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GUIDE ON TRANSFORMER LIFETIME DATA MANAGEMENT

**Working Group
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GUIDE ON TRANSFORMER LIFETIME DATA MANAGEMENT

WorkingGroup A2.23

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Foreword

Transformer lifetime data management is important for a cost efficient and risk minimized asset management and maintenance process in the utility. The condition of a power transformer can be more accurately determined based on transformer lifetime data.

One of the main questions regarding lifetime data is what to collect and why? In the report this is addressed having as a base the view of the power electric engineer on transformer lifetime changes. From this perspective the reasons to collected lifetime data are derived.

A generic transformer lifetime data model is then proposed and detailed in appendix 1. The generic transformer data model is extendable and adaptable by the user. It describes the main data categories, together with key items and more detailed examples to consider, and is intended as a framework, a guideline and as exemplification.

The transformer lifetime data model is information technology independent. However, in order to support the steps in implementation of a transformer lifetime data management approach some details on the technological and aspects to consider are also discussed in the report.

The present report is regarded by the WG as a step towards a systematical and structured approach of dealing with transformer lifetime data with emphasis on the asset management and assessment decision support.

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1 Transformer Lifetime data management - a paradigm change

Three major operational and financial challenges are encountered by transformers professional around the world: work transformers to the limit, extend their operational life, reduce the lifetime costs associated with the transformer asset. These challenges lead to higher operational stresses, increasingly aging transformer populations and increasing efforts to keep transformer operational in order to minimize the failure risk. Aggravating these challenges is the continued pressure to reduce capital and maintenance budgets. These aspects are important since the power transformer is second only to some generation equipment as the most expensive family of physical assets owned and operated by a utility. Also transformers play a key role in delivering energy to the end-user.

To respond to these challenges and meet utility objectives for timely and efficient operation, tailored maintenance and replacement decisions are required for each individual transformer unit. Asset and maintenance managers must know the current status of each transformer be ready to take proper and timely actions when a change of status is predicted or experienced. For these decisions, the data over transformer' life is a key issue.

Within the CIGRE SC A2, power transformers, discussions on the transformer lifetime data started at the CIGRE 2000 Paris session. This discussion identified the need for a new paradigm to deal with transformer lifetime data and to face the needs of a dynamically changing power industry environment, essentially marked by deregulation and competition.

The WG believes that transformer life management decisions can be made more systematic, precise and repeatable and the decision risks reduced, if proper transformer lifetime data is available.

The WG also considers that data has to be relevant, sufficient and qualitative adequate for any individual transformer unit of interest. Also this data has to be managed and made available to the decision-maker, at the right time and at reasonable costs.

The current situation for power transformers is characterized by improved on-line measurement and diagnostic capabilities along with a better understanding of internal phenomena and aging processes. At the same time, considerable advances in computer and information technology (IT), data management, data processing and advances in communication have been made. As a result, it is increasingly easier to create and store more and more data from operation and maintenance activities accumulated throughout the enterprise.

By simply having more data the problems are not solved, since transformer data does not necessarily mean transformer information. Information technology improvements offer a good support and provide good means and tools to manage effectively the complex problems but are not the solution in itself.

A new structured lifetime data management approach is needed for managing lifetime transformer data in a more systematic and goal oriented way, by considering data over the whole transformer life.

The incentives for addressing in a more thorough and systematic way the problem of transformer lifetime data management (TLDM) lay in the need for better and faster asset management and maintenance decisions.

Additional reasons for this work result from the changes seen in the last decades:

- Important changes in utilities related to downsizing, split-up, consolidation, restructuring has affected negatively personnel and transformer records negatively.
- Transformer data, especially for old units, many times is no longer available due to changes in design and manufacturing, factory closures, company mergers etc.
- Advances in information and communication technologies provide the ability to transmit and save vast amounts of data, however, special attention is needed to ensure that the information is handled correctly, is always linked to the power transformer and only appropriate data is collected and stored.

The report addresses the key aspects related to the lifetime data management of power transformers starting from an transformer engineering view of the needs and relevant transformer life aspects.

The WG report offers a guideline, examples and a framework to the utilities for addressing transformer assessment and lifetime data management.

Presently most technical individuals in utilities regard lifetime data for transformer as important for the future transformer asset operation and asset lifetime management.

2 Goals and Objectives

Definition

One of the first issues addressed by the WG was to propose a definition for transformer lifetime data:

"Lifetime data - refers to an individual power equipment unit e.g. power transformer, and represents the totality of relevant data from the point of view of condition, capability, degradation and risk assessment collected over the whole life of the equipment".

The focus in the definition is on the individual transformer unit since operational stresses, events over life, maintenance and repair activities affect each individual and determine its present suitability for use [1].

Goal

The goal of the CIGRE WG was defined as:

"Describe methods and strategies for lifetime data/information management to support decision making for life and operational management of transformer assets".

The WG has addressed this goal, given examples, described a structure for a systematic approach, and offers the user the possibility to create their own blend of solutions without missing important issues.

Scope

The WG has attempted from the onset, to clearly define the borders of the activities to be covered. Because of the potential expansiveness of the topic, it was critical that the WG established and contained its activity within these boundaries.

The data itself, without any processing or interpretation is considered as a clear boundary for the activities of the lifetime data management, working group. The Working Group considers such things as pre-processing or processing of data as important but ambiguous relative to its defined boundaries and scope definition and consequently, these aspects will not be included in this work. It is not the intention of WG A2.23 to discuss any generally accepted limits, test techniques, methodologies, diagnostic and monitoring techniques as described in the "Guide for life management techniques for power transformers" prepared by CIGRE WG 12-18, [2].

The report is structured with a main body presenting and positioning the lifetime data problem within the utility enterprise. This part of the report also analyzes the status of the transformer lifetime data management, its positioning, key aspects and challenges of a systematic transformer lifetime data approach.

Two appendixes follow. The first appendix describes a generic transformer lifetime data model. This proposes a data structure, which is left open for extensions to the reader or future work, and for each section the key data and detailed data as examples.

The second appendix addresses in more detail with the information technology aspects related to transformer lifetime data management. Status analysis, conclusions and recommendations are also presented

3 Transformer data in the power industry enterprise

3.1 Lifetime data - needs, benefits, stakeholders

Issues to be addressed here:

- why we need lifetime data, benefits
- drivers
- utility view on lifetime data
- stakeholders

The main need, benefit and key incentive to use lifetime data is for making efficient and better informed decisions for operation, maintenance, repair or replacement of power transformer units.

The available lifetime data builds the foundation for judging the equipment status, the risks for continuing operation, evaluation of refurbishment, repair and replacement options. Under financial constraints typical for modern utilities operating in an deregulated environment the decision maker will need increasingly more information to reduce decision risks and minimize life-cycle costs.

The main transformer lifetime data stakeholders are members of utilities or power companies, transformer manufacturers, insurance companies , external consultants and service provider groups:

- The asset management group/manager
- The transformer service group
- The planning group and the group dealing with new equipment specification
- Enterprise management
- Operation group
- Finance
- Protection and control
- Information systems group
- Manufacturers
- Insurers
- Consultants and external service providers
- Utility regulator.

Figure 1 shows the main stakeholders in an electric power enterprise

Each stakeholder is interested in certain aspects or specific parts of the lifetime data for a specific unit, although the data may need to be heavily (pre-)processed for some stakeholders. Also the timeliness for receiving the data varies widely among the various stakeholders.

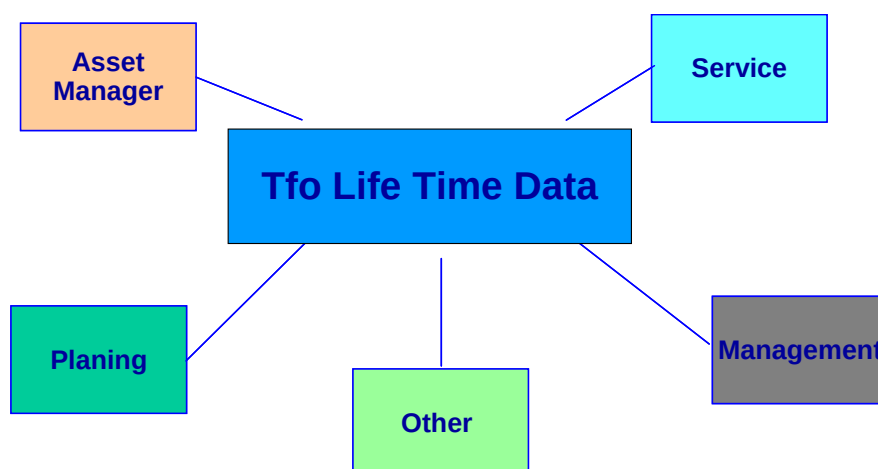


Figure 1 The main stakeholders for transformer lifetime data in an utility.

3.2 Transformer Lifetime data positioning

From an electric power industry point-of-view, individual power transformer lifetime data must be considered in relation to following facts:

1. The transformer as important equipment both from energy delivery point of view and as an valuable asset. Transformers are often the highest value single asset in a substation. In a power station it is the sole means of transferring energy from generator to the transmission network and the reliability of the generator is directly linked to the generator step-up (GSU) transformer. In the transmission system, like the transmission lines the transformer is a key element for transferring between power systems interconnections and to the distribution network.
2. The transformer must be considered in its natural 'environment':
 - Within a substation,
 - Within the power system,
 - Within an enterprise.
3. The transformer is in a continuous and dynamic interaction with its environment in terms of
 - Operational decisions
 - Maintenance and replacement actions
 - Data production and data exchange
 - o With the surrounding protection and control equipment in the substations (SCADA)
 - o Linked with monitoring devices.
 - o Uses data interfaces and protocols to perform exchange and communication tasks.

3.2.1 System View

From a system view, the power transformer and its data is positioned in a multiple nested structure, interacting locally with the surrounding substation and bay, as well as interacting remotely with the power system, the enterprise and the society, as shown in Figure 2.

There are some multiple interactions between the nested items, some data exchange, sharing or communication. The first three levels including equipment, substation and system are mainly interaction dealing with technical aspects and functionality, while the enterprise level deals mainly with economical and strategic decisions.

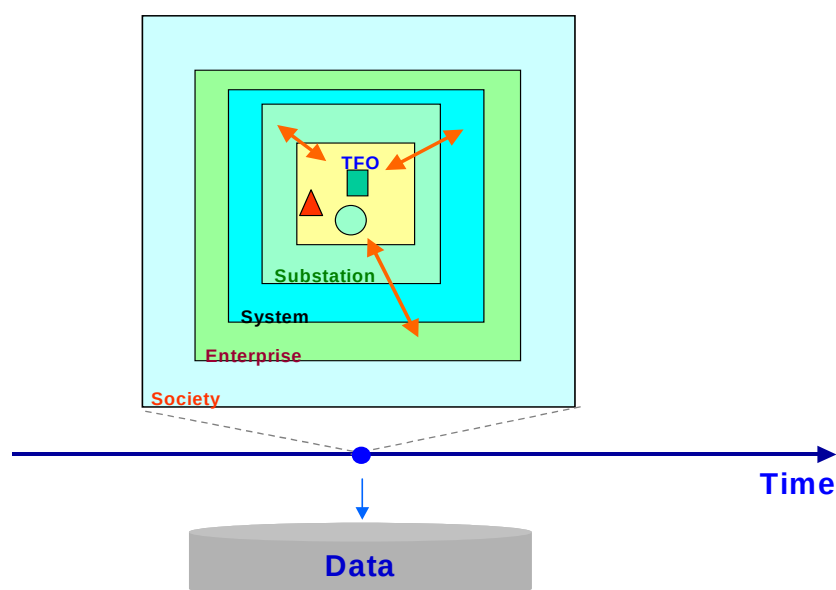


Figure 2 Positioning lifetime data of power transformers in the enterprise. A system view.

At any moment in time there exists a set of data which can be linked logically/mentally to the transformer, system operation, a substation status, a specific ongoing event or a system situation. This data may have technical and/or economical impact and be an important element of the total enterprise information system.

Transformer data accumulates continuously over the transformer's life. In principle, at any instant in time it is possible that data from the transformer and the data from its surrounding is generated, collected and made available to one or more systems or groups within the enterprise. The collection of all this data over the transformer lifetime yields the transformer life data pool, which must last as long as the transformer's life, typically tens of years.

In real life situations there are several important considerations, which ultimately result in the current perspective on transformer lifetime data.

There are technical, organizational and economical reasons or aspects related to the historical evolution of the transformer data pool:

- Technical reasons, are related to measuring possibilities, technical relevancy and practical usability of the data
- Economic reasons, which are linked to the limited capabilities/possibilities available in a real system, substation or transformer, the limited time/cost to collect and store data or often short term cost/benefit decisions.
- Organizational reasons, especially due to the fact that the data and engineering environments are very heterogeneous and dynamic. There is no such 'unique' data pool available today making data usability quite challenging. For example, sometimes data might be available in the organization but cannot be practically used by the interested people i.e. different parts of the organization or different storage/access methods.
- Finally all of the above are influenced by the historical development both in terms of development of engineering knowledge and technology, but also due to the changes in economic constraints, company re-organizations, with regulated or de-regulated environments and the electricity needs of the society etc.

3.2.2 Engineering view

From an engineering perspective the transformer lifetime data can be positioned, as shown in Figure 3. Lifetime data is in relation with design, manufacturing, testing, network operation and events, maintenance, refurbishment and work on the unit, diagnosis and monitoring as well as environmental and economic constraints.

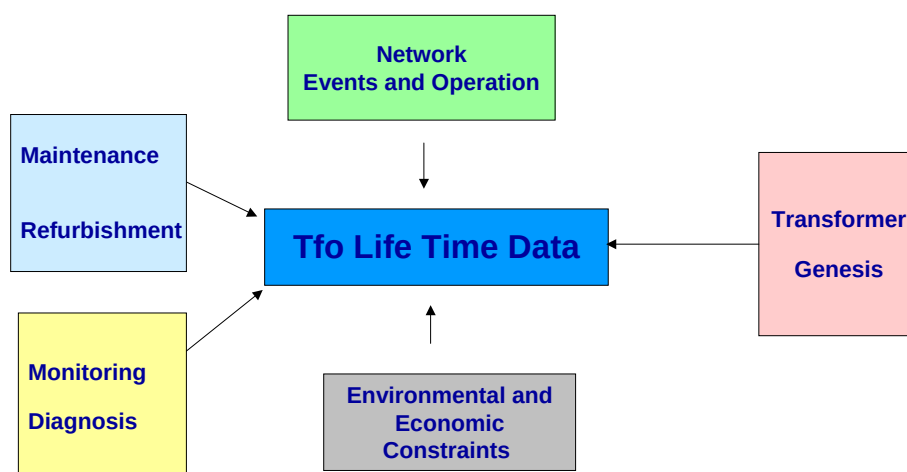


Figure 3 Positioning lifetime data of power transformers - a simplified engineering view.

From an engineering and operational point-of-view, the condition of a power transformer can not be accurately determined by only looking at a current snapshot of the transformers operating

environment, maintenance or diagnosis data. Reliable transformer operational condition can only be assessed by analyzing the transformer "individual" with it's entire maintenance, operation, change and diagnosis history.

3.2.3 Population management

The positioning of transformer data with respect to transformer population management becomes a major issue for the electric power enterprise.

A few key items related to data can support transformer population and fleet management:

- Demographics
- Groups (MVA, kV, identical units, make, types like step down, phase shifters etc.)
- Performance (Outage Rate, Failure Rate)
- Population Utilization
- Age profile for long term refurbishment and replacement planning
- Spares Inventory (entire units and spare parts i.e. bushings, etc.)
- Financial
 - Annual Capital Expenditures
 - Purchase Price
 - Cost of Preventive/ Corrective maintenance
 - Penalty cost when unavailable due to maintenance or other reasons

Evaluation of such data, as transformer population (installed units) as shown in Figure 4, failed units profile etc., can give an insight in the actual situation of a transformer population and facilitate analysis.

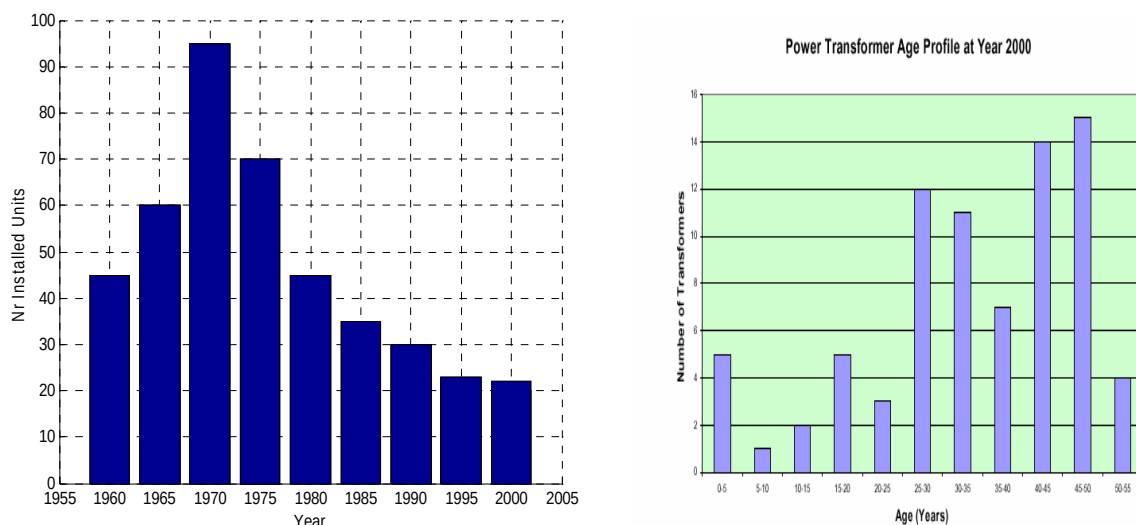


Figure 4 Principle examples for TFO population from data stemming from individual unit information: a. Installed units, b. Age profile for year 2000.

Some information from transformer populations, especially reliability/survival curves can be the coordinated result of a larger group of utilities or countries, e.g. like CEA report for hydro assets [3], however the very detail information stems from the utility itself and from manufacturer.

4 Transformer lifetime data - key aspects

4.1 Data categories

To support a systematic approach to transformer lifetime data management; data classification is necessary and thus some general data categories or data groups must be identified. These data categories refer to functional areas of interest where data is necessary to manage the transformer's performance and secure its operational life

Depending on ones point-of-view, generic data groups can be identified which are focusing on:

- Lifetime and life extension
- Failure modes and failure causes
- Source/Origin of data
- Transformer subsystems
- Data time pattern/behavior
- Level of detail, etc.

Lifetime oriented data categories

For the lifetime data four main categories of information to be created for each transformer have been identified and consist of:

- Basic transformer data and accessories data
- The 'Life story'
- Stresses over life
- Condition and life assessment.

