c. Obtain approval from PVVNL on the proposed inspection plan d. Develop procurement and installation plan with timelines for shortlisted DTs

Stage	Activities
Post inspection	<ul style="list-style-type: none"> e. Develop / curate specifications, procurement and installation plan post conducting the inspection at site f. Obtain approval from PVVNL on the proposed specifications, procurement and installation plan g. Develop baseline data for success indicators (please see section 2.4) h. Obtain approval from PVVNL on success indicators and baseline data

2.3 Selection of DTHM type specification

Electrical sensing is typically done by AMI / AMR meters which captures electrical parameters such as phase-wise voltage, current, max. demand, active and reactive power etc. Non-electrical parameter sensing includes lug temperature, oil level, oil temperature, winding temperature, ambient temperature, humidity etc. Some of these sensors are factory fitted in transformers whereas other need to be retrofitted.

The non-electrical sensors should be capable of communicating the data wired/ wirelessly to a DCU, through suitable media such as Bluetooth, Zigbee, Modbus RS485 etc. Typically, a DCU aggregates all data from Meters, Sensors, etc. through the communication channels in real-time. The GPRS gateway transmits the data from DCU to the host computer at the SDCC/ Central Monitoring Unit for processing.

Most of the currently available solutions in the market offer a SaaS based analytics solution which works in Opex mode. In addition, some sensor manufacturers have their own proprietary analytics solution. An alternative approach for enabling DTHM is by engineering and configuring Digital Input (DI) port on DT Meters for communicating non-electrical sensor data through the DT meter itself. However, the solution needs to be designed specific to PVVNL use and can be explored in consultation with PVVNL.

Suggested DTHM type specification based on the availability of a working DT meter is given below as a reference point:

Metering status	Suggested DTHM type
A. No DT meter installed / meter not working	<ul style="list-style-type: none"> 1. DTHM with energy monitoring facility, or 2. Non-invasive DTHM with sensors in Energy meter
B. DT meter installed and working	<ul style="list-style-type: none"> 1. DTHM with non-electrical parameters from sensors (information relayed through separate DCU) and electrical parameters from integration with existing MDMS 2. DTHM with non-electrical parameters from sensors coupled with electrical parameters from data communication using DI/ DO or NIC cards on pre- installed DT smart meters. Communication of both type of parameters shall happen over existing DCU and HES communication medium. 3. DTHM with sensors as well as CTs for measurement of both electrical and non-electrical parameters - with separate DCU / modem

2.4 Baselineing of electrical and physical parameters

The selected bidder / implementing agency shall support PVVNL in choosing and baselineing of electrical and physical parameters. Few suggested parameters are as follows:

- Annual maintenance cost for distribution transformers (INR. Cr.)
- Annual DT replacement / augmentation cost for distribution transformers (INR. Cr.)
- Annual DT failure rate (%)
- Technical loss (%) (if calculated)

2.5 Procurement and installation plan for meters and sensors

The selected bidder / implementing agency shall prepare and present a detailed procurement and installation plan for meters and sensors to PVVNL for approval.

2.6 Integration with other technologies

The Distribution Transformer health monitoring solution is envisaged as a standalone analytics software solution which only has real time monitoring function. Thus, in pilot stage, integration with other technologies such as SCADA / DMS and OMS is not required.

However, in certain solutions, electrical parameters may need to be sourced from existing DT meter (refer section 2.3). In case this data would be available at the MDMS system, as such integration requirement with MDMS shall arise. In such cases, the selected bidder / implementing agency shall be responsible for creating the integration bridge between existing technology (say MDMS in this case) and the new DTHM system.

2.7 Testing and commissioning of the solution

Type test reports of tests conducted in NABL accredited Labs or internationally accredited labs with in last 5 years / or validity of test of certificate whichever is lower - from the date of bid opening may be submitted. In case, the submitted reports are not as per specification, the type tests shall be conducted without any cost implication to PVVNL before approval during design & engineering.

Utility may optionally ask the selected bidder / implementing agency to stage ad-doc testing in presence of team identified by the nodal officer of PVVNL.