Each category contains some typical data and is characterized by some time pattern and the format this data is typically encountered. An overview is shown in Table 1.

Table 1 – Lifetime oriented data categories

Category	Typical data	Time pattern	Format
Basic data	Specification / order data, nameplate data, installation and details, factory test information, pre-commissioning on site test information	Once and episodic upgrades	<i>Text, data</i>
Life story	Historical events, maintenance, ...	Episodic	<i>Text, data</i>
Stresses	<i>External factors acting on transformer</i>	(Continuous, episodic)	<i>Data, text</i>
Condition and life assessment	<i>Diagnosis, monitoring</i>	(Episodic or continuous)	<i>Data, text</i>

Failure oriented data categories

From the function failure perspective, data can be related to:

- Voltage transformation
- Insulation
- Conduction
- Capacity/Cooling
- Indication/Sensing

From the failure modes prospective data can be related to:

- Thermal
- Mechanical

- Dielectric
- Accessories.

Source/Origin oriented data categories

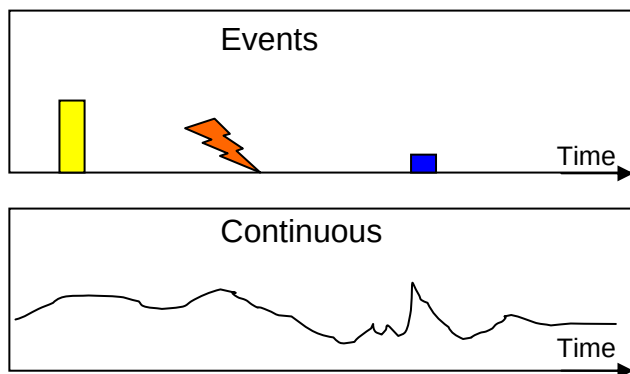
- Data from design and manufacturing
- Data from testing
- Data from transportation, installation, and commissioning
- Data from operation
- Data form monitoring
- Data from diagnosis
- Data from inspections
- Data from preventive and corrective actions
- Data from sister units
- Data from decommission and scrap.

Subsystem oriented data categories

- Data about TFO main/active part (winding, core, oil)
- Data about TFO Auxiliaries (cooling, bushings, TC)
- Data about TFO supervising and control (sensors, instrumentation, control and protection, monitoring system)

Data time pattern/behavior

- Sporadic events
- Continuously changing data.



A schematic view of the time pattern / time behavior of data showing continuous lifetime data versus lifetime events is shown in the sketch above.

With the continuously changing data we can also distinguish on the ways these are recorded between a “sampling” and (quasi-) continuous recording, i.e. monitoring.

Detail oriented data categories

This group of data categories points towards the level of detail of the data, and is closely linked to the costs of obtaining the data but also to their informative content.

Data categories distinguish between

- Foundation or fundamental – the basic data
- Enhanced – the medium detail data, and
- Advanced or detailed data.

There is also the possibly to distinguish between other categories too, possibly related to new-to-be-installed units and old installed ones, as well as possibly to distinguish generations of units according to installation time and technology.

4.2 Data amount

The amount of lifetime data for transformers is evolving and changing with time. When dealing with transformer lifetime data, two extremes are encountered:

- Only scarce and uncertain life data about the transformer is available,
- Detailed information both from off-line and online sources exists.

Presently, most practical cases are somewhere in between.

The first situation applies usually to older or less important transformers while modern and important transformers typically have good diagnostic records and sometimes even monitoring data. The trend is obviously towards more data more and better details especially stemming from monitoring systems, from diagnosis or field work. This trend is also due to the fact that data is becoming easier to produce and store with the evolution of modern hard and software.

The quantity of data that a transformer owner collects over time has grown along with the business pressures to extend operational life and the availability of technical resources such as sensors, monitors and data storage devices. As quantity has grown so has the requirement to collect the data in a more frequent and timely manner. Figure 5 presents a simple picture of the evolution of transformer data. The data evolution can be broken down into four simple groups and levels of sophistication:

- **Foundation Data:**
Data available at the time of transformer purchase and installation. It also includes current economic and operating constraints
- **Event Data**
Data from discrete yet important events that affect the performance and life of the transformer. Included are failures, maintenance, through fault and other salient events
- **Age/Operation Data**
Data that is continuously collected over the operation of the transformer. Included can be loading, voltage, tap changer operations etc.
- **Continuous / Dashboard Data**
Real time monitoring and condition assessment of the transformer.

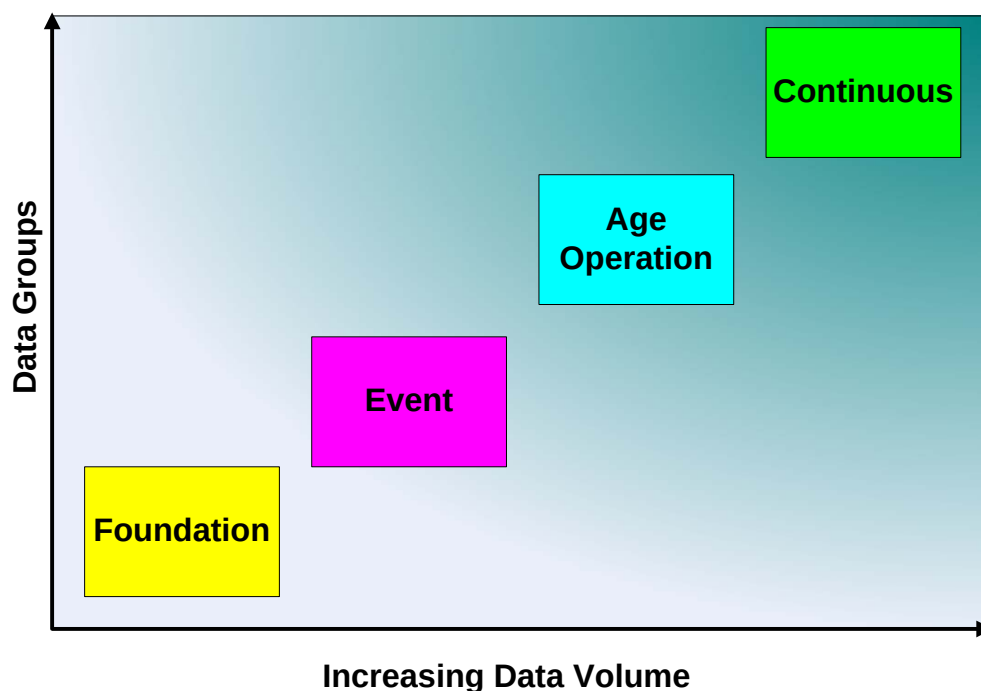


Figure 5 Data groups and data amount.

The challenge is to not store hordes of data but rather transform it into useful information. Systematical approaches and best practices have to be collected and recommendations worked out.

4.3 Data quality

High data quality is an embedded goal of any data system, unfortunately, data quality is generally compromised as one tries to reduce the cost of collecting data or increase the flexibility of the collection process. From a quality point of view, the lower the volume of data the higher the quality requirements, important decisions must be made on only a few data points and thus they must be as accurate as possible. As the volume of data increases, the ability to identify data errors becomes easier and thus one can be more tolerant of random quality problems.

Legacy pen and paper based systems have a extremely high degree of flexibility at a very low cost, but the consistency of the data and its ultimate quality degenerates as the number of humans recording data increases. The volume of data collected by most legacy systems is low and thus the ability to “filter out” errors become increasingly more difficult.

With the advent of the digital revolution, the ability to store enormous amounts of data becomes simple and of low cost, the collection process though still can be quite costly. The new paradigm is to collect the “right data” and automatically correct or identify errors.

Once we identify the right data to collect, we many times find us in a “hybrid” situation. A situation where our historical base data is of low quantity and questionable quality and our current data is of both higher quantity and quality. In cases where the use of both data sets is required, resultants may only be as good/accurate as the legacy data. In cases where only current data is of importance, the resultants are of high quality.

In some cases information is very poor e.g. only vague and uncertain such as “lots of through faults”, “frequent overloads”, “almost full load” or is missing for some events, maintenance or diagnostics. For other cases data is very detailed and stored digitally. However lots of even digitally stored data do not mean necessarily more information.

There is a great diversity in the quality of information obtained at different points in time for each type of transformer data. For example the single page factory test report for older transformers compared with more recent comprehensive reports which provide much more data for later evaluation, or the transformer book in the substation compared with the information in SCADA systems or in information systems holding maintenance and diagnosis records.

Lack of co-ordination of data collected by different departments or even different companies being readily available to all who might need that information, for example: maintenance information, number and severity of through faults, system incidents covering over-voltages, overloads i.e.–e.g. maintenance department, protection engineer, distribution utility (e.g. for system faults and location) etc. Some information such as load history may only be available for recent time.

The data quality depends on the practices of the specific utility, the internal long term replacement, repair and planning strategies.

4.4 Data dynamics

Transformer lifetime data is dynamic and multiple changes can occur during the 40+ years transformers are in operation.

The first type of dynamics is due to the changes occurring in the transformer or its surroundings as well as the changes in devices, technology and the enterprise organization.

Devices and technology changes can be related to the transformer itself such as issues related to the transformer related technologies and sensing and measuring devices. Such examples can relate to

sensors and monitoring systems, measuring instruments, protection etc., but also some design features like conservator system or materials used for repair.

Data dynamics are also affected by non-transformer issues like changes in software, changes in operating systems, in database technologies, or user interfaces and data formats. Changes in computer hardware, peripherals and data support media are occurring at a high rate compared to transformer life and have to must also be considered.

Organizational changes due to factors like

- Deregulation
- Mergers
- Restructuring
- Selling and purchasing of used transformers.
- Privatization
- Downsizing

have an impact on the transformer data dynamics.

These aspects do not affect the data itself but affect the way data is found, collected or available for decisions. Historical data may be lost with some of these changes.

A second type of dynamics is due to the fact that transformer data is simultaneously used/consumed by the owner and continuously produced by operation, maintenance or diagnosis activities. The generated data has to be continuously added to the transformer life record.

4.5 Data types

The transformer lifetime data of interest is available in a very heterogeneous format. The three main categories of data classified by their format are:

- simple data
- bloc data
- link to data or pointer to data

Simple data are numerical values or strings describing transformer individual parameters or one value for operational stresses. They have clear meaning but informational content can be obtained only in combination with other available data. This type of transformer data can be easily fetched and exchanged easily and also fits well to further processing. Depending on the organization the total amount of data may be overwhelming. They can be located in various operational or archiving systems.

Bloc data is data with rich informational content like large binary files, picture files – photographs or scanned from paper, office documents like Word, Excel or Power-point, postscript documents etc. Two examples of such data are shown for exemplification: in figure 6 a recording of a failure and in figure 7 a name plate data photography.

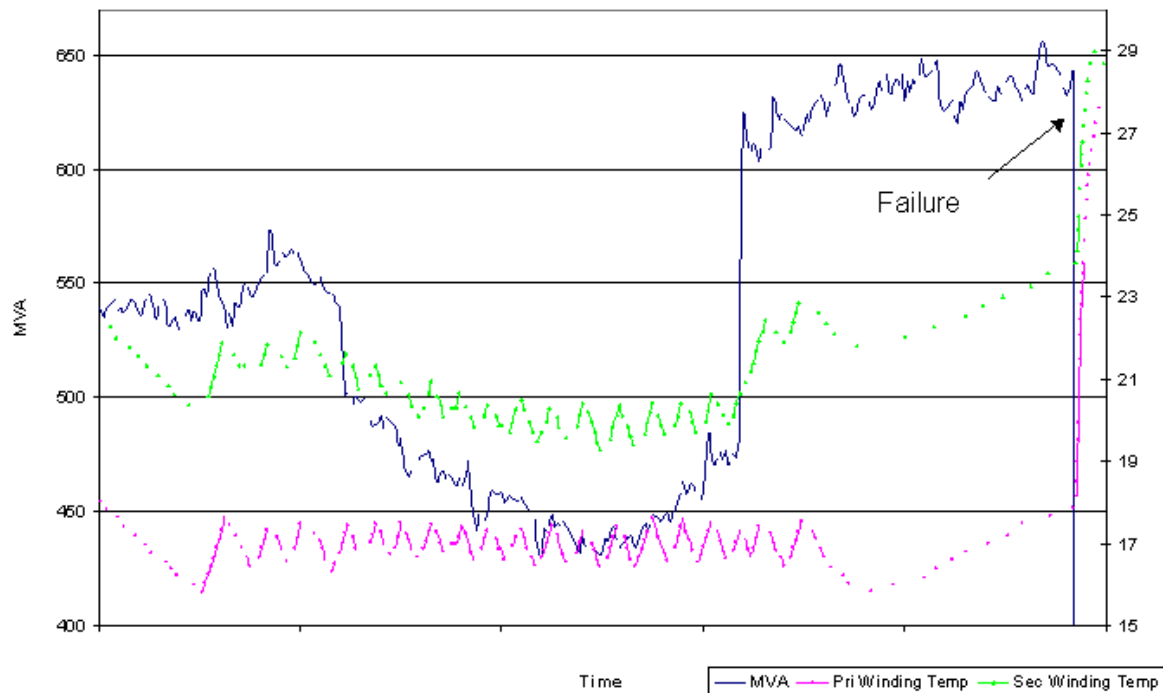


Figure 6 Example transformer data from a failure recording, available on paper or digital.

The main drawback of bloc data is the difficulty to extract a certain piece of information from them. Storing in this format has become common for office documents. Also, more and more digital photographs and scanned documents are used. Sometimes this is the only way to store the information e.g. on a failure effect on a part. In other situations bloc data, like pictures, is chosen for getting immediate information archived, as in the nameplate example. While these are of immediate help, such solutions may become inefficient in the log run, especially due to the fact that has to be analyzed by knowledgeable humans.

Data links are often used in complex systems in conjunction with bloc data. These systems do not store the main data but merely the link to the true information repository, e.g. a document, which is efficient in terms of storage. The information stored in the link itself is meaningless without the document where it points too. User applications must fetch the transformer data in two steps, however this is most often transparent to the end user.

4.6 Data - final remarks

There are a number of aspects influencing the amount and quality of data available for a certain transformer unit.

Some aspects are utility specific in terms of process and internal organization, maintenance and service practices, financial constraints, (re-) organization history or internal technology level.

Other aspects depend on the technology evolution over the unit's life, especially related to monitoring and diagnosis techniques, depends on the specific transformer unit and it's position and importance in the power system and also on the organization of the power electric industry, regulated or not.

Daily business or sudden changes in organizations or in software can sometimes force some less systematic or even ad-hoc solutions to be adopted just to keep business going. Often, large amounts of data are collected without a well-defined information goal, ending up in data rich but information poor situations.

Often the transformer data quality aspects or those related to data dynamics are underestimated and do not receive the necessary attention in the organization, which leads to less informed decisions and additional costs. Many times this is the result of inconsistent methods for managing, collecting and using lifetime data.

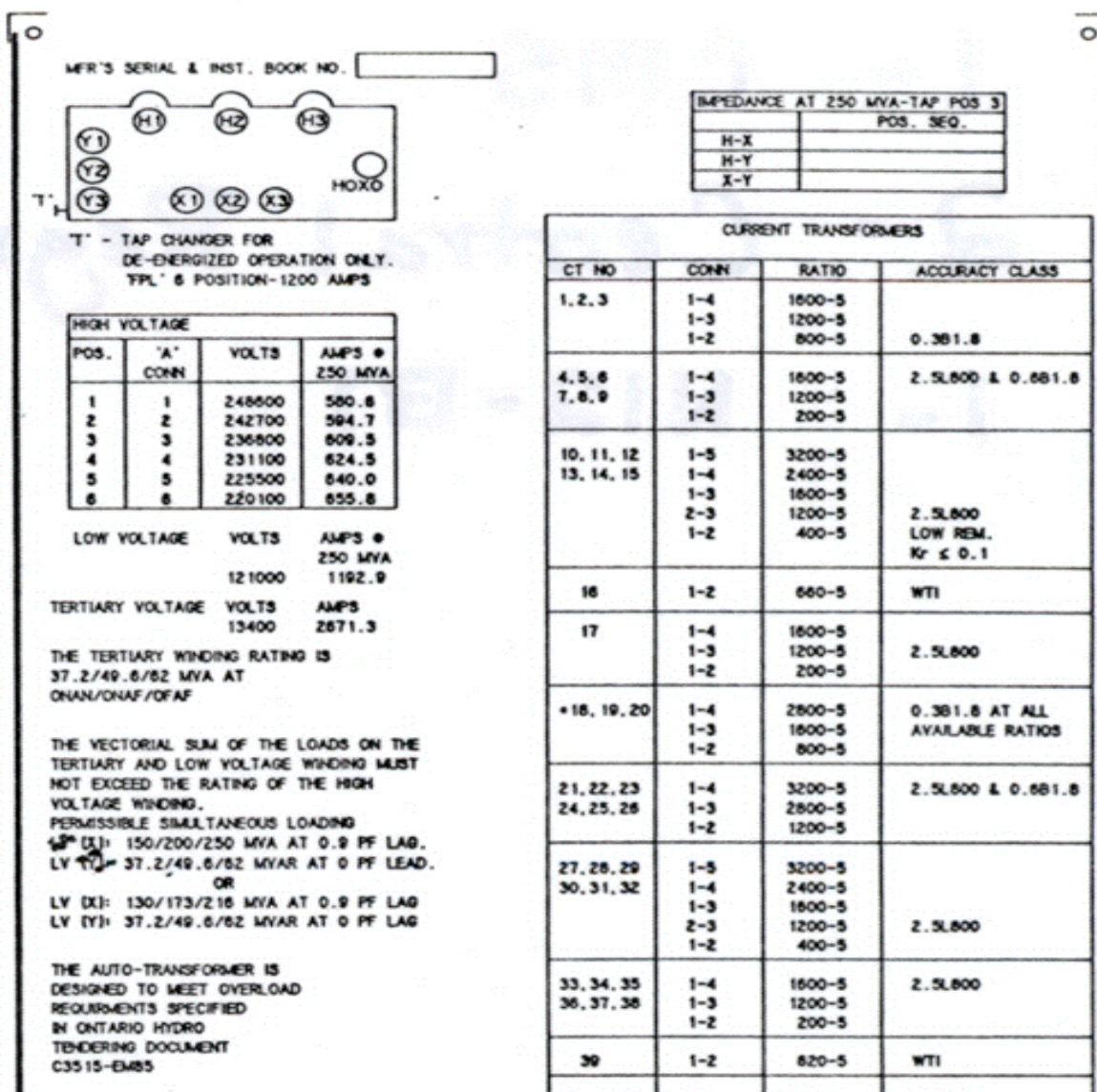


Figure 7 Example of nameplate data stored as a bloc data document – e.g. as pdf or jpg.

5 Transformer lifetime data management

5.1 What to collect and why

For effective transformer lifetime management a set of technical, operational and maintenance data must be collected systematically over the whole transformer life.

Transformer Lifetime data management deals with the collection of data for the individual transformer unit during his life. As schematized in Figure 8 beside data on the transformer unit such as maintenance, repair and refurbishments, it is of interest to have also sufficient information on the “transformer environment”, e.g. changes in network and loading, location, special events, environmental issues etc.

The main data groups from a technical view are detailed in Figure 8 and refer to:

- TFO genesis: specification, design, manufacturing and tests
- TFO operation: network details, operation and events
- TFO maintenance and refurbishment
- TFO diagnosis and monitoring
- TFO environmental and economical constraints.

Starting from these groups which state the information of interest, a set of data items and documents to be collected and managed over transformer lifetime could include:

- Full size transformer manual including all results of factory test
- Transport issues
- Erection documents and test (also in case of relocation)
- Relocations
- Inspection documents during life time
- Maintenance activities during life time
- Repair issues during life time
- Stand by time and conditions.

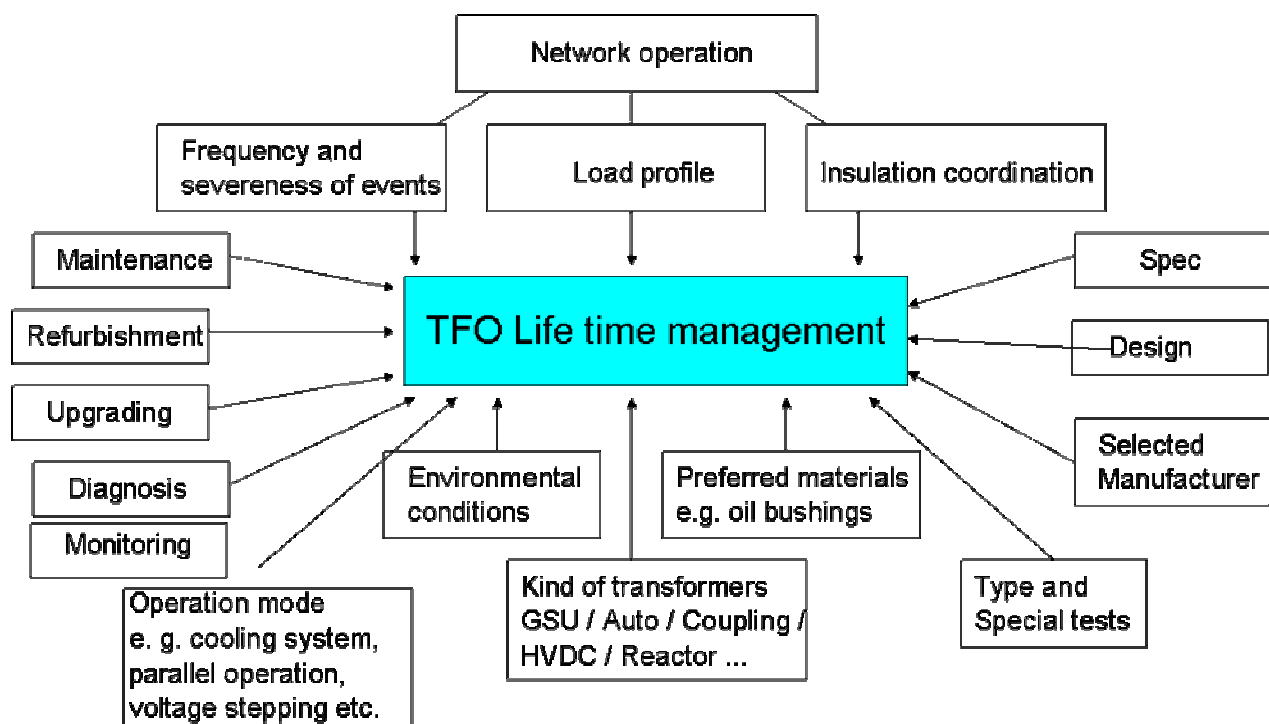


Figure 8 Transformer lifetime data management - a detailed technical and operational view

The Annex 1, “Transformer Generic Lifetime Data Model” gives details on how to structure the lifetime data and defines a generic transformer life data model and on how to perform with the data.

The groups and examples of data which may be collected over time and presented are not exhaustive and should be understood as a recommendation only. Also the WG A2.23 believes that details on specific sets of transformer data have to be specified in future work.

At the same time it is clear for the WG that not all mentioned items in this report must be collected for each and every transformer. The level of detail of data collection can be decided by the utility depending on its internal strategies for maintenance, replacement and repair as well as its risk aversion profile.

The reason for developing the lifetime data management guide is to define a generic and structured set of data from a transformer lifetime perspective. This data responds to the long time transformer assessment needs and is not solely data for immediate and operational decisions. The main goal of the report is to aid the utility in building their own specific lifetime data strategy that effectively supports their own transformer asset management, maintenance and strategic planning processes.

The data available and ready to be collected for a transformer is virtually unlimited, however if data / information is collected it should be preferably structured, chosen by relevance or pre-processed such that it helps the utility in its transformer assessment process.

Few examples are given below to illustrate this. They refer to loading, operation time, and oil and winding temperatures:

- If loading is registered it could be condensed to some kind of simplified load profile indicating the stress below and beyond nameplate rating.
- If operating time of equipment (part) is counted, this should be linkable to an individual specific hold point which requires action (e.g. change a fan after x hours in operation).
- If oil temperatures are measured and registered they should be classified to get indication for increased ageing. The measurement principle / method should be stored too, to be able to judge later the values and tolerances.
- If winding temperatures are measured and registered it makes sense to classify the readings in 6...7°C-steps to correlate with the ageing of insulating materials.

There is a gray zone on how much processing if any to apply to the transformer data, where does data stop and information start.

One extreme is to store all raw data over the life of the transformer. The main disadvantages are data volume and the lack of relevance a specific piece of data possess; however any type of data processing can be applied later to the data stored. The other extreme is to have a full and detailed processing of the data, storing only the resulting key information. In this case the original data is forever lost.

In practice a mixed solution could be interesting where a certain amount of structuring, sorting and pre-processing is applied. Which data and parameters are of interest has to be decided by the user.

5.2 How to collect from operation / online

Current transformer data is generated on a continuous basis and we either decide to store it or not. In the future, new data types are possible and more data like data from sensors, to be increasingly generated and collected. It is important to stress that true actual historical data cannot be re-invented or re-generated, if it does not exist, it can only be estimated or theorized.

Of all the data available for a transformer over its life, the smallest volume of data is many times the data that has already been collected and the largest volume is the data that can be potentially collected in the future e.g. from monitoring systems. For transformers that have not reached end-of-life, it is this future data that has the greatest operating and financial impact. From the data quality point of view this is exactly opposite – old data is poor and newer data more precise – however not always relevant.

Collecting data from operating transformers is not a trivial or inexpensive task. One must thoughtfully determine:

- Which data to be collected
- Data availability and sensor requirements
- The required accuracy of the data to be collected
- The frequency of collection
- The mechanism for transporting data from the collection point to the storage point
- The amount of pre-processing of the data required
- The amount of post processing of the data required
- The allowable latency between collection and post processing

Operational data to be collected

The operational and online data to be collected is intended give information on:

- the loading,
- the current operating positions of transformer,
- temperature and cooling system.

This data is mainly intended for immediate action but can give also useful information in a lifetime perspective. Can be collected through monitoring, SCADA and can be linked to Energy Management Systems, but can also include some sporadic registration by hand e.g. once per day. Such data includes:

- Loading
- Tap position and LTC operation count
- Temperature (windings, core, cooling agent, ambient)
- Cooling operation, and if possible additionally
- Stresses like the number of over-current or over-voltage events and severeness class

Other data to collect can be added depending on the degree of sophistication of monitoring, installed sensors and SCADA system.

Transformer supervision/observation data to be collected

The collection of data for transformers supervision has to be divided into:

- Continuous data collection using different kinds of sensors - monitoring and
- Time based diagnostic measurements.

Currently "Monitoring" forms an early warning system. Its efficiency depends upon the number of different kinds of sensors, the on-line connection with operational data and the use of more or less sophisticated build-in "models" for deriving calculated values.

Typically sensors are used for:

- Dissolved gas (minimum: hydrogen)
- Temperatures
- Water content in oil
- Tap changer supervision
- Pump and fan operation
- Bushing supervision (Voltage ratio, tan-delta)
- Partial discharge

and so on, depending on experience and available sensors

Time based diagnostic measurements are performed e.g. once per year, on request (e.g. after severe short circuits or simply after warning of monitoring system) or sporadic. For some of the measurement the transformer must be shut off.

Typical diagnosis measurements are:

- winding resistance
- no load current at low voltage
- insulation resistances
- Tan-delta measurements
- full scale gas in oil analyses
- full scale oil physical chemical analyses (including color, moisture, sulfur, inhibitor content, breakdown voltage, oil tan-delta, surface tension, sludge, acid, ...)
- Furan compounds in oil

- FRA (preferably after unusual stresses)
- PDC-analysis
- RVM-analyses
- Vibration-analyses
- Short circuit impedance
- Clamping forces estimation
- DP and moisture in paper (if probes available)
- Thermo-vision pictures of loaded transformer
- PD-analyses and localization, etc.

Additionally also visual inspection reports and functional check reports have to be added e.g. corrosion, functional tests of tap changer, fans, pumps, cooler, etc.

The collected data can be later processed and used, by considering for example the absolute values, the tendencies etc.

Data availability and sensor requirements

Most sensors and devices required to collect operational status data existed and can be/are embedded in the transformer by the manufacturer of new units. For older transformers sensors and devices to measure/monitor the transformer can be added after the transformer has been operational for a period of time or after a critical situation.

Many of these sensors are of high cost and sophistication and some with not too long operational history. These sensors and the monitoring system require external power, specialized communication requirements and even sometimes their own maintenance program.

A few sensors are relatively simple and have a long operating history of measuring simple parameters such as temperature, pressure, contact closures etc.

The required accuracy of the data to be collected

As one begins to monitor critical parameters that indicate a functional failure is near, it becomes readily apparent that some end-of-life indicators require an extremely sensitive and accurate sensor while others do not. Measurement of some dissolved gas requires sensitivity at the parts per million level while temperature measurements may only require a sensitivity of 1 or 2 °C (after correction of systematical measurement failures).

The frequency of collection

In order to identify an imminent functional failure, it is important that the proper data be available at the correct time. Some failure modes evolve slowly; some are initiated immediately by a discrete event while others and others have a gestation period before failure occur. Because of the varying failure triggering mechanisms, and the intrinsic sensor physics the data collection frequency requirements can range from daily to real-time.

The mechanism(s) for transporting data from the collection point to the storage point

Power transformers are installed in a wide variety of locations. Some locations have high speed broadband connectivity while others only have access to "snail mail". In order to speed up the delivery of transformer data to a central location, utility engineers have devised and use numerous clever communication schemes including:

- Mobile transport of a recorder media
- Power Line Carrier
- Radio
- Data over Voice Communications
- Satellite
- Dedicated networks and internet protocols
- Optical fibers.

Each of these transport mechanisms comes at a specific cost, through-put capability, and latency. It is of paramount importance that the mechanism for identifying a potential functional failure account for the delays associated with the data transfer mechanism

The amount of onsite-processing of the data required

In order to reduce the amount of data transmitted from the transformer site to a central operations center, logic processes are often executed at the transformer site to reduce the data transfer

requirements. While this type of approach may make economical sense, it also requires a high degree of processing reliability and maintenance of the processing routines. The main drawback is that data is irrevocably changed and the original cannot be restored in case of failure or if more details are needed.

The amount of remote-processing of the data required

In order to reduce the effort and drawbacks associated with a onsite-processing approach to data gathering, one may decide to bring in as much raw data as possible to a central location and process it there. While increasing efficiency, data transfer requirements also increase.

The allowable latency between collection and remote- processing

For slow evolving functional failures, the need to identify an incipient functional failure on a timely basis greatly decreases. For these failure modes, numerous data transport mechanisms including “snail mail” are acceptable. For those failures that evolve extremely quickly, high speed data communication or local data processing is a must.

The trend for data collection is to move toward a real time central collection and post processing approach. This approach results in the “best of all scenarios”. With the proliferation of high speed data networks, both latency and volumetric issues go away. Unfortunately, high speed, low cost communication systems are not yet ubiquitous. As they expand, so does the trend of using IP internet protocols. IP protocols provide means or solve the issues of:

- Data security
- Standardization of protocols
- Efficient use of bandwidth
- Latency.

5.3 How to handle and manage transformer lifetime data

The present arrangement for handling data about individual transformers varies greatly between electric power industry organizations depending on the structure of the organization and their historical development. For instance the purchasing group may be completely separate from the asset group or the field/maintenance group. Traditionally information was collected as paper copies and important technical information could be held within a number of volumes of contract documents requiring appropriate expertise to recognize such information and extract it for electronic storage. The operation history may be held elsewhere within a further mass of information about many things. To retrieve all of this information and compile it in to a suitable form for access when needed requires a large amount of resources and as older equipment approaches time for retirement, it is unlikely there will be any cost benefit, however a to do it on a case by case base, as need arise seems to be more realistic and practicable.

Decisions need to be made in every utility on key issues related to transformer life data handling and management. Some critical topics such as:

- Generic transformer data model
- Time and archiving
- Storage aspects
- Data management for whom?
- Handling data in the view of technology changes software and hardware - caution aspects,

will be analyzed below aiming to support the individual utility decisions:

Generic transformer data model

Identify relevant transformer data and have a generic transformer data model is important. The basic guideline, the categories and the structure are given in this report. This is an important issue but the details were left for future work and for every utility decision, since it is linked to changes, human effort and costs.

The transformer data model should be based on technical, operational, maintenance and replacement needs as shown in Figure 8, and has to support the asset management strategy of the utility.

Time and archiving

Decide on the time frame for each data or category. Some data will be needed possibly in 20 years from now some other tomorrow, possibly other may become less relevant after some time elapses. The typical lifetime of a transformer is continuously increasing such that 40 – 50 years old units are encountered today. Accordingly the time data is stored changes too.

Some transformer data will be relevant after scrapping too, so a decision must be made about which data to keep— possible as long as similar types of units as the scrapped one are in operation.

Storage aspects

As data storage costs diminish, the hurdles to data storage solutions are much easier and cost effective to implement. The net result is the need to design a transformer data repository with the following characteristics:

- The right transformer data is collected
- Data necessary volume is handled
- Data quality is extremely important
- Data access must be easy and quick.

Data management - for whom?

Once a transformer lifetime data repository is implemented, it is easy for the user/analyst to be overwhelmed by the volume and breadth of the stored data. It also becomes very time consuming to “search” the data because of the extremely large number of records that must be accessed and the very small number of records that are result by any single query. To overcome this obstacle data management concept must be used such that allow every user gets the subset of data it needs. One such solutions available today is using multi-dimensional data structures (“data cubes”) which contain only a subset of the total data. These cubes increase access speed and reduce complexity for the user groups like:

- Asset managers
- Service providers
- Planning engineers
- Management
- Service teams.

Handling data in the view of technology changes software and hardware - caution aspects.

The most difficult issues here are related to changes in the technologies from hardware and storage devices to operation systems and data handling software. One has to keep in mind that we are dealing with a time range of 40 – 50 years and that one may expect, based on the rates we see nowadays 5 to 10 or more technological changes during this time period. Important aspects to consider are the maintenance, the upgrading of systems and possibly periodically migration of the data to other computing platforms.

It becomes more and more important that changes and migration can be made at the lowest cost. With the cost of technology implementation being significant, it must be designed to both last for a long period of time and be easily upgraded. The dominant solution to this dilemma is to embed as much of the technology as possible in software which allows for fast and low cost upgrades even remotely and by technologies already available. However changes in the underlying hardware and peripheral device technology can be well expected over such time periods and then a hardware change will become necessary too.

With new larger more easily managed electronic storage and retrieval systems available, new transformers will have a lot more information recorded and some information on older transformers will likely be included too, much of it as digitally recorded or as scanned data. The practical way to do it will depend on work and data collection process implemented by each utility.

The solutions to be adopted depend on the technology especially on what means are/will be available to collect and store data and what is the total cost including technology cost for systems and communication, the manpower and cost for long time service and maintenance

TLDM and Enterprise Information Systems

There is a trend and a need in utilities for the integration and consolidation of enterprise information systems in order to support power equipment lifetime data and asset management. Too often important information is stored in silos and not readily available to the asset manager or technical decision maker.

It could be argued that power transformers are second only to some generation equipment as the most expensive family of physical assets owned and operated by a utility. While reliable transformer operation and long life is extremely desirable, it is only one of the many “links” in the supply chain necessary for successfully delivering energy to the end-user.

The asset, service and operational data associated with transformers are just a small segment of the total data requirements of the utility and thus it must be viewed not only in the context of the apparatus but also in the context of the utility enterprise. While the transformer as an apparatus is naturally integrated in the energy system, so must the transformer data management be integrated in the information system of the enterprise.

From the discussions WG A2.23 has had with representatives from utilities, monitoring systems manufacturers, diagnostic methods developers, power transformer manufacturers, universities and research centers it is universally agreed that TLDM only makes sense if supported by adequate information and communication systems. Furthermore, the information needs of utility staff members is much more than data visualization, warnings and abnormal evidences indication.

Transformer Information Systems (TIS) are desired - systems that can use the full potential of digitally stored historical data, to help users on their maintenance, operation and management decisions. These systems must be very specialized, considering the operative context and risk acceptance limits of the enterprise, and able to give best recommendations and possible proactive actions.

With the use of such systems, an evolution from scheduled preventive maintenance to Condition Based Maintenance (CBM), Reliability-Centered Maintenance (RCM) and Performance Focused Maintenance (PFM) is expected. Necessarily all relevant data must be considered, and also the operating context and inter-system correlations.

Such a “transformer information system” (TIS), can be implemented either virtually as a ‘functionality’ within a complex IT environment of the utility or as a physical system. In either case, the “transformer information system” needs to have transformer lifetime data capabilities, links to other related data systems and embedded expert knowledge or capabilities to clearly present this information to a human expert.

The existence of lifetime data is extremely important to reach these objectives and there are important aspects related to information, communication and data acquisition technology that must be considered in order to support Transformer Lifetime Data Management. Some of these requirements are discussed here after.

Appendix 2 is dedicated to the positioning of transformer lifetime data management in the enterprise information systems.

6 Transformer lifetime data management – status and outlook

The lifetime data management practices for power transformers are continuously changing and evolving and may differ by geographical area and utility.

More and broader effort is needed to get the whole true picture. The WG has identified a couple of aspects related to the status of TLDM by the individual effort of the members in their areas. These findings will be presented below without claiming to be complete and without replacing the need for a more detailed information basis such as from a questionnaire.