Functional performance test shall be carried out by the selected bidder / implementing agency after commissioning stage in presence of the team identified by nodal officer of PVVNL. The Functional performance test shall comprise of the following as minimum:

1. Testing of the proper functioning of the DTHM software application in line with the requirements of the technical specification.
2. Simulation of field input error and failure conditions
3. Testing / verification of electrical and non-electrical parameters measured by the meter / sensors.
4. Verification of Security & Encryption using SSL for all external connectivity.
5. Confirmation of cyber security compliance of products through software and networking devices to be carried out by Cyber Crisis Management plan (CCMP) & its implementation during SAT by CERT.IN empaneled agency.
6. Verification of data exchange with other systems (such as MDMS or as appropriate)
7. Verification of LAN and WAN interfaces with other computer systems (as appropriate)
8. Testing of all user interface functions, including random tests to verify correct database linkages

9. Simulation of hardware failures and input power failures to verify the reaction of the system to processor and device failure
10. Demonstration of all features of the database, display, dashboard, and report generation and all other software maintenance features on both the primary and backup servers. Online database editing shall also be tested on primary server.
11. Logic verification of DT failure reports and API for transfer of data to other systems (as appropriate)
12. Verification of data transfer and backup
13. Testing of basic functionality of the AI / ML predictive failure algorithm

2.8 Operating the solution for stated period

The selected bidder / implementing agency shall own and operate the Distribution Transformer Health Monitoring solution for a period of one (1) year after commissioning. After this period, the DTHM solution shall become the property of PVVNL upon successful handover.

2.9 Analytics platform (SaaS)

An AI / ML based analytics software is required to process the real-time data condition monitoring of distribution transformers. The cloud hosted analytics platform shall create a health profile (over voltage, under voltage, phase imbalance, low oil level, high temperature etc.) for each DT. It shall predict any potential problem before failure / fault using appropriate AI / ML algorithm.

The solution can be hosted at the CMU / SDCC, and reports can be generated for analysis / actions at the center. Alternatively, PVVNL may direct the selected bidder / implementing agency to host the solution at a suitable cloud hosting platform. A middleware may also be integrated with analytics software to further send critical alerts through SMS or mobile push notifications to concerned personnel for necessary action.

2.10 Data analytics (AI / ML)

The DTHM solution shall conduct predictive failure analysis / diagnostics and generate actionable insights for DT failure % reduction and predictive maintenance actions. The AI / ML algorithm should support prediction of DT failure probability and suggestion on preventive measures. The generated report should prioritize the distribution transformers which require urgent maintenance and should also clearly state the kind / nature of maintenance required.

2.11 Data security

The selected bidder / implementing agency shall maintain all information including but not limited to documents, data, and outcomes relevant to project strictly confidential and shall not share with any third party under any condition. Suitable NDA may be signed for protection of data and information.

2.12 Handling of data

All the data and related reports shall be shared with the nodal officer of PVVNL on a monthly basis. Sensitive data shall be encrypted and kept in a cloud storage service. Relevant formats shall be shared with the nodal officer for handover of data each month together with signoff.

2.13 Dashboard and Reports

The application shall have an interactive, user-friendly dashboard which shall clearly show the distribution transformers requiring urgent maintenance in a clear and time-bound manner. Crucial DT health parameters such as oil temperature, winding temperature, load imbalance, etc. shall be displayed clearly with proper analysis for preventive / corrective maintenance activities.

The following reports shall be generated as a minimum -

1. DT failure probability and suggestion on preventive measures
2. Reasons for DT failures (if any)
3. Exception report for each instance of DT failure covering why, where, how and when for field inspection
4. Actionable insights for DT failure % reduction and predictive maintenance actions.
5. Cost benefit analysis report considering, but not limited to the following:
 - Cost of pilot project considering hardware, software, and costs under capex and Opex scenarios
 - Benefits from improved detection of DTs requiring immediate preventive maintenance.
 - Reduced Labor costs of crews to perform periodic inspections.
 - Reduced cost of repairing / replacing DTs.
 - Improved revenues due to reduction on DT failures and reduction in Energy Not Served (ENS).