Status

In the opinion of the WG the present status is characterized by:

- Presently most technical individuals in utilities regard lifetime data for transformer as important for the future transformer asset operation and management.
- In practice a systematical approach for transformer lifetime data management is however often postponed considering daily or urgent matters, existing processes and practices and the cost of putting such systems into operation.
- TLDM is influenced by the historical background, present operation and maintenance strategy in the utility and by local or individual initiatives.
- A major problem today is the availability of power transformer data. Especially for old transformers data on design, operation, maintenance or diagnostic might be very poor.
- The data is often heterogeneous in terms of data format or even data support on which it is stored like paper, digital, etc.
- The lifetime data has a distributed nature in terms of:
 - various enterprise information systems or data repositories it may be found,
 - organizational structure with various groups, departments, data responsibilities and data ownership
 - physical data location.
- The data for a transformer unit can be inconsistent and differ in various locations and systems. The data inconsistency starts often with the unit identification and can also include design/nameplate parameters, maintenance records or diagnostic measurements.
- Data quality is also a critical issue. Considerable effort has often to be spent for converting, cleaning-up or selecting relevant data for an individual transformer unit, before any analysis can be started.
- Data amount is bounded by the two unwanted extremes: lack of data and considerable amount of not completely used data – e.g. from monitoring. There are cases where lots of data exist in the enterprise data management systems regarding transformers, most often together with other power system equipment, which is not properly used.

All these are leading to considerable effort and cost for lifetime data collection even before any transformer analysis can even start and when the data is urgently needed.

Outlook

The developments and trends in the area of transformer lifetime data management are seen by the WG as follows:

- The lifetime data for transformer and other equipment is becoming more important to an increasing number of people in the utility and this awareness process will continue.
- Lifetime data specification will contain a sort of common structure but also be adapted to the utility needs, existing practices and systems.
- Efforts will continue towards definition and specification of a lifetime management process.
- Evolution is expected for specification of the software tools and interfaces suitable to the lifetime data collection and analysis needs.
- Data integration in enterprises will continue at increasing rate. The power transformer data will be an important part in the picture. Also the use and integration of already existing data for transformers from various enterprise data sources.
- Standardization of data categories, data formats and even equipment designations will become a topic.
- Extension of the definition of the data and information content e.g. for transformer asset management purposes (inventory, transformer demographics, status, performance, value, repair/replacement costs), population/fleet assessment.

A couple of aspects need more detailed investigation and additional work

- How is transformer lifetime data used and needed, today or medium/long term for:
 - Operative decisions
 - Asset management decisions
- Which are the best practices regarding TLDM.
- Transformer data a stand alone or a part of an integrated utility solution?
- Importance of transformer data for a utility
- A set of more detailed and specific recommendations on data and formats based on best practices and experience in power electric industry.
- Where is the best balance between technical data and economical information?

- What to data to keep and for how long?
- Which data to be processed and what processing to apply to go from data to the information needed in operation, planning or asset management decisions?

7 Conclusions

Presently most technical individuals in utilities regard lifetime data for transformer as important for the future transformer asset operation and asset lifetime management.

The WG considers that transformer lifetime data management is important for a cost efficient and risk minimized asset management and maintenance process in the utility.

From an engineering and decision making point-of-view, the condition of a power transformer can be more accurately determined by analyzing the entire history of the device and therefore a transformer lifetime data management is important.

Transformer lifetime data management is influenced the by utility historical background, the present operation and maintenance strategy and hence the right decisions will adapt to the individual local human experience and existing data infrastructure.

The lifetime data management is very broad subject and linked strongly to other aspects like life management of the transformer and transformer status and failure evaluation, data analysis, data processing, the data gathering from monitoring systems and from off-line diagnosis, with the basic questions of what to keep and what to throw away form the transformer data accumulating over life. Each of these items is a subject in itself.

The WG work presented in this report starts form the power engineer view of the transformer lifetime, and the reasons to collected data. A generic lifetime transformer data model is then proposed and detailed in an appendix. The generic model is extendable and adaptable by the user to his specific demands. It describes the main data categories, together with key items and more detailed examples to consider, and is intended as a framework, a guideline and exemplification. This generic transformer lifetime data model is information technology independent. However, in order to support the steps in implementation of a transformer lifetime data management approach some details on technologies and aspects to consider are also given in the report.

There are a couple of challenges and steps to go basically implementing the lifetime data concept on a broad basis and then moving towards transforming this data into information and ultimately support specific decisions and actions.

The present report is regarded by the WG as a step towards a systematical and structured approach of dealing with transformer lifetime data with emphasis on the asset management and assessment decision support.

Acknowledgements

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8 References

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ANNEX I

Transformer Generic Lifetime Data Model

9 Annex 1 – Transformer Generic Lifetime Data Model

This appendix of the WG report gives details on the generic, lifetime oriented, data model for power transformers². The generic transformer data model is a follow-up of the questions on what data to collect and what to keep from transformer life, as addressed in the main part of the report.

The main challenges for a generic data model are

- the heterogeneity of transformer life data,
- the data quality available and
- the cost, benefit and usability aspects related to lifetime data.

Obtaining data on-line and off-line has become more and more affordable both technically and economically. The increased capability and affordability of monitoring is reflected in the parts dealing with monitoring of: transformer, OLTC and bushing, in this annex.

To cope with this, a special view of monitoring data is considered in the Annex, which can be useful both for lifetime assessments and for immediate/operational decisions. The recent recorded data is often kept for up to 1 year in the monitoring system and easily accessible from there. The data for lifetime use have to be derived by some processing from the operational data and stored for lifetime use in a database.

As a consequence of feasibility and affordability of sensors and on-line monitoring systems it may become very tempting to record “everything” technically possible. The generic model intends to help to keep a balance between data possible to get and data relevant for lifetime issues. Also it tries to consider and offer alternative views of the amount and detail of the data to collect, in order to cope with economical constraints of the utility and to use or adapt the TLDM to it's needs and ambition level and match it to gained own experience.

The worksheets below are split into two main data groups

1. Key data items to consider, and
2. Detailed Items as guideline/example.

These detailed items reflect the view of the WG and are intended as orientation and guideline only. By this structuring we hope that every user can choose which part(s) to use for his special needs.

The generic data model presented here has a transformer life focus, i.e. the contained data should be mainly useful for investigation the status, condition and risks related to the unit, and to a lesser degree with the operational aspects.

This annex should not be considered or read as a standard. In the intention of the WG it should highlight the main areas of interest of data and the view of life time use and relevance. Also it was not possible or feasible to cover in the frame of the WG tasks all methods or details.

Finally the generic transformer data model is not seen as a closed work. The WG is aware that there are more other diagnosis methods to describe and new methods and sensing devices are possible to arise, and therefore we expect that in a similar way as the presented parts it will develop further.

² Note: the abbreviation ‘TFO’ is often used instead of the word ‘transformer’

9.1 Overview of Generic transformer lifetime data model

The table below shows the considered areas for lifetime data and the corresponding data sheets. Additional data can be considered to further extend the ones addressed in this report. Such to-be-added-later items are for example those in grey give only hints on the diagnosis methods can be added later to generic data model but which were not considered in this release of the report, but may be added later.

Area	Data sheet name
TFO identification	Table 1 – Transformer unit basic data
	Table 2 – Transformer bank basic data
	Table 3 – Transformer location data
Bushing	Table 4 – Bushings basic data
OLTC	Table 5 –OLTC basic data
Cooling System	Table 6 – Cooling System - basic data
Control Protection Instrumentation Monitoring Devices	Table 7 – CPIM Control-Protection-Instrumentation and Monitoring basic data
Transformer Tests	Table 8 – Transformer Test - Thermal
	Table 9 – Transformer Test - Electrical
Transformer Diagnosis	Table 10 – Transformer Diagnostics - DGA
	Table 11 – Transformer Diagnostics - Oil
	Table 12 – Transformer Diagnostics - Furan
	Other diagnosis methods can be added by the user such as:
	Diagnosis-Insulation Resistance
	Diagnosis-Thermo Vision
	Diagnosis-FRA
	Diagnosis-RVM
	DIAGNOSIS-PDC
	DIAGNOSIS-Degree of Polymerization
	DIAGNOSIS-Noise Level
	DIAGNOSIS-Load Loss
	DIAGNOSIS-Iron Loss
	DIAGNOSIS-PD-Acoustic
	DIAGNOSIS-PD-Electric
	DIAGNOSIS-Power Factor
	DIAGNOSIS-Winding Resistance
	Short circuit Impedance, etc
Maintenance Work Repair	Table 13 – Transformer Maintenance/Work/Repair
Stress Recording	Table 14 – Transformer Stresses
Monitoring	Table 15 – Transformer Monitoring
	Table 16 - TC Monitoring
	Table 17 - Bushing Monitoring

9.2 Generic transformer lifetime data model – data sheets

9.2.1 Table 1 – Transformer unit basic data

Table 1 – Transformer unit basic data

"data type: installed equipment / inventory "

Note:

Describe the main characteristics of the transformer.

Basic data give a status or inventory description of the TFO at a moment in time.

Should be useful for immediate access and identification.

Are complementing the full size transformer manual including all results of factory tests - typically found as paper documents.

1. Key Items

Name	Description	Data type
Nameplate data	The information from transformer nameplate	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files.
Available manufacturer design or installation data - conditional	Any available manufacturing data - if exist	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files.

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
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TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
TFO Unit Recording Date	The date when the TFO data was recorded / apply. It is a time stamp.		
Date of manufacturing	Manufacturing Date of the unit	dd/mm/yyyy	date
Date of Installation	Beginning of Operation Date of the unit in the utility	dd/mm/yyyy	date
Transformer Model	Name or code given by the manufacturer to a group of transformers with the same project characteristics	none	string
Manufacturer	Transformer manufacturer name	none	string
Standard	IEC 60076 , IEEE etc		
Constructive Type	The constructive type of the transformer e.g. CORE, SHELL	none	string
Type of Transformer	Single-phase, Three-phase, Autotransformer	none	string
Nominal Power	Nominal Power	MVA	real
Nominal Frequency	Frequency to what a transformer is projected	Hz	integer
Impedance	For each winding pair, in %. Could be expressed as equivalent network (base MVA).		real
Zero sequence Impedance..			real
Ambient Temperature	The design ambient temperature	C	real
Exist Tertiary Winding	Yes or not	none	boolean
Primary Nominal Voltage (kV)	Nominal voltage value (principal tap)	kV	real
Secondary Nominal Voltage (kV)	Nominal voltage value (principal tap)	kV	real
Tertiary Nominal Voltage (kV)	Nominal voltage value (principal tap). Used if there is a Tertiary winding	kV	real
Primary Nominal current		A	
Secondary Nominal current		A	
Tertiary Nominal current		A	
Note: may use also winding naming HV, LV, etc.			
Number Of Phases	Single or three phase		
Cooling	IEC : ONAN, ONAF, ODAF etc. / Natural, OA, FA, FOA etc.		
Rating Stage 1		MVA	
Rating Stage 2		MVA	
Rating Stage 3		MVA	
1 hour Overload Rating		MVA	
24 hour Overload Rating		MVA	string
Type of Winding Connections	Data sheets for windings		binary object

			(file)
Polarity	Subtractive, Additive	none	string
Vector Group	Defined according to standards. IEC terminology, e.g. YNyn0d1, YaN0,d1, Dyn1 or Dyn11, etc	none	string
Phases Sequence	ABC or ACB	none	string
Exist OLTC	Yes or No		
Winding with OLTC	Specify the TFO winding.	none	string
OLTC oil is isolated from oil of the main tank	Yes or No	none	boolean
Type of regulation if fitted with tap changer	Variable voltage constant flux, constant voltage variable flux	none	string
Type of Cooling System	ODAF, ODWF, OFAF, OFWF, ONAN, ONAN-ONAF, ONAN-ONAF-ONAF. More information can be stored also e.g.: attached coolers, separate cooler bank, high efficiency type OFAF coolers, etc	none	string
Type of Oil Conservation System (breathing)	free, N2 Sealed, N2 Blanket, with Rubber, without Rubber, Dry Cool, Open silica-gel system	none	string
Type of insulation medium	Oil (Naphtenic, Paraffinic or Synthetic), gas (e.g. SF6)	none	string
Temperature Class of insulation	55 or 65 °C	°C	integer
Oil volume	oil volume in liters	l	real
Basic Insulation Level (BIL) – Primary	BIL as manufacturer project	kVpeak	real
Basic Insulation Level (BIL) – Secondary	BIL as manufacturer project	kVpeak	real
Basic Insulation Level (BIL) – Tertiary	BIL as manufacturer project	kVpeak	real
Basic Insulation Level (BIL) – Neutral	BIL as manufacturer project	kVpeak	real
Note: Also Lightning impulse withstand Level for HV, MV, LV and Neutral can be used.		kVpeak	real
Type of Insulating Material (paper)	Paper Kraft, Thermally upgraded/Termostabilized, Polymeric.	none	string
Insulating Material Mass (paper mass)	Mass of paper used in the active part	Kg	real
Commercial name of the insulating material (paper)	Name used by the manufacturer to identify the insulating paper	none	string
Active Part Weight		Kg	real
Transformer Total Weight		Kg	real
Height	Height of transformer tank	M	real
Width	Width of transformer tank	M	real
Depth	Depth of transformer tank	M	real

Transportation weight

Recommendation

Record or update this table :

At installation and when any change occurs in the basic data e.g. after upgrading.

9.2.2 Table 2 – Transformer bank basic data

Table 2 – Transformer bank basic data

"data type: installed equipment / inventory "

Note:

Describe the main characteristics of the transformer.

Basic data give a status or inventory description of the TFO at a moment in time.

Should be useful for immediate access and identification.

Are complementing the full size transformer manual including all results of factory tests - typically found as paper documents.

1. Key Items

Name	Description	Data type
TFO bank scheme	The transformer bank electrical scheme	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files.

TFO bank location

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Bank Identification Code	As used by the company (unique identifier of the bank in the utility)	none	string
TFO Bank Recording Date	The date when the TFO data was recorded. It is a time stamp.	dd/mm/yyyy	date
Data Recording Responsible	The responsible for the data recording. It is a responsibility stamp	none	string
Substation Name	Substation name where the bank is installed at the "TFO Bank Recording Date"	none	string

Connection of Primary	Delta, Star, Star earthed, zig-zag.	none	string
Connection of Secondary	Delta, Star, Star earthed, zig-zag.	none	string
Connection of Tertiary	Delta, Star, Star earthed, zig-zag.	none	string
Note: may use also winding naming HV, LV, etc.	Note: Other details could be added too.		
Phase A Transformer Serial Number	Serial Number of Phase A unit	none	string
Phase B Transformer Serial Number	Serial Number of Phase B unit	none	string
Phase C Transformer Serial Number	Serial Number of Phase C unit	none	string
Phase A TFO - Manufacturer	Serial number and manufacturer should be unique in practically all cases.	none	string
Phase B TFO - Manufacturer	Serial number and manufacturer should be unique in practically all cases.	none	string
Phase C TFO - Manufacturer	Serial number and manufacturer should be unique in practically all cases.	none	string

Recommendation

Record or update this table :

At installation and when any change occurs in the data e.g. after change of units.

9.2.3 Table 3 – Transformer location data

Table 3 – Transformer location data

"data type: installed equipment / inventory "

Note:

Describe the items typically used to identify the location of the o TFO geographically and in the power system at a certain moment in time.

For basic/inventory like data we do not need anything about sampling or time frame for acquisition / collection

1. Key Items

Name	Description	Data type
Location information	The information about location of the unit.	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files.

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
TFO Location Recording Date	The date when the location data were recorded / apply. It is a time stamp.		
TFO Location Substation	The name of the substation where the TFO is located at a time given by "Location Recording Date"		
TFO Location Bay	substation bay where the tfo is located at a "Location Recording Date"		
TFO Local Name	The name used for the transformer at the current location e.g. XF23, TF#1		
TFO Usage Category	Defines the way the TFO is used after its movement to the current Local Name Position(In-Operation, In-Reserve)	none	string

TFO_GPS Z	GPS Location Coordinates		
TFO_GPS Y	GPS Location Coordinates		
TFO_GPS X	GPS Location Coordinates		

Recommendation

Record or update this table :

After installation
After movement/relocation of the unit.

9.2.4 Table 4 – Bushings basic data

Table 4 – Bushings basic data

"data type: installed equipment / inventory "

Note:

Describe the main characteristics of the bushings used at the time of installation or at a certain other moment in time later.

One set of data for high voltage, medium voltage, low voltage, neutrals and others is required.

Should be useful for immediate access and identification.

For basic/inventory like data we do not need anything about sampling or time frame for acquisition / collection.

1. Key Items

Name	Description	Data type
Nameplate data	The information from nameplate	1) Isolated data items or 2) One-block information, i.e. picture of the nameplate as file
Available manufacturer data - conditional	Any available manufacturing data - if exist	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files.

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
Manufacturer	manufacturer name		
Bushing Serial Number	Serial number given by manufacturer. Should be unique.	none	

Bushing Recording Date	The date when the bushing data was recorded. It is a time stamp.		
Date of manufacture		dd/mm/yyyy	
Data of Installation		dd/mm/yyyy	
User Identification Code	unique identifier used by utility - if any	none	
Rated voltage	Specify both Rated voltage Un and rated phase to earth voltage (refer IEC standard)	kV RMS	
Principal insulation type	Paper oil impregnated; Paper resin impregnated; Paper resin agglutinated; ceramic; glass; inorganic material; organic material; casting organic material; bushing composed of several insulation materials; insulation liquid/oil; gas insulation.		
Insulator Material (external housing)			
Basic Insulation Level		kV peak	
Note: Also lightning impulse withstand can be used.			
Switching voltage impulse test		kV peak	
Rated continuous current		A	
Bushing filling material			
Bushing maximum interior rated working pressure - if applicable		bar	
Insulation oil type			
Available length for bushing CTs		mm	
Bushing use			
Maximum permissible top oil temperature		°C	
Creep distance		mm	

Bushing conductor type			
Conductor material inside bushing			
Conductor cross section - if available		mm ²	
Standard	IEC or IEEE etc		
Maximum ambient air temperature		°C	
Bushing total weight		kg	
Bushing voltage tap			
Voltage tap rated voltage			
Bushing inclination angle		mechanical degrees	
Critical mounting and installation dimensions	Detail mounting arrangement and critical dimensions for replacements. A key drawing with dimensions can be used or the key dimensions recorded.		
Cantilever strength		N	
Bushing maximum application altitude		m	

Recommendation

Record or update this table :

At installation and when any change occurs in the data e.g. after change of a bushing.

9.2.5 Table 5 –OLTC basic data

Table 5 –OLTC basic data

"data type: installed equipment / inventory "

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Note:

Describe the main characteristics of the TCS used at the time of installation or at a certain other moment in time later.

Should be useful for immediate access and identification.

For basic/inventory like data we do not need anything about sampling

1. Key Items

Name	Description	Data type
Nameplate data	The information from nameplate	1) Isolated data items or 2) One-block information, i.e. picture of the nameplate as file
Available manufacturer data - conditional	Any available manufacturing data - if exist	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files.

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM.

They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
OLTC Serial Number	Serial number given by manufacturer. Should be unique.	none	
OLTC Data Recording Date	The date when the TFO data was recorded. It is a time stamp.		
Date of manufacturing		dd/mm/yyyy	

Data of Installation		dd/mm/yyyy	
User Identification Code	unique identifier used by utility - if any	none	
OLTC Model	Name for the model of OLTC given by the manufacturer	none	
Manufacturer	Name of the manufacturer of the OLTC		
Tap-changer environment			
Classification			
TC Location	Main Tank or separate compartment in main tank or external. [clarify if this applies to a combined selector diverter tank or the selector switch only]	to check for redundancy	
TC Winding		to check for redundancy	
Rated through current		A	
Maximum through current		A	
Transition Impedance	Resistor or reactor		
Operating cycle	flag cycle, symmetrical pennant cycle, asymmetrical pennant cycle (for tap-changers with resistor transition only)		
Rated frequency		Hz	
Number of phases			
Number of inherent tapping positions	the highest number of tapping positions for half a cycle of operation for which a tap-changer can be used according to its design		
Highest voltage for equipment		kV	
Rated step voltage		V	
Rated lightning impulse withstand voltage (peak)		kV	
Maximum rated step voltage		V	
Rated short-duration power frequency withstand voltage (r.m.s)		kV	
Type of insulation medium			
Height		m	

Length		m	
Depth		m	
Diameter		m	
total weight without oil			
oil volume		l	
Applicable standard			
Year of standard	Year the standard was issued	yyyy	
Number of service tapping positions	the number of tapping positions for half a cycle of operation for which a tap-changer is used in a transformer		
User Identification Code	unique identifier used by utility		
Date of manufacturing of the OLTC	manufacturing date of the OLTC	yyyy	
Commissioning date of the OLTC	Commissioning date of the OLTC	dd/mm/yyyy	
Motor drive unit - model	Name for the model of OLTC given by the manufacturer	none	
Oil filter unit	Name for the model of OLTC given by the manufacturer	none	

9.2.6 Table 6 – Cooling System – basic data

Table 6 – Cooling System - basic data

"data type: installed equipment / inventory "

Note:

Describe the main characteristics of the Cooling system and devices/ associated with the transformer
Should be useful for immediate access and identification.

For basic/inventory like data we do not need anything about sampling or time frame for acquisition / collection (NF)

1. Key Items

Name	Description	Data type
Cooling system information	The information about cooling system from manufacturer.	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files.

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM.
They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
TFO Cooling System Data Recording Date	The date when the TFO data was recorded. It is a time stamp.		
Cooling system type			
Manufacturer			
Motors type			
Pumps	Include details of oil flow liters/minute at " m" head & number of pumps	l/min	
Fans	Include details of air flow m ³ /min and number of fans		
Heat exchanger type	Radiator type, Air/oil high efficiency type cooler, water heat exchanger		

9.2.7 Table 7 – CPIM Control-Protection-Instrumentation and Monitoring basic data

Table 7 – CPIM Control-Protection-Instrumentation and Monitoring basic data

"data type: installed equipment / inventory "

Note:

Describe the main characteristics of the CPIM devices/ associated with the transformer

Should be useful for immediate access and identification.

For basic/inventory like data we do not need anything about sampling or time frame for acquisition / collection (NF)

1. Key Items

Name	Description	Data type
Control devices installed - information or link	Information or link to the information resources	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored
Protection devices installed - information or link	Information or link to the information resources	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored
Monitoring and sensors installed - information or link	Information or link to the information resources	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored

Instruments installed - information or link	Information or link to the information resources	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored
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2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only. The issues on control where not detailed here just mentioned for completeness.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
TFO CPIM Data Recording Date	The date when the TFO data was recorded. It is a time stamp.		
Control data details ..			
Protection details ..			
Monitoring and sensors details ..			
Instrumentation details ..			

9.2.8 Table 8 – Transformer Test - Thermal

Table 8 – Transformer Test - Thermal

"data type: over life event"

Note:

Describe the data from manufacturing heat run/thermal test - if available.

One time TFO life data.

1. Key Items

Name	Description	Data type
Thermal test information	The information from transformer laboratory test	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
TFO Test Recording Date	The date when the TFO data was recorded / apply. It is a time stamp.		
Applicable Standard	Name of the applicable Standard (ANSI , IEC, etc)	none	string
Oil Temperature - Ambient Temperature	Difference between Top-oil temperature and Ambient temperature for thermal modeling - For each type of cooling specified.	°C	real
Winding Temperature - Ambient Temperature	Difference between Winding Top temperature and Ambient temperature for thermal modeling. For each type of cooling specified.	°C	real

Winding thermal time constant	Winding thermal time constant for thermal modeling - For each type of cooling specified.	h	real
Oil thermal time constant	Oil thermal time constant for thermal modeling. For each type of cooling specified.	h	real
Factor R for rated MVA	Factor R = W_{cu} / W_{fe} .	pu	real
<u>Note:</u> depending on the thermal model used some additional items could be also considered in this section such as: exponent n and m, winding temperature differences, initial loss of life etc.			

Recommendation

Record or update this table :

At delivery time or at installation.

9.2.9 Table 9 – Transformer Test - Electrical

Table 9 – Transformer Test - Electrical

"data type: over life event"

Note:

Describe the data from manufacturing tests - if available

One time TFO life data.

1. Key Items

Name	Description	Data type
Electrical test information	The information from transformer laboratory test	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
TFO Test Recording Date	The date when the TFO data was recorded / apply. It is a time stamp.		

Impulse test			
Applicable Standard	Name of the Applicable Standard (ANSI , IEC, etc)	none	string
<i>Here more detail test data can be added.</i>			
Digital Test Record ID	Electronic file name/ID of the test record		object/string

Recommendation

Record or update this table :

At delivery time or at installation.

9.2.10 Table 10 – Transformer Diagnostics - DGA

Table 10 – Transformer Diagnostics - DGA	<i>"data type: over life event"</i>						
Note: Describe the main data related to DGA analysis. -ready to form ratios or to compare with max. values -to be used also for trend analysis							
1. Key Items							
Name	Description	Data type					
DGA analysis reports	The information from transformer laboratory test	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored					
2. Detailed Items as guideline/example							
Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.							
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none					
Utility TFO Identification Code	Unique identifier used by utility	none					
TFO Diagnosis Recording	The date when the TFO						

Date	data was recorded. It is a time stamp.						
Analysis Date	Date when the oil was analyzed in laboratory	dd/mm/yyyy	date				
Oil collection Date	Date of Oil collection in site	dd/mm/yyyy	date				
Oil Sampling Place	where the oil was collected: Tank, OLTC, Bushing	none	string				
H2	Hydrogen	ppm	real		Gas Chromatography		
CH4	Methane	ppm	real				
C2H2	Acetylene	ppm	real				
CO	Carbon Monoxide	ppm	real				
CO2	Carbon Dioxide	ppm	real				
O2	Oxygen	ppm	real				
N2	Nitrogen	ppm	real				
C2H6	Ethane	ppm	real				
C2H4	Ethylene	ppm	real				
C3H4	Propyne	ppm	real				
C3H6	Propylene	ppm	real				
C3H8	Propane	ppm	real				
TCG	Total of combustible Gases (this is a calculated data)	ppm	real				
Total of Gases	Total of Gases (this is a calculated data)	ppm	real				
Digital Test Record ID	Electronic file name/ID of the test record		object				
Lab conclusion on findings	Conclusion of lab findings (incipient fault or no incipient fault, etc.)						
Recommendation							
Record new set of DGA data:	normal : 12 - 60 month suspect: 1 - 3 month critical: 1 day or less						

9.2.11 Table 11 – Transformer Diagnostics - Oil

Table 11 – Transformer Diagnostics - Oil	<i>"data type: over life event"</i>						
Note: Describe the main data related to physical-chemical analysis of oil.							
1. Key Items							
Name	Description	Data type					
Oil analysis reports	The information from transformer laboratory test	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored					
2. Detailed Items as guideline/example							
Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.							
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none					
Utility TFO Identification Code	Unique identifier used by utility	none					
TFO Diagnosis Recording Date	The date when the TFO data was recorded. It is a time stamp.						
Analysis Date	Date when the oil was analyzed in laboratory	dd/mm/yyyy	date				

Oil collection Date	Date of Oil collection on site	dd/mm/yyyy	date				
Oil Sampling Place	where the oil was collected: Tank, OLTC, Bushing	none	string				
Moisture In Oil	Water content in the oil	ppm	real				
Breakdown Voltage ASTM		kV					ASTM/678, 2.5mm
Breakdown Voltage IEC		kV					IEC
Color		none	real				
Acidity		mg KOH/g	real				
Interfacial Tension		N/m	real				
Tan delta Oil at 100 °C		%	real				
Tan delta Oil at 25 °C		%	real				
Oil Viscosity		cSt	real				
Oil Density			real				
Flash Point	if available	°C	real				
Sediments		%	real				
Appearance			string				
Particles	Particles detected in oil – if applicable	none	Boolean				
Digital Test Record ID	Electronic file name/ID of the test record		object/string				
Recommendation							
Record new set of Oil data:	normal : 12 month - 60 month suspect: 1month - 3 month critical: 1 day or less						

9.2.12 Table 12 – Transformer Diagnostics - Furane

Table 12 – Transformer Diagnostics - Furane	<i>"data type: over life event"</i>						
Note: Describe the main data related to the analysis of furanes in oil.							
1. Key Items							
Name	Description	Data type					
Furane analysis reports	The information from transformer laboratory test	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored					
2. Detailed Items as guideline/example							
Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.							
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none					
Utility TFO Identification Code	Unique identifier used by utility	none					
TFO Diagnosis Recording Date	The date when the TFO data was recorded. It is a time stamp.						

Analysis Date	Date when the oil was analyzed in laboratory	dd/mm/yyyy	date				
Oil collection Date	Date of Oil collection on site	dd/mm/yyyy	date				
Oil Sampling Place	where the oil was collected: Tank, OLTC, Bushing	none	string				
2FAL	2 - Furfuraldehyde	ppm		.. Example only .. normal : 12 month - 60 month suspect: 1month - 3 month			
2ACF	2-acetyl furfural (ppm).	ppm					
5HMF	5-Hydroxy Methyl Furfural	ppm					
5MEF	5-methyl-Furural	ppm					
[some also include Phenols and creosols]							
Digital Test Record ID	Electronic file name/ID of the test record		object/string				
Recommendation							
Record new set of Furan data:	normal : 12 month - 60 month suspect: 1month - 3 month						

9.2.13 Table 13 – Transformer Maintenance/Work/Repair

Table 13 – Transformer Maintenance/Work/Repair

"data type: over life event"

Note:

Describe the maintenance work and time when performed.

Records the defect and work details.

Work report document can be added / attached to life data.

The worksheet is only indicative and does NOT cover all maintenance or work categories.

1. Key Items

Name	Description	Data type
Maintenance reports	The information from transformer repair activity.	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored
Repair and test and commissioning reports	The information from transformer maintenance activity.	1) As isolated data items or 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored

2. Detailed Items as guideline/example

Note: The following table contains in more detail data which can be considered for TLDM.

They reflect the view of the WG and are intended as an orientation and guideline only.

Variable Name	Variable Description	Unit	Data type
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none	
Utility TFO Identification Code	Unique identifier used by utility	none	
Date Time Start	Date and time of execution of the maint/work - start		datetime

Date Time	Date and time of execution of the maintenance/work - stop		datetime
Defect Details	Details on the defect or anomaly etc. , requiring maintenance/inspection work.		string
Work Category (only examples are shown)	Maintenance task1, Maintenance task2, .. Oil exchange Oil treatment Off-line drying On-line drying .. Repair, etc.		string
Work Details	Details on the work performed		string
Work Location	Location where the work was performed. On-site, workshop.		
Work Report	Attach work report or text description if possible.		binary object (file)
Tests Details	Details on the tests performed before going operational.		string
Test Location	Location where the test was performed		
Test Report	Attach test report if any		binary object (file)
Work Executed By	Group, department, external company, etc.		string

9.2.14 Table 14 – Transformer Stresses

Table 14 – Transformer Stresses	<i>"data type: over life event"</i>						
Note: Describe the main stresses to be recorded. Describe the categories of stress to be recorded.							
1. Key Items							
Name	Description	Data type					
High Current	Information or link to the information resources	1) As isolated data item or 2) Link to the location where the full information is stored					
Overvoltage	Information or link to the information resources	1) As isolated data item or 2) Link to the location where the full information is stored					
Overload	Information or link to the information resources	1) As isolated data item or 2) Link to the location where the full information is stored					
Environment	Information or link to the information resources	1) As isolated data item or 2) Link to the location where the full information is stored					
2. Detailed Items as guideline/example							
Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.							

Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none					
Utility TFO Identification Code	Unique identifier used by utility	none					
High Current		ppm					
DateTime							
Short circuit current peak		kA		on event			
Short circuit type	Ph-Ph, Ph-G, ..			on event			
Short circuit current duration				on event			
Short Circuit Category	approximated value e.g low, medium, high						
Overvoltage							
DateTime				on event			
Overvoltage peak				on event			
Overvoltage type				on event			
Overvoltage gradient	du/dt			on event			
Overvoltage Category	approximated value e.g low, medium, high						
Overload							
DateTime	time of the overload			on event			
Overload value		A		on event			
Overload duration				on event			
Overload type				on event			
Overvoltage Category	approximated value e.g low, medium, high						
Environment							

ambient temperature		C					
exceptional events weather							
exceptional events system	Data sheets						
Recommendation							
Record stresses on transformer	In case of anomalies from operation In case of failures caused by the stresses						

9.2.15 Table 15 – Transformer Monitoring

Table 15 – Transformer Monitoring							
Note: Describe the main monitoring data for the transformer. Describe the condensed key data items from monitoring records of longer time intervals.							
1. Key Items							
Name	Description	Data type					
Event records	Records from events with high current (overloads, short circuits), high voltage, failures in the substation or system affecting the unit.	1) As (time, value) data records 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored					
Yearly data records		1) One-block information, i.e.file, or 2) Link to the location where the full information is stored					
Yearly data average and Min/Max values	Average and min/max values for 1 year.	numerical					
Winding temperature - Yearly data average and Min/Max values	Average and min/max values for 1 year.	numerical					
Load - Yearly data average and Min/Max values	Average and min/max values for 1 year.	numerical					
2. Detailed Items as guideline/example							
Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.							
2.1 Data from monitoring for lifetime use:							
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
Serial Number	Serial number given by	none					

	manufacturer. Unique for a manufacturer.						
Utility TFO Identification Code	Unique identifier used by utility	none					
Loading for TFO lifetime data:							
Average yearly load	Average yearly load			1 year			
Peak Load	Peak Load			1 year			
Average ambient temperature	Average ambient temperature	C		1 year			
	- example -						
Total time at load below 50%	Time spent by the considered unit below 50% of rated load.	h		1 year			
Total time at load 50% to 60%	Time spent by the considered unit at 50% rated load.	h		1 year			
Total time at load 60% to 70%	Time spent by the considered unit at 60% to 70% rated load.	h		1 year			
Total time at load 70% to 80%	Time spent by the considered unit at 70% to 80% rated load.	h		1 year			
Total time at load 80% to 90%	Time spent by the considered unit at 80% to 90% rated load.	h		1 year			
Total time at load 90% to 100%	Time spent by the considered unit at 90% to 100% rated load.	h		1 year			
Total time at load 100 to 110%	Time spent by the considered unit at 100 to 110% rated load.	h		1 year			
Total time at load above 110%	Time spent by the considered unit above 110% rated load.	h		1 year			
Top oil temperature for TFO lifetime data :		h		1 year			
Total time at top oil temperature below 70 °C	Total Time spent by the considered unit with top oil temperature below 70C						
Total time at top oil temperature (70 °C, 80 °C]	Total Time spent by the considered unit with top oil temperature in interval.	h		1 year			
Total time at top oil temperature (80 °C, 90 °C]	Total Time spent by the considered unit with top oil temperature in interval	h		1 year			
Total time at top oil temperature (90 °C, 100 °C]	Total Time spent by the considered unit with top oil	h		1 year			

	temperature in interval						
Calculated Winding Hot spot temperature	- schema -			1 year			
Total time at winding hot spot temperature below xxC	Total Time spent by the considered unit with hot spot temperature in interval.			1 year			
Total time at winding hot spot temperature (yyC, zzC]	Total Time spent by the considered unit with hot spot temperature in interval.			1 year			
Total time at winding hot spot temperature above zzC	Total Time spent by the considered unit with hot spot temperature in interval.			1 year			
				1 year			
Monitored Dissolved Gases							
Average - for key gases				1 year			
Max Value - for key gases				1 year			
Min Value - for key gases				1 year			
Monitored Moisture In Oil							
Average - for key gases				1 year			
Max Value - for key gases				1 year			
Min Value - for key gases				1 year			
2.2 Data from monitoring for operational and immediate use:	<i>Detail data can be obtained from monitoring system handbook –only few examples are shown</i>						
Variable Name	Diagnosis-Furan	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a						

	manufacturer.						
Utility TFO Identification Code	Unique identifier used by utility						
Monitored Dissolved H2	Dissolved hydrogen detected by monitoring system and sensor.	ppm	real	6h			
Monitored Dissolved C2H2	Dissolved methane detected by monitoring system and sensor.						
Monitored Dissolved CH4	Dissolved acetylene detected by monitoring system and sensor.						
Monitored Dissolved Gas Sum	The measured sum of following gases - is sensor dependent						
Monitored Moisture In Oil	Measured the moisture in oil				sensor XYZ,..	where placed or other if relevant	
Monitored Moisture In Paper Calc	Calculated moisture in paper				Internal model in monitoring system.		
Monitored load				15 minutes			
Monitored Current PhA, add..	Measured current in phase A	A	real				
Monitored Voltage PhA, add..	Measured the voltage ...	V					
Monitored Temperature Oil Top	Measured temperature of top oil						
Monitored Temperature Oil Bottom		C	real				
Winding Temperature – hot spot (fiber optics) – direct							
Oil Temperature (top)							
Oil Temperature (bottom)							
Moisture Content in Solid Insulation							
Oil Level							
Tank pressure							
Sudden Oil Pressure							
Dissolved Gasses in Oil							