2.14 Events and Alarms

The following types of events shall be registered by the software application:

- Oil temperature threshold exceeded
- Winding temperature threshold exceeded
- % loading threshold exceeded
- Load imbalance threshold exceeded
- Missing voltage
- Missing current
- Meter / sensors not communicating
- Any other event(s) defined by nodal officer of PVVNL in mutual consultation with the selected bidder / implementing agency

The above events shall trigger an alarm to the team identified by nodal officer of PVVNL by means of SMS or push notifications on mobile / email.

2.15 Monitoring and evaluation

In order to monitor, evaluate and improve the DTHM solution, the selected bidder / implementing agency shall deploy a suitable team of engineers stationed at PVVNL, Noida. This team shall coordinate with nodal officer of PVVNL on a regular basis. Review methodology and frequency of review shall be defined in consultation with nodal officer of PVVNL.

3. System specifications

3.1 Specification of meters

Meters and metering equipment accompanying the Distribution Transformer Health Monitoring solution, if not exist in Distribution Transformer shall comply with the following standards:

Sl. No.	Standard No.	Standard Description
1	IS 13779	Specification for AC Static Transformer-operated Watt Hour & VAR-Hour meters (class 1.0 & 2.0S)

Sl. No.	Standard No.	Standard Description
2	IEC 62052-II	Electricity metering equipment (AC) - General requirements, tests and test conditions - Part II: Metering equipment
3	IEC 62053-21	Electricity metering equipment (AC) - Particular requirements - Part - 21: Static Meters for Active Energy (Class 1.0 & 2.0S)
4	IS 15707	Specification for Testing, evaluation, installation & maintenance of AC Electricity Meters - Code of practice
5	IS 15959	DLMS Indian Companion Standard - Category A for Energy Accounting and Audit Metering
6	IEC 62056-21	Electricity metering: Data exchange for meter reading, tariff, and load control - Part 21: Direct local data exchange
7	IEC 62056-31	Electricity metering: Data exchange for meter reading, tariff and load control - Part 31: Local Area Network data exchange
8	IEC 62056-61	Electricity metering: Data exchange for meter reading, tariff and load control - Part 61: Object identification system (OBIS)

The equipment meeting with the requirements of other authoritative standards, which ensure equal or better quality than the standard mentioned above, also shall be considered. Furthermore, the following points shall be ensured:

- The meter would be capable of measuring fundamental energy as well harmonic energy i.e., total energy.
- The energy meter shall have a galvanically isolated IEC 1107 optical communication port located in front of the meter for data transfer to or from a handheld Data Collection Device. The sealing provision should be available for optical port.
- For remote meter reading, compatible GSM / GPRS modem / DCU and suitable accessories shall be provided for automatic and remote data transfer from energy meters installed at the distribution transformer.
- The GSM/GPRS modem shall be an integral part of the meter. The modem shall be accessible only after opening the front cover of the meter. For placing the SIM Card, a SIM Card Holder shall be provided and shall be accessible by removing the terminal cover.
- A data enabled SIM card shall be procured by the selected bidder / implementing agency for the location where the meter & GSM / GPRS modem is to be fitted.
- Both ports will support the default and minimum baud rate of 9600 bps
- Meter shall be suitable for mounting on the support of Distribution transformer structure.
- The current transformer shall have suitable ratio for accurate current measurement for the rating of distribution transformer it is meant to be installed at. All CT ratings shall be pre-approved by the nodal officer of PVVNL.

3.2 Specification of sensors

The Distribution Transformer Health Monitoring solution shall depend on hardware such as lug temperature sensors, oil level sensors, oil temperature sensors, 5G gateways, Data Concentrator Units (DCU), etc.

A variety of products are available in the market from which the selected bidder / implementing agency shall choose and get the specifications approved from PVVNL. As a pre-requisite, the selected bidder/implementing agency shall ensure that all shortlisted sensors shall comply with Industrial IoT standards and protocols to ensure maximum flexibility and interoperability.

3.3 Specification of computer system

Computer system for DTHM solution shall have the same specifications as that of the SCADA/ DMS computer system to be operated in standalone mode.