Vibration							
Tank Leakage Current							
Core Ground Current							
Neutral Current							
Insulation Aging (LL% Arhenius) (accumulative loss of life)							
Fans - Motor currents							
Fans - Motor voltage							
Fans – Overload							
Radiators Air Flow							
Heat Exchangers - Efficiency / Heat Losses							
Cooling System Temperature							
Oil Pumps – Voltage							
Oil Pumps – Current							
Forced Oil Flow							
Forced Water Flow							
Incoming Water of Exchangers - Temperature Measurement							
Pumps Vibration							
Fans Vibration							
Heat Exchangers - Leakages							
Voltage (primary, secondary, Tertiary)							
Current (phases A,B,C / primary, secondary, Tertiary)							
Substation Ambient Temperature							
AC Auxiliary Voltage							
DC Auxiliary Voltage							
Cabinet Internal Temperature Control							
Cabinet Internal Moisture Control							

9.2.16 Table 16 – TC Monitoring

Table 16 – TC Monitoring	<i>"data type: monitoring"</i>						
Note: Describe the main monitoring data for the TC. Describe the condensed key data items from monitoring records of longer time intervals.							
1. Key Items							
Name	Description	Data type					
Event records	Records from events potentially affecting the bushing.	1) As (time, value) data records 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored					
Number of operations	from counter	numerical					
Cumulative Mechanical wear indication factor	depends on construction and operations	numerical					
Cumulative Electrical wear indication factor	depends on construction and operations	numerical					
2. Detailed Items as guideline/example							
Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.							
2.1 Data from monitoring for lifetime use:							
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none					
Utility TFO Identification Code	Unique identifier used by	none					

	utility						
OLTC Serial Number	Serial number given by manufacturer. Should be unique.						
Number of operations	operating counter for total number of tap change operations						
Number of operation after last maintenance	operating counter for number of tap change operations after last maintenance						
Contact wear of transition contacts	accumulated wear of transition contacts	mm					
Contact wear of switching contacts	accumulated wear of switching contacts	mm					
Difference of wear between transition and switching contacts	difference between accumulated wear at transition contacts and wear at transition contacts	mm					
Oil flow of the oil-filtering unit	actual quantity of oil the oil-filtering unit pumps per minute	l/min					
Carbonization level of the tap changer oil		%					
Water content in the tap changer oil	water content in the tap changer oil	ppm					
Service recommendation	Indicating the date of the next OLTC maintenance calculated by the monitoring system	dd/mm/yyyy					
statistics of OLTC switching operation	show over a certain time span how long/often the OLTC stays at which position; might be used for definition of number of operations for new transformers						
maximal number of permissible switching operations of the tap changer (diverter switch and selector combined)	maximal number of permissible switching operations of the tap changer (diverter switch and selector combined)						
maximal number of permissible switching operations of the diverter switch	maximal number of permissible switching operations of the the diverter switch						
2.2 Data from monitoring for	<i>Detail data can be obtained</i>						

operational and immediate use:	<i>from monitoring system handbook –only few examples are shown</i>						
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.	none					
Utility TFO Identification Code	Unique identifier used by utility	none					
OLTC Serial Number	Serial number given by manufacturer. Should be unique.						
Indication of present tap position	Indication of present tap position						
Pressure relief device indication	Pressure relief device indicates overpressure inside the tap changer oil compartment and trips the transformer						
Oil flow relay indication	oil flow relay of the OLTC tripped the transformer						
Oil temperature of diverter switch insert	temperature of oil inside the diverter switch insert	C					
Oil temperature of OLTC selector	temperature of oil inside the diverter switch insert	C					
gases dissolved in the OLTC oil of a reactor type OLTC							
temperature difference between diverter switch insert and OLTC selector	temperature of oil inside the diverter switch insert	C					
standardized torque of the OLTC during the different phases of one switching operation							
maximum torque of the OLTC during a tap change operation		Nm					
switching operation completed	Indication if the switching operation has a failure and gives an alarm						
drive shaft supervision	detecting if there is a loose drive shaft (mechanical connection between motor drive unit and OLTC)						

9.2.17 Table 17 – Bushing Monitoring

Table 17 – Bushing Monitoring		"data type: monitoring"						
Note: Describe the main monitoring data for the bushing. Describe the condensed key data items from monitoring records of longer time intervals.								
1. Key Items								
Name	Description	Data type						
Event records	Records from events potentially affecting the bushing.	1) As (time, value) data records 2) One-block information, i.e. Documents or pictures stored in files, or 3) Link to the location where the full information is stored						
Yearly data average and Min/Max values	Average and min/max values for 1 year.	numerical						
2. Detailed Items as guideline/example								
Note: The following table contains in more detail data which can be considered for TLDM. They reflect the view of the WG and are intended as an orientation and guideline only.								
2.1 Data from monitoring for lifetime use:								
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol	
tan delta				season or yearly average or peak				
Capacitance				season or yearly average or peak				
Loss Current				season or yearly average or peak				

Oil Temperature				season or yearly average or peak			
2.2 Data from monitoring for operational and immediate use:							
Variable Name	Variable Description	Unit	Data type	Data acquisition rate	Measuring method or sensor	Measuring Arrangement details	Standard/Name/Symbol
TFO Serial Number	Serial number given by manufacturer. Unique for a manufacturer.						
Utility TFO Identification Code	Unique identifier used by utility						
Bushing Serial Number	Serial number given by manufacturer. Should be unique.						
tan delta			real				
Capacitance			real				
Loss Current			real				
Oil Level			real				
Oil Temperature			real				
Internal Pressure			real				

ANNEX II

Transformer Lifetime Data Management (TLDM) and Information Technology Aspects

10 Annex 2 – TLDM AND INFORMATION TECHNOLOGY ASPECTS

This Annex shows information technology aspects related to possible implementation of the transformer lifetime data management and positioning in the enterprise IT infrastructure.

An example of a possible architecture for a Transformer Information System (TIS) will be presented. This is based on the Transformer Lifetime Data Management concept, as described in this report, but in the following with special emphasis on monitoring and diagnosis.

The TIS example is used in the following sections to discuss in more details some of the IT related aspects of transformer lifetime data management, focusing on the data management and IT aspects but mentioning related aspects like analysis and links with the other utility systems.

The items presented in the sections of Annex 2 - TLDM AND INFORMATION TECHNOLOGY ASPECTS - are summarized below:

- 10.1 POSITIONING TLDM IN AN ENTERPRISE INFORMATION SYSTEM ARCHITECTURE
- 10.2 ENTERPRISE APPROACH FOR MANAGING TRANSFORMER INFORMATION
 - 10.2.1 Transformer Data in the enterprise process
 - 10.2.2 TFO On-line Data Acquisition and Transmission Topologies
 - 10.2.3 Decision Level Impact
 - 10.2.4 Hardware Robustness
 - 10.2.5 Reliability and Availability of Monitoring components
- 10.3 ENTERPRISE ASSET DATA MANAGEMENT
 - 10.3.1 Data Repository Characteristics
 - 10.3.2 Data Storage Models
 - 10.3.3 Master-Slave Model
 - 10.3.4 Enterprise Data Warehouse Model
 - 10.3.5 Common Information Model (CIM)
 - 10.3.6 Economic Aspects
- 10.4 INFORMATION SYSTEMS FOR TLDM USING A LAYER ARCHITECTURE
 - 10.4.1 General Aspects
 - 10.4.2 Software Layer Architecture
 - 10.4.3 Data Transfer Layer: Common Data Transfer Archive Format and Layout
- 10.5 TLDM vs Conventional approaches

10.1 Positioning TLDM in an Enterprise Information System Architecture

There is a trend and a need in utilities for the integration and consolidation of enterprise information systems in order to support power equipment lifetime data and asset management. Too often important information is stored in silos and not readily available to the asset manager or technical decision maker.

Due to the importance of an transformer asset in an utility enterprise the Transformer Lifetime Data Management requires special attention.

The asset, service and operational data associated with transformers are however just a small segment of the total data requirements of the utility and thus it must be viewed not only in the context of the apparatus but also in the context of the utility enterprise. While the transformer as an apparatus is naturally integrated in the energy system, so must the transformer data management be integrated in the information system of the enterprise.

From the discussions WG A2.23 has had with representatives from utilities, monitoring systems manufacturers, diagnostic methods developers, power transformer manufacturers, universities and research centers it is universally agreed that TLDM only makes sense if supported by adequate information and communication systems. Furthermore, the information needs of utility staff members is much more than data visualization, warnings and abnormal evidences indication.

Transformer Information Systems (TIS) are desired - systems that can use the full potential of digitally stored historical data, to help users on their maintenance, operation and management decisions. These systems must be very specialized, considering the operative context and risk acceptance limits of the enterprise, and able to give best recommendations and possible proactive actions. With the use of such systems, an evolution from scheduled preventive maintenance to Condition Based Maintenance (CBM), Reliability-Centered Maintenance (RCM) and Performance Focused Maintenance (PFM) is expected. Necessarily all relevant data must be considered, and also the operating context and inter-system correlations. Such a "transformer information system" (TIS), can be implemented either virtually as a 'functionality' within a complex IT environment of the utility or as a physical system. In either case, the "transformer information system" needs to have transformer lifetime data capabilities, links to other related data systems and embedded expert knowledge or capabilities to clearly present this information to a human expert.

The existence of lifetime data is extremely important to reach these objectives and there are important aspects related to information, communication and data acquisition technology that must be considered in order to support Transformer Lifetime Data Management. Some of these requirements are discussed here after.

10.2 Enterprise Approach for Managing Transformer Information

Data is of low value unless it can be transformed into **information** that can be used to manage both individual transformers as well as the fleet of transformers. Transformer lifetime information management in an enterprise can typically be considered as a three-stage process:

- Risk evaluation of the transformer group;
- Operation condition analysis of individual transformer;
- Decisions related to the transformer life cycle.

The first stage of data/information management consists of a filtering process which, based on statistical methods, intends to identify and to prioritize the transformer units with higher level of risk. However, this does not identify, individually, the real operational condition or the vulnerability of each individual transformer.

The objective of the second stage is to accurately produce guidelines for a standalone evaluation of individual transformers. This stage involves the establishment of functionalities, identification of techniques and characterization of the state of the art of the available technologies. The results of this stage provide support to transformer users in decisions associated to transformer life cycles. However, given the extensive list of functional variables and the circumstances that govern the decision process in each organization, particularly in technical or financial aspects, the establishment of a unique set of rules or standards for the life cycle management of the whole equipment fleet is formidable.

The objective of the third stage of the process is the development of a life cycle management program focused on those transformer units considered to be strategically and tactically critical and whose operative condition is already known. This stage allows the establishment of managerial actions and policies aimed at:

- identifying units that can continue to operate as status quo
- identifying units that can operate with loading above of the normal rated power;
- calculating cost-benefit ratios that include the possibility of fines or additional remuneration in the eventual necessity to operate with loading above of the normal rated power
- supporting actions to be taken in an eventual contingency, including the anticipation or delay of the disconnections of the units
- preventing unnecessary disconnections
- identifying units that must be refurbished or repaired
- identifying units that can be relocated
- identifying units to be definitely removed from operation.

10.2.1 Transformer Data in the enterprise process

The lifetime data for power transformers has to fit in the enterprise processes for operation, maintenance, asset management as well as in the existing IT systems of the utility. The transformer data should be guided by the generic data model developed for the power transformer asset, which suggests what data to collect and what data to keep while offering the user choices to fit their specific budget and ambitions. The generic model identifies a wide range of data elements necessary or usable for transformer life assessment including data from operation, maintenance, from diagnostic, from other available systems and from sensors and monitoring devices.

In recent years, there has been strong interest and significant activity by transformer asset managers to employ sensors and monitoring devices on power transformers. In the context of transformer information systems, it is worth mentioning that it is the opinion of the WG monitoring that this type of data is very important but only a part of the transformer lifetime data model. However, monitoring data is useful and may be much easier to integrate into the existing utility IT system than other types of data due to the fact that it is in digital format and can be obtained using existing communication networks. Considering the electronics and information technology evolution on the last decade, it is possible to say that the collection and storage of sensor derived data on electrical power equipment, such as transformers, is no longer a huge challenge.

More important than getting/collecting data is the process of transforming large amounts of data that is available into useful information. This information should support the utility maintenance staff and managers, the process of handling and managing historical data. The goal is to minimize the impacts on system performance, availability and most of all to guarantee data exchange between different systems (new and legacy ones), from different manufacturers. These aspects that will be discussed in the following paragraphs.

There are nowadays integration challenges related to legacy systems, containing various amounts and types of transformer data. These challenges are more acute when it comes to legacy monitoring systems which often were designed with proprietary architectures making communication and integration a significant technical and financial challenge. The challenges continue to increase as new monitoring and control devices are implemented with embed data and intelligence at the hardware or

sensor level. These different technologies must work together not only at the same substation but also across the whole utility enterprise. The net results are greater integration expenses and increased difficulty for the utilities to get the most use of their own data.

These aspects are still more relevant if one considers the fact that the most monitoring systems are quite recent. So, it is natural that there are still no common standards to provide direction and unify the subject. Some attempts are nevertheless in progress in IEC 61850 and all these contributions should be considered.

An example of a possible architecture for a Transformer Information System (TIS) is depicted in detail in Figure 9.. The example emphasizes monitoring and diagnosis and is based on the elementary schema described previously in this Transformer Lifetime Data Management document. This architectural view serves as an exemplification of a complete system and shows a possible implementation of the Transformer lifetime data management concept. This example will be used to discuss in more details some of the IT related aspects of TLDM. Aspects related to data analysis, which are closely related to transformer lifetime data model, but not the subject of the WG activities will only be mentioned in passing so to provide a fuller picture the TIS architecture.

The example architecture includes interaction between the TIS, supervisory/control (SCADA) systems, existing protection data systems, existing financial/economic data systems and monitoring/prognostic/diagnosis systems. The following definitions apply:

- "Transformer Monitoring (TM)" – refers to the application of technologies and procedures for gathering data associated with the transformer, including its components and accessories, at a defined moment or period, with emphasis on systematic supervision and data/event storage.

- "Transformer Diagnosis (TD)" – refers to a set of procedures to analyze transformer data, identifying possible cause(s) of an abnormal operative condition and degradation trends, inferring scenarios associated to past and current evidences.

From a maintenance point of view, the basic monitoring and diagnostic levels that are inherent in a TIS, and are adequate to support the concept of TLDM are:

- (1) Monitoring Stage: includes the collection of data from special high speed sensors (special tests), low speed variation variables and acquisition sensors (e.g. process variables), direct alarms and warnings emitted directly from hardware components. In a larger sense it may contain also variables originated from protective devices (protection variables), or human inspections, which should be stored in suitable tables for future access.
- (2) Analysis Stage: the phase where access and presentation of historical data allows the users to have graphic visualization along with first level caution indicators (warnings and/or alerts to the maintenance department). At this level there is the possibility of interaction with protection and supervision/control systems as well as with other corporative systems (economic data), as indicated in the Figure 9.
- (3) Prognosis / Diagnosis Stage: a phase where methodologies and computational intelligence can be applied to give the users failure-cause possibilities and adequate action indications.
- (4) Risk Analysis and Management Stage: a phase where methodologies and computational intelligence can be applied to give the users the least risk and highest value actions (technical and economical) based upon risk analysis evaluations and maintenance recommendations within the operative and fleet management context.

It is assumed, although not explicitly shown in Figure 9, that basic transformer identification information, such as serial number and nameplate data is stored in the TIS.

Each TIS stage may have its own inputs and outputs, and these may be used also by other computational systems and/or utilities specialists for their own decision processes and analysis. When specifying a TIS, the user may choose various levels of complexity and functionality by implementing all or part of stages1, 2, 3 or 4 above.

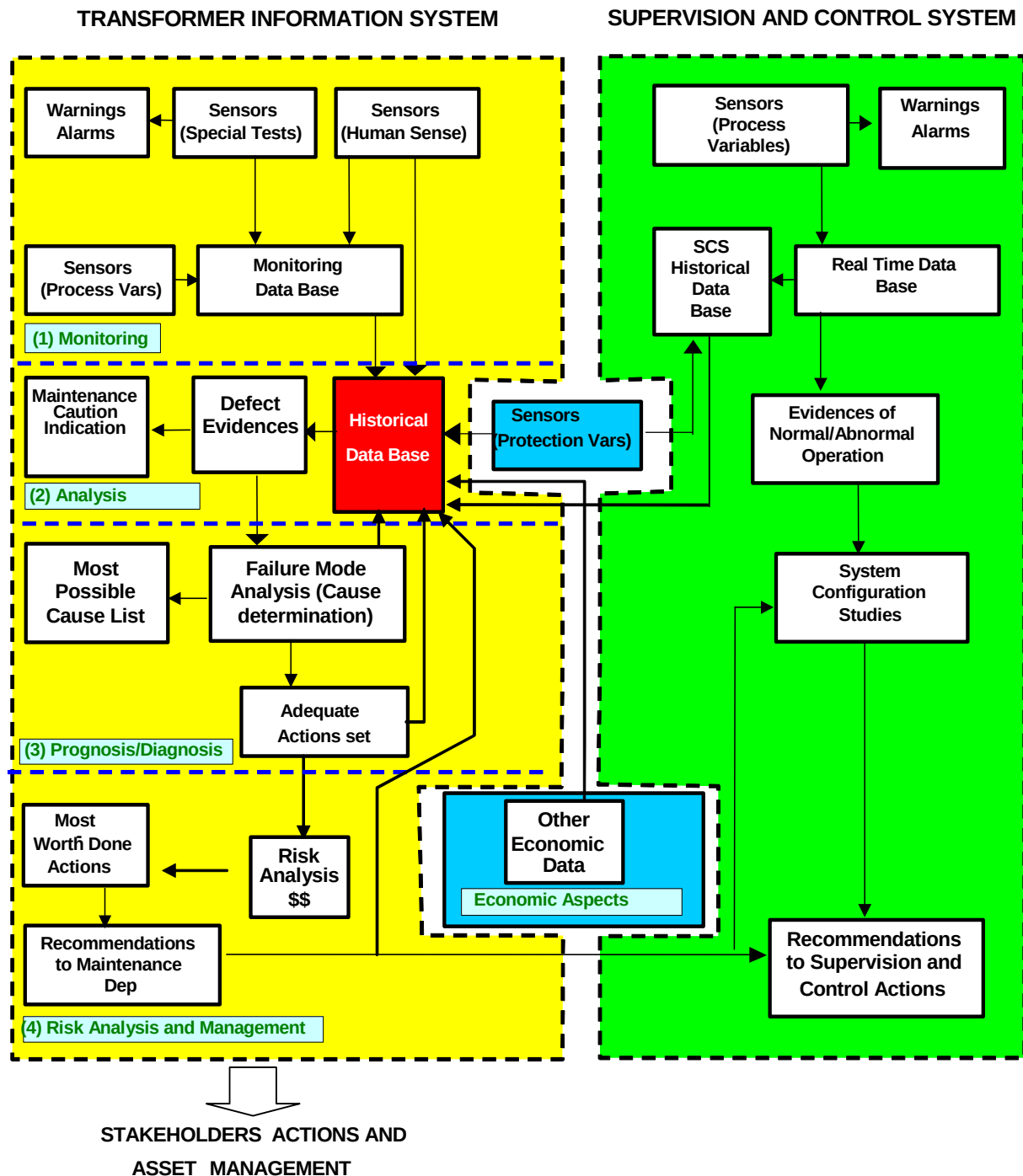


Figure 9 High Level Block Diagram of an Example Transformer Information Systems (TIS) ,

10.2.2 TFO On-line Data Acquisition and Transmission Topologies

On-line transformer data collection requires certain data acquisition and transmission topologies. While some lifetime data (basic and/or periodic off-line) must be manually inserted into the data repository by the user, an automatic data import would most likely be used for monitoring data.

The following discussion considers a base system whose topology is displayed in Figure 10, and applies only to the TLDM data whose origin is from an On-line Transformer Monitoring System or an

Intelligent Electronic Device (IED). This topology is intended to be quite general and not to cover all possible combinations of existing and future configurations.

The overall idea explored here is that manufacturers and utilities may choose various combinations of the alternatives described in Figure 10 so to best fit their technology stage and needs. The various sensors that can be used to gather some kinds of lifetime data comprise the level zero or sensor level interface in Figure 10. The first level is comprised of data concentrators, hubs, switches and routers. The second and third levels comprise the higher-level computational network inside the enterprise (local and remote sites).

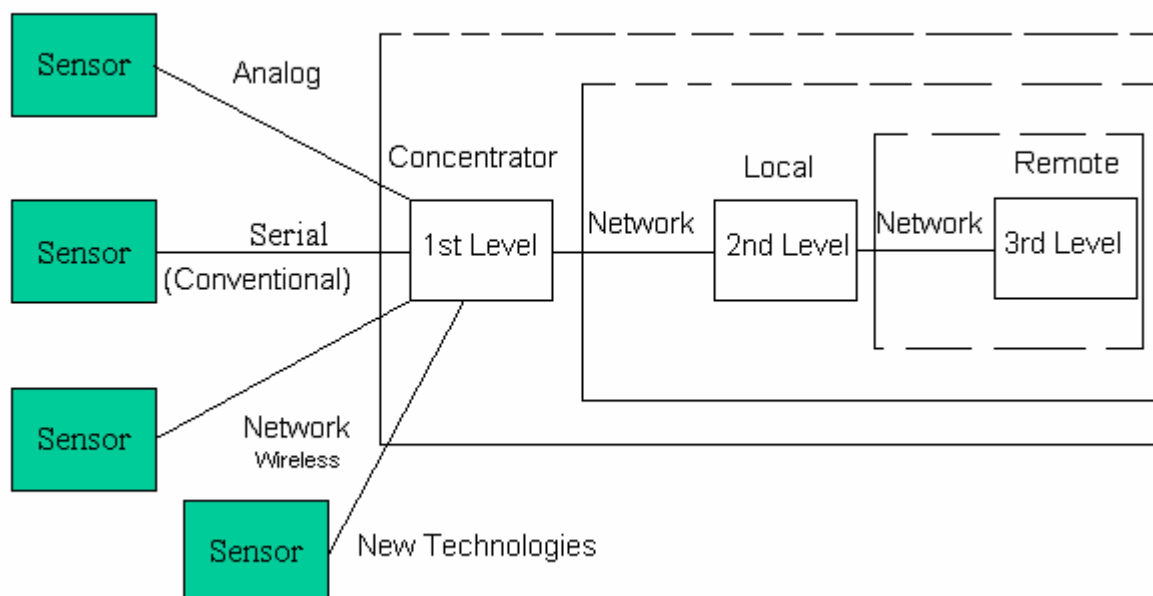


Figure 10 Simple Monitoring System, Data Acquisition and Transmission Topology Example

The interface between the measuring sensors and the first concentration level should be standardized and may be chosen from one of the following alternatives / categories:

- Analog Interface Sensors: use 4-20mA, 0-10V or other market standards, adequate to the specific application requirements (e.g.: optic fibers, shielding, etc.).
- Conventional Serial Communication: use physical standards (e.g.: RS485, RS232, etc.) and an open and standard communication protocol (e.g.: ModBus, ProfiBus, DNP 3.0 etc.).
- Serial/Network Communication: in terms of conventional serial network communication there is a strong tendency to utilize Ethernet channels with TCP/IP protocols, which, due to large economy of scale manufacturing and use, are experiencing significant cost reductions. In the case of monitoring systems, this alternative may be used for communication among specific sensors and the first level of concentration. This is the desirable alternative if no technical restrictions exist in the substation. Care must be taken to guarantee that the encapsulated protocols in the TCP/IP are open. If wireless communication is available, it may be employed in order to increase the facilities flexibility and reduce costs. In all cases, much attention must be given to both communication and data security.

The use of a common nomenclature for substation data, as proposed by the UCA 2.0 and IEC 61850 standards, regardless of the chosen interface topologies, is highly recommended and would ease the implementation of both hardware and software if consistently applied to monitoring systems.

Data both received and originating at level 1 of Figure 10, may be processed to generate warnings and substation alerts. This processed data, along with the level 0 source values, should also be transmitted to level 2. All transmitted data must be time synchronized using a standard format for year, month, day, hour, second, etc.

All data generated at level 1 must be adequately stored on hardware by the monitoring system manufacturer. The storage capability at level 1 must be enough to assure that no historical data is lost or missed before being sent to level 2, where it will be stored in an appropriate lifetime corporate database or data warehouse.

10.2.3 Decision Level Impact

The design of a TIS to accomplish the TLDM concept must incorporate adequate functionalities in hardware and software to be able to send warnings, alerts or action recommendations (necessary to operate or maintain the transformer), providing users with all the needed support for their decision making process. Figure 11 shows this idea in a block diagram form.

With this approach, the physical locations for making decision may be inside the substations, maintenance areas, engineering department or manager offices. This means that decisive actions can be taken anywhere inside the enterprise. Limiting the decisions to a less than optimal level will result in the impacts on the utility.

- Local Decision (Figure 11): The least useful / robust decision structure alternative. Decisions are made inside the substation (SS), with local data being stored in a local data repository (DR). There is the need of local software and a trained operator at the substation to make all decisions. The global view of the impact on the whole utility due to the local decision is lost in this alternative, only the transformers physically located in the substation are considered in the process.



Figure 11 Local Decision Structure Block Diagram

- Remote Centralized / One-way Decision (Figure 12): Includes the Local Decision of Figure 11 and the possibilities of remote decisions. Decision can be made both locally or remotely. There must be a data repository and software on each substation. The generated on-line data and information are replicated at the main office where a centralized off-line lifetime database is located (for historical data and ease of consultation – real time data from the substation is not part of this alternative). Specific synchronization software is necessary to automatically download the data from the desired substation to the central office. Decisions made by the central office can only be executed if someone inside the substation is contacted or an outside maintenance crew is designated to perform those activities if the substation is automated.

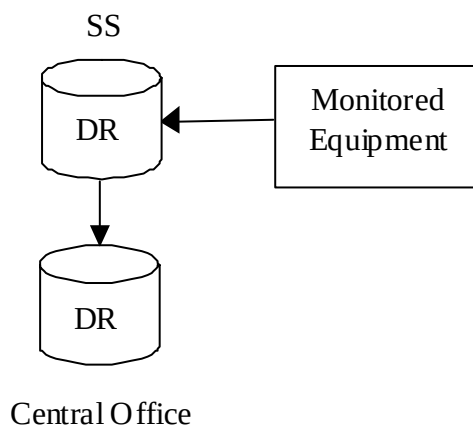


Figure 12 Remote and Centralized Decision Structure Block Diagram

- Remote Distributed Multilevel / Two-way Decision (Figure 13): This is the most general and robust alternative and extends the above decision models. Decision can be taken on multilevel situations. An off-line or on-line central lifetime relational database and a defined user hierarchy structure like, Central Office, Regional Office, Substation, etc, are used. The decision process can occur at each place isolated (one-way) or interactively by involving multiple users (two-way). The structure admits, if desired, even external database access and decision agent participation.

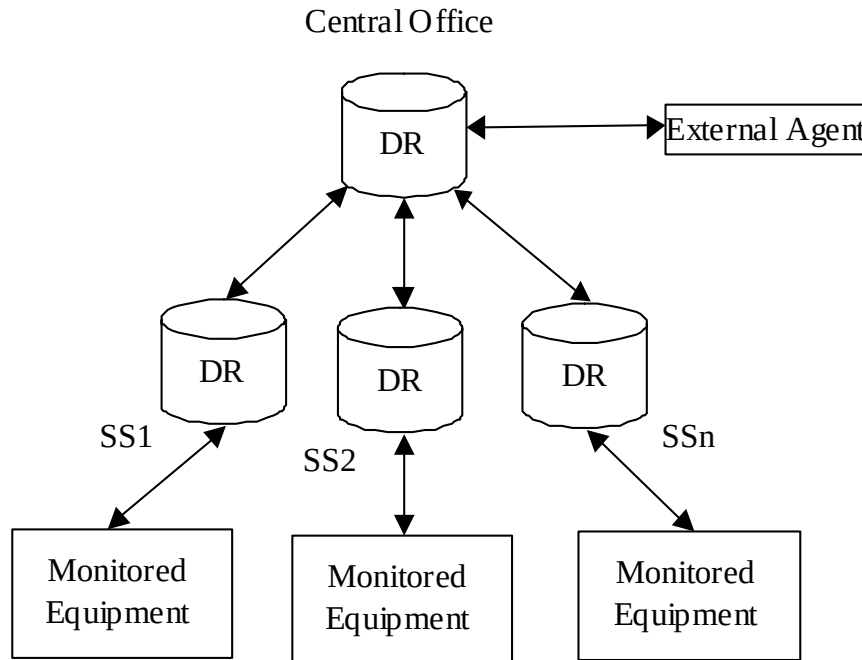


Figure 13 Remote Multilevel Decision Structure Block Diagram

For all described decision structures, compatibility between the existing systems and lifetime upgrades in software and/ or hardware must be planned (open system requirements: interchangeability, portability, interconnectivity, expansibility, modularity and scalability). These upgrades may occur due to an increase in the number of variables being monitored, implementation of new or diversified ways of data collection, needs for computational performance improvements, hardware obsolescence, changes in commercial software, deployment of new enterprise hardware platforms, etc.

10.2.4 Hardware Robustness

The specific environmental and operating conditions of the transformers monitoring hardware, sensors, data acquisition units, cabling, communication/transmission units, power supplies etc must , be considered. Interferences (e.g.: vibration, electric transients, thermal cycles, humidity, pollution, etc.) and external aggressions must be evaluated. The specification of the devices must include, preferably, tests prescribed in international standards (ANSI/IEEE and IEC). The use of proprietary standards should be avoided, because it dilutes the reference base to be used by the market to accomplish conformity requirements.

The lifetime of the hardware, which is part of the power transformer, (e.g. sensors incorporated during manufacturing process or during refurbishment, which are internally located in the transformers) must be the longest possible, since the service interruption for replacement or maintenance of that transformer will cause high costs.

10.2.5 Reliability and Availability of Monitoring Components

Data acquisition sensors and on-line monitoring systems must have higher reliability than the equipment they monitor. Also, high availability is desired from these systems, the monitored equipment should not need to be de-energized due to sensors or monitoring systems technical needs.

Sensor and monitoring components should be extremely stable making systems calibration requirements minima. The presence of self-supervision or hardware watchdogs should be seriously considered so that failures are immediately identified and appropriate notification given. The hardware manufacturer must recommend realistic system maintenance activities, frequencies and calibration intervals.

10.3 Enterprise Asset Data Management

Transformer data is just a small piece of the enterprise picture and must integrate with other utility data systems. The data needed to manage an important asset such as a transformer over a life of several decades is both significant task in terms of data volume and diversity. The necessary data must come from a variety of sources including:

- Engineering
- Operations
- Maintenance
- Standards
- Mapping
- Accounting
- Etc.

10.3.1 Data Repository Characteristics

The chosen data storage architecture must have characteristics like scalability, connectivity, performance, availability and interchangeability that in turn makes feasible the layer implementations described in section 10.2 "Enterprise Approach for Managing Transformer Information". The most desirable characteristics of a data repository, which represent at the end, the TLDM overall characteristics, are those of known open software/hardware architectures:

- Interchangeability: capability of data transfer between different systems in a practical and easy way;
- Portability: capability of implementing the same functionality in different platforms (hardware and software);
- Interconnectivity: capability of connecting distinct hardware platforms, both in type and size, through a standard network;
- Expansibility: capability of incremental growth of the hardware (addition or substitution) and software (addition of new functionalities);
- Modularity: capability of inclusion, elimination and alteration of functions and modules with minimum impact on the other components of the system;
- Scalability: capability of the same software to be used in all the decision levels inside of the company (local centers, regional centers etc.).

10.3.2 Data Storage Models

Every organization within the utility has it's own specific data requirements. In order to fulfill their needs, many organizations have built their own data silos. This approach, while initially very expedient in solving a particular organizations individual requirement, often results in serious inefficiencies, duplications and long term technical challenges. Because these data silos tend to be very organizational centric and of limited scope, the often are of reduced value for other utility entities.

As the short comings of data silos become more acute, an enterprise approach to data management becomes necessary. Three distinct approaches to enterprise data management are used today:

- Master-Slave Model
- Enterprise Data Warehouse Model
- Common Information Model

10.3.3 Master-Slave Model

The Master-Slave Model attempts to make the most of the investments made in the existing data silos and leave them intact as much as possible. It allows data redundancy to occur but acknowledges the need to have a single “master silo” for each unique data entity. Data from the “Master Silo” is periodically synchronized with the various “Slave Silos”

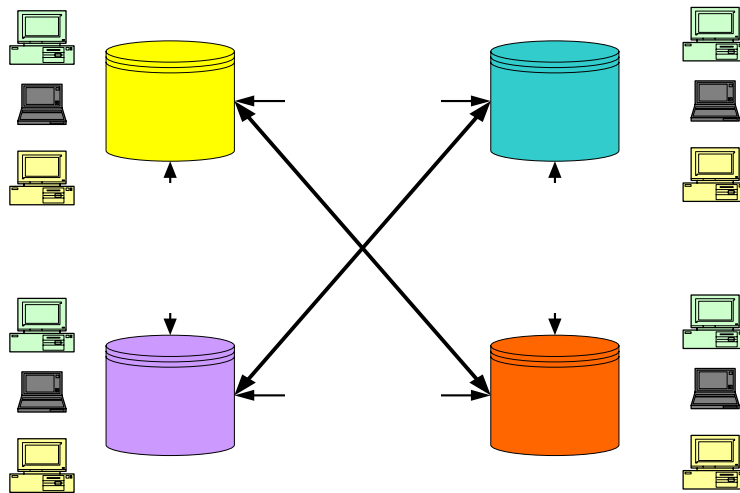


Figure 14 An overview of the master-slave architecture from both technical and organizational perspectives.

When the number of databases is low, synchronization and maintenance of the master-slave relation is not too difficult. As the number of databases increases, so does the complexity of synchronization. A method for reducing complexity involves the creation of one additional database known as the key register index.

The key register helps to synchronize key data about the main data objects and used to control the master-slave relation. The essential fact is that this register only contains keys or pointers to keys in connected systems and only a very limited number of data elements that identify the object in the real world, so that data duplicity is avoided. As an example for a transformer this can be the serial-number and manufacturer that are referenced and interchanged by all enterprise systems.

10.3.4 Enterprise Data Warehouse Model

The master-slave models described above create some significant operational challenges as the size of the various databases grows as their design changes and as the communication routing becomes more complex. One method of solving these operational challenges is to create unified data architecture with all the data contained in a single data warehouse. With unified data architecture, data can be highly normalized and all ambiguities eliminated. A typical data warehouse is shown in Figure 15 below.

The data warehouse by definition contains an enormous amount of data from numerous entities. Because of its size and complexity, it can be very difficult for users to efficiently access the data needed for their specific applications and analysis. To make the data warehouse more user friendly, smaller data marts are created. These data marts contain only a subset of the data contained in the data warehouse. The data mart contains only the data needed to support the user's application

requirements and make the complexities of the data warehouse transparent to the user. Such a data mart could be designed for transformers.

There are several approaches to building a data mart. No matter the approach, they all have three major goals in mind:

- Simplify data access for the end user
- Accurately represent the data found in the data warehouse
- Increase the access speed to the data

In order to achieve these three goals, the data mart may take on various forms. In some cases they may be a “real-time” view of the data contained in the data warehouse. Other times they may be a separate set of tables that are periodically refreshed with data from the warehouse.

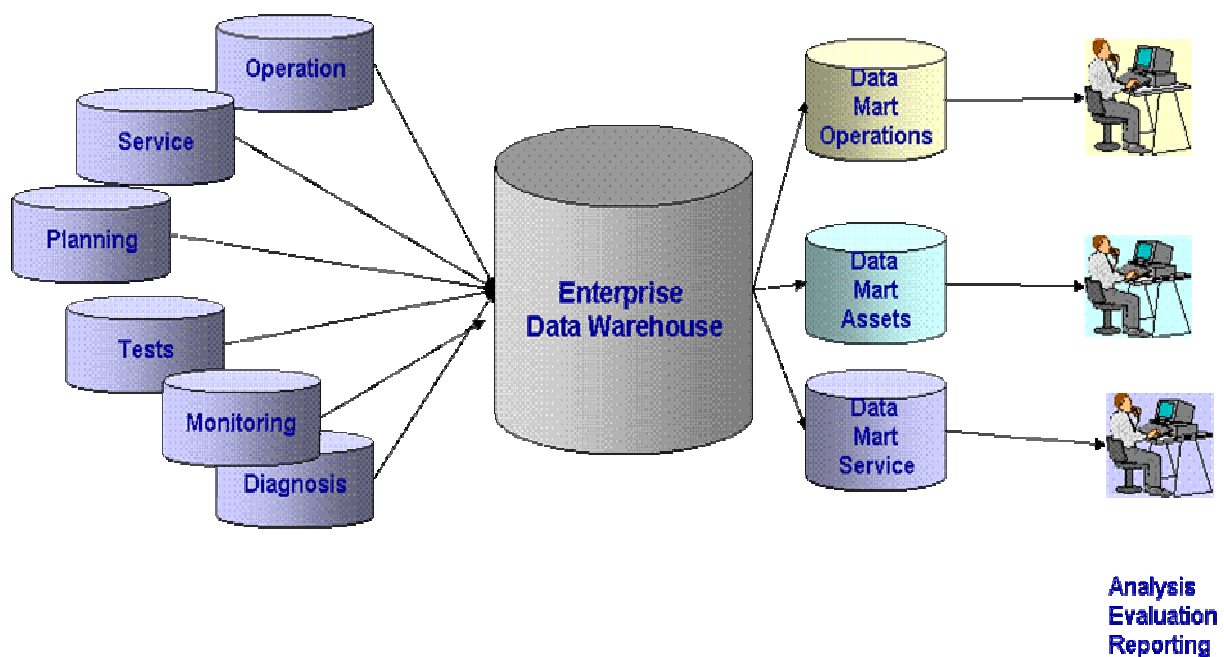


Figure 15 Typical Utility Data Warehouse

The advantages of the data warehouse model are summarized as follows

- Integration of various data sources
- Single architecture eases maintenance requirements
- Promotes application consistency

The disadvantages of the data warehouse model are mainly related to:

- Long development times
- High development costs
- Difficult to integrate “off-the-shelf” applications
- Users find it (sometime) difficult to build custom reports and queries, unless appropriate tools are provided.