3.4 Specification of communication system

- The DTHM solution shall deploy suitable communication protocols for local data transfer from IIoT devices.
- The non-electrical sensors should be capable of communicating the data wired/ wirelessly to a DCU, through suitable media such as Bluetooth, Zigbee, Modbus RS485 etc.
- The DCU shall aggregate all data from Meters, Sensors, etc. through the communication channels in real-time.
- The GPRS gateway shall transmit the data from DCU to the host computer at the SDCC/ Central Monitoring Unit for processing.

4. Testing and documentation

4.1 Testing requirements

The selected bidder / implementing agency shall be responsible for the testing processes such as planning (includes preparing test plans and defining roles and their responsibilities), preparation (consists of preparing test specification, test Environment and test data) for all tests viz. Type tests, FAT, SAT, and successful commissioning (refer section 2.7).

The selected bidder / implementing agency shall also be responsible for successful conduction of cyber security audit by CERT.IN empaneled agency.

4.2 Documentation requirements

The selected bidder / implementing agency shall be required to maintain and produce the following documents -

- DT selection criteria and plan
- Document containing list of shortlisted DTs with metering status, area and other relevant information mutually defined and agreed with nodal person
- Site visit and equipment installation plan in mutually defined format agreed with nodal person
- Site visit and equipment installation reports in mutually defined format agreed with nodal person
- Sign off document to validate assets i.e. Sensors, DT Meters installed in PVVNL area
- Monthly exception report for each instance of DT failure covering why, where, how and when for field inspection
- Monthly actionable insights report for DT failure % reduction and predictive maintenance actions

5. Training and Safety

5.1 Training requirements

The selected bidder / implementing agency shall organize training to the core Group of implementation team of PVVNL as well as end user training. Representatives from the selected bidder / implementing agency, Purchaser's implementation project and change management teams will

be involved throughout in the development of training strategy, training material design and development, standards, and training delivery to ensure that change management issues are incorporated, and that training strategies and materials are aligned to the requirements of the project and as business specific as possible.

5.2 Operational safety

The selected bidder / implementing agency shall be responsible for maintaining safety related to site, infrastructure and manpower during civil works, foundation, sensor installation / removal, CT installation / removal, meter installation / removal, and all related commissioning and testing activities. Hazard identification and risk assessment shall be conducted prior to undertaking any site activity and proper Personal Protective Equipment (PPEs), training and implements shall be provided to site technicians as per the findings and mitigation plan.

The selected bidder / implementing agency shall indemnify PVVNL from any loss of property and life during installation / removal of DT health monitoring equipment at project site.

6. Deliverables

The following deliverables shall be expected from the selected bidder / implementing agency:

No.	Deliverable
D1	Work plan & kick-off <ul style="list-style-type: none"> • Approach and Methodology outlining how the selected bidder / implementing agency will accomplish all the tasks illustrated in the scope of work within the due deadlines • List of required data, data collection, development of templates to obtain inputs from PVVNL • DT selection criteria and final list of DTs shortlisted (2,900 nos. out of 4,488 nos.)
D2	Post inspection activities <ul style="list-style-type: none"> • Specifications, procurement and installation plan - presentation and approval • Baseline data for success indicators - presentation and approval
D3	Asset mobilization on ground <ul style="list-style-type: none"> • Sign-off between selected bidder / implementing agency and PVVNL nodal person for deployment of procured assets • Actual installation and commissioning of the solution • Testing of the meters and sensors • Testing of AI / ML based software solution
D4	Monthly exception reports and actionable insights based on use cases <ul style="list-style-type: none"> • List of recommendation, insights and reports regarding DT failure reasons, predictive maintenance, asset health etc. • Support to PVVNL in applying the recommendations based on output of analysis (if required) • Evaluation and validation of report outcomes • Monthly Cost-benefit analysis
D5	Pilot assessment, completion sign off and showcasing of results to PVVNL <ul style="list-style-type: none"> • Final Cost-benefit analysis • Sign-off and approval from PVVNL on pilot results • Presentation on project experience and key highlights to PVVNL in Dissemination workshop