10.3.5 Common Information Model (CIM)

Overlapping information requirements among utility functional organizations typically results in higher operating costs due to lack of integrity and operating efficiency caused by data duplication and data concurrency issues. An example of some information needed by a few of the functional organizations involved in the lifecycle of equipment is depicted in the Figure 16.

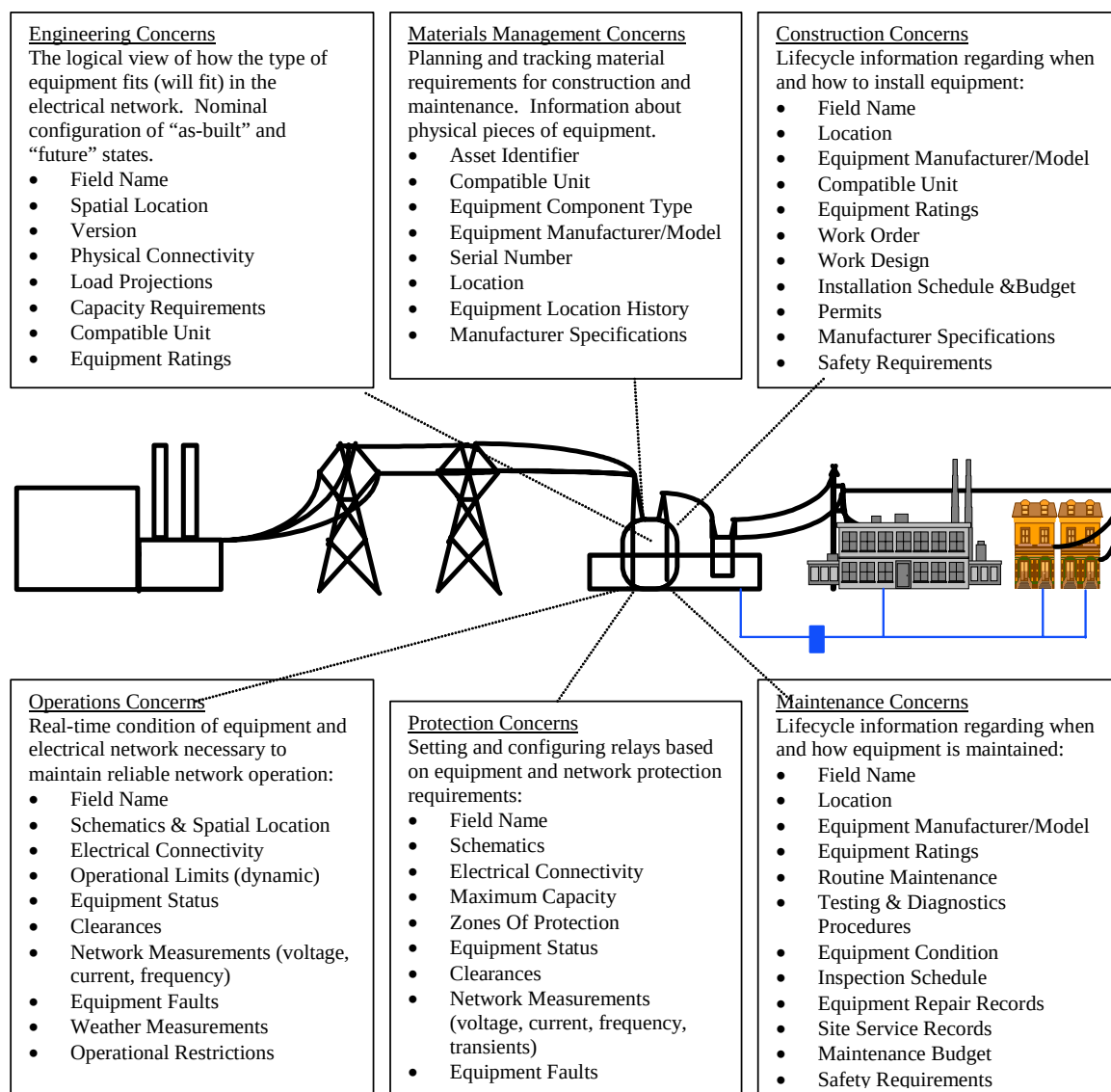


Figure 16 Disparate and Overlapping Information Needs Among Utility Organizations

Few, if any, attributes of a given equipment asset (e.g., transformer) are used by all functional organizations. While only a subset of organizations care about any one attribute, most attributes are needed by more than one organization. However, which organizations care about a specific attribute varies on a per attribute basis. During the lifecycle of the asset, it is noteworthy that each organization ‘touches’ a given asset at significantly different times, that business process requirements change, and that technical requirements change. Various views of any given asset must be congruent with other views wherever there is information overlap. Along with these views comes the need to deal with different divisional and geographic boundaries for utility organizations assigned to any given asset.

Recognizing that much of the same attribute data will necessarily be replicated among the many application systems supporting the various organizations, it is desirable to employ a method for keeping this data synchronized among these application systems that is not at the expense of an organization’s ability to procure the most appropriate applications for meeting its objectives. Applications will continue to be procured from many different suppliers at varying points in time.

In the early 90's, the EPRI CCAPI (Control Center Application Program Interface) Project began looking at the specific problem of integration of energy management software (EMS) for control centers and identified the need for a non-proprietary information model that could be referenced by many vendors. This resulted in the definition of the 'Common Information Model' (CIM) to describe the logical (analytical) model of an electrical network and related entities. In collaboration with EPRI and leveraging contributions from many utility projects, the CIM continues to be extended by the IEC (working groups 13 and 14 of Technical Committee 57).

The CIM represents all the major objects in an electric utility enterprise, including the relationships among them. A key purpose of the CIM is to provide a common language for describing exactly what data is being exchanged among applications.

To facilitate information exchange among autonomous applications and data stores, there therefore needs to be agreement on common terms and definitions for shared asset data. The CIM, along with data conventions, provides the means to avoid semantic conflict, which is a term to describe the errors and ambiguities that can arise with different interpretations about the intended meaning of information exchanged between systems:

- Confounding conflicts, where information appears to have the same meaning, but does not.
- Scaling conflicts, where different reference systems measure the same value
- Naming conflicts, where naming schemes differ significantly.

The fundamental electrical network, measurements and generation models within the CIM are published by the IEC as parts of 61970. Other parts of the model, such as those supporting distribution management, asset management, work management, etc., are published as parts of IEC61968. When used on a project, a base-line of the current CIM is placed under configuration management procedures in much the same way as any software is handled. The IEC now maintains change records between each release of the CIM. Configuration management is important in order to track extensions made by the IEC as well as the ones made by the utility.

As more companies use the CIM, additional increments for needed industry functionality are identified in the model. As common industry practices become evident, it is in everyone's best interest that these functional increments become standardized CIM extensions. It should be noted that the IEC endeavors to minimize changes to existing parts of the model so that utility implementations are not significantly impacted whenever a utility incorporates a new release of the standard CIM. Therefore, utilities are using configuration management primarily to re-incorporate their custom extensions into new releases of the CIM. A utility may want a new release of the CIM, for example, to take advantage of new functionality that the utility and its vendors are planning to implement.

Commercially available off-the-shelf products that are CIM compliant have been developed, (*EPRI's Maintenance Management Workstation, ATI's Aware Maintenance Management System are two examples.*) The software has the following characteristics that have helped configure the CIM model definitions for utility assets such as transformers and import utility information into the database:

- The software enables you to define a CIM-compliant database based on the CIM model without any programming
- The software automatically creates & manages the database schema based on the CIM model as this model evolves.
- The software provides user tools needed to manage the data including security, manual data input, import from external sources, reporting, etc.
- Has an easy to use interface for users to build a web-based application
- Has a well established, documented, and tested API to easily interface with other applications
- Has been installed around the world as a platform and repository for power plant equipment.

CIM compliant software can be designed as a platform to manage equipment and equipment related data using objects that are user configurable based on the customer's adopted modeling standards. It can host objects of any type – including the ones defined in the Common Information Model. The view to users and to external application modules is that of objects. The application is configured by defining classes that represent the various equipment types and attributes that define the various data collected on these equipments. These classes are then used as templates for creating instances of these objects.

The concepts behind building a model in a CIM compliant software package are as follows:

- Classes – the different equipment types (cables, circuit breakers, transformers, etc.). Each class consists of attributes.
- Documents - activities that can be performed on systems (Transformer Failure, Bushing Failure)
- Inheritance / Association - for classes, defining new class based on another similar class
- Instances - specific equipment (e.g. a specific substation SUB001 in a network) of a defined type. Each instance is defined in the three dimensions defined above.

Defining CIM classes and attributes in a CIM Compliant Software package

There are typically four dimensions to the CIM compliant software configuration that together define the model the application will use for information management. The four dimensions are:

- System Types (Classes) - objects that will be part of the application domain are categorized into various system types. For example, in an Industry Transformer Database application, one would have system types such as transformers, tap-changers, bushings, etc. In simple layman terms, a system type is a definition of a type of equipment.
- Inspection Types (Document Class) - all the different types of activities that may be performed on the different system types. Each inspection type can have its own set of attributes. A given system type can have associated with it any number of inspection types and this controls what kind of data can be collected for that type of system. For example, you may have defined that Maintenance History and Operation History inspection types (each having its own set of attributes that are recorded when performing that activity) can be performed on system type Transformers. This means that an end user can store and manage Maintenance and Operational inspection data on any transformer in the system.
- System Organization - the rules that govern how all the different system types in your application should physically exist. These rules will be used when the user defines the actual instance of how the equipment is physically laid out in your plant. For example, a transformer can appear as part of a substation, but it would not appear as part of a bushing.
- System Hierarchy - the actual representation of transformers and bushings in your system. This is built by creating “instances” of system types in the system organization defined above.

The advantages of CIM model are numerous and summarized as follows

- Highly consistent
- Allows for disparate application to easily share data
- Promotes data consistency
- Easy to integrate “off-the-shelf” applications if they are CIM compliant
- Users find it easy to build custom reports and queries

Which of the data model to apply in the utility enterprise, depends of: the used information technology, the existing IT infrastructure, but also of the utility processes, time and cost issues.

10.3.6 Economic Aspects

The acquisition and installation processes of sensors, monitoring systems, prognostic and diagnosis systems that follow the TLDM concept must be declared in the utilities technical specification documents and follow basically the recommendations and directives of this document. It must be considered as part of the initial cost of the adopted solution just as the costs of training courses, installation / operation / maintenance manuals and spare parts judged fundamental.

Additional costs for spare parts, accessories out of warranty, technical support, proper maintenance, specialized maintenances, operational costs, upgrades of software and hardware, licensing, etc, should be considered by the utilities in its cost-benefit analysis.

The CIGRE A2 has worked out a guideline report on economical aspects for power transformers [4].

The utility must considered at the time of specification and acquisition of the systems, all the costs related to the implementation of communication protocols, relational data models and the needs for future system software/hardware expansion if applicable.

The value of the TIS must provide proper balance between delivered functionality, TIS maintenance costs and its strategic importance to the net. On the other hand, the commercial considerations by the suppliers of solutions, whole or partial, must reflect and distinguish clearly between those products for simple monitoring from those that also incorporate more advanced diagnostic tools, which allow control of both maintenance and non-availability costs of the equipment. This way, final the TIS costs must consider the equilibrium between the amounts of implemented functionalities and resulting expected utility benefits.

10.4 Information Systems for TLDM using a Layer Architecture

10.4.1 General Aspects

The implementation of a transformer lifetime data management system needs a historical database. This is the heart of the Transformer Information System (TIS). This database should be capable to store the relevant transformer data for each considered individual unit.

Some aspects should be considered:

- The transformer data requirements and ambition level should be decided with all the stakeholders in the organization.
- The data sources and the process for TLDM should be specified.
- The need for the coexistence in a heterogeneous environment of various software and hardware products has to be considered. In case of monitoring products, many standards of hardware and software and a great amount of communication protocols can be found.
- The need to consider the functional aspects, data exchange aspects, user interface aspects and commercial aspects when deciding on a certain data acquisition system. It is not uncommon in utilities for the adoption of a data acquisition product to be based on some characteristic that better fits the user necessities, however with a poor graphic interface and vice versa, leading to the simultaneous adoption of a second product that corrects the deficiencies of the first one. Other times, commercial issues can be a decisive factor for the use of a third system, which must be installed together with those already in use.
- The need to have standardized solutions. For example, although the search for differentiation among monitoring products is important to guarantee the continuous evolution of the systems, the consequence is the loss of standardization.

- Use of state-of-the-art technologies for data transfer among systems and databases. In heterogeneous environments it is very usual to use formatted text files, else transfer mechanisms offered by database systems for data exchange should be used.
- The connectivity between data systems. The ODBC standard (Open Database Connectivity), guarantees a high degree of data interchangeability among many products available on the market.

The great difficulty in exchanging data among different systems is related to the large number of possibilities of structuring one piece of information within a database. Even in relational structured systems, the organization of data may make the exchange of information difficult. Many times it is necessary to create specific software or plug-ins to map one structure onto another, which requires vast knowledge of the structures and a significant engineering effort to develop. Even if the process is in fact efficient, it still consumes extra processing resources, which could be used for other tasks.

The great challenge that arises is to solve the dilemma of how to deal with this reality in a sustainable way, in order, on the one hand, not to stem new developments and, on the other hand, to get interaction among several products.

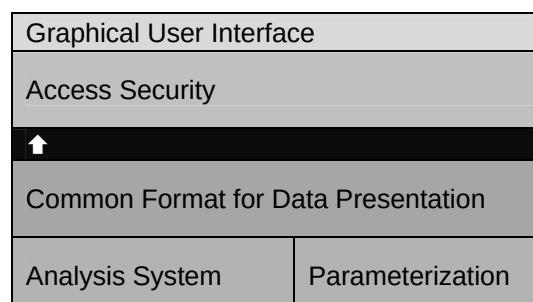
10.4.2 Software Layer Architecture

A Transformer Information System as in Figure 9 should fulfill a set of minimum requirements:

- Have data management capabilities
- Have the capability to analyze the acquired data and provide precise information for the decision making (the data analysis is directly connected to the diagnosis techniques associated with the variables collected - those techniques are the object of study for WG A2.18, and will not be discussed in this work);
- Have adequate User Interfaces capabilities;
- Use of a state-of-the-art database technology.;
- Easy interaction with other systems in order to allow data synchronization, as well as the capability to deal with data provided by systems from several suppliers, e.g. by means of the adoption of standards (e.g. UCA - IEC);
- Information exchange capabilities in order to facilitate direct and open integration among different systems, possibly by the adoption of a the Common Information Model or Common Format for Data Transfer based on standards;

As a possible approach to deal with the functional requirements, the Layer Architecture shown in Figure 17. is suggested. Emphasis is placed on monitoring aspects, linking sensors to data storage layers and ultimately providing the user with desired information.

The main idea is to create layers in the system to allow the compatibility among the different developed monitoring products, guaranteeing freedom to the manufacturers in the development of their own solutions, demanding however that they should provide, within the solutions not only their proprietary format but also a common and standardized format for data exchange. Such Common Format for Data Transfer will be subject for further group studies. Nevertheless it is suggested here how would be the layer architecture to accomplish this goal.



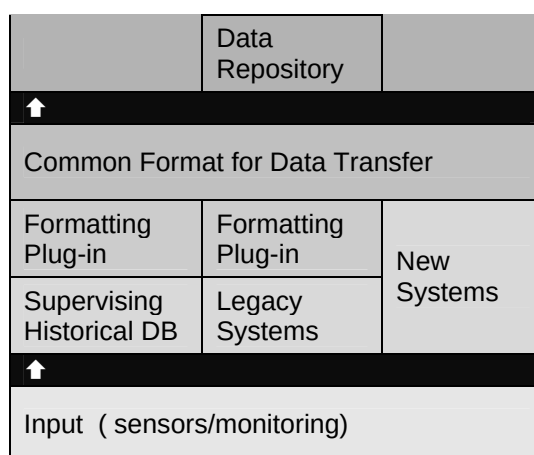


Figure 17 TIS for Transformer Lifetime Data Management – Layer Architecture

In the bottom layer one important aspect is the “Input” block, responsible for the translation of the original signals into digital information, user input etc.

In the second layer one finds a set of blocks responsible for the data flow from the input to the data repository: “Supervising Historical DB”, “Legacy Systems”, “New Systems”, “Formatting Plug-ins” and “Common Format for Data Transfer”.

In Figure 17, the signals received from the input are made available for the supervising system, legacy systems of the company or new systems to be acquired. Depending on the characteristics of each one of those systems, the use of formatting plug-ins may be necessary, to provide acceptable outputs. The information already converted is transferred from the acquisition point to a corporative data repository, through a communication channel, passing through a data transfer block preferably in a common format. Several technologies for that communication and several accepted standards are available or in development. The use of serial communication is spread out, generally using standards as RS232C, RS485, Fieldbus and Ethernet, as well as protocols such as: MODBUS, DNP3.0, IEC60850-5 and, more recently, TCP/IP. Up to this layer, it is suggested the adoption of a unified standard like UCA + IEC 61850.

In this second layer, it would be also feasible to think about data exchange between systems of the same layer, however the solutions are generally developed to guarantee reliability and availability for communication to remote equipment, to provide a friendly interface to the user and to be an information link with the system database. Even being, in most of the systems, a layer where the information is concentrated, this layer generally holds back the data only for a short period, just enough for the operations of supervision, control and data transfer to the upper layers.

With the introduction of the “Common Format for Data Transfer” block, the available data in the layer can automatically be transferred between the applications, guaranteeing the interaction among the systems, objective pursued by IEC 61850. Once automation and standardization become a reality, the data transfer will allow integrating distinct sources of data in a single centralized data repository or to transfer the data between applications. An example of standard for electronic data interchange that would allow constructing a “Common Format for Data Transfer” is the Extended Mark-up Language (XML), proposed by the World Wide Web Consortium (W3C).

In the third layer one finds four blocks: “Data Repository”, “Analysis System”, “Parameterization” and “Common Format for Data Presentation”. In those blocks, the collected and the processed information, as well as the data, are available and, many times, in a concentrated form (central server). It is recommended, in this level, to perform the data interchange through export and import of data archives or using tools that allow SQL queries.

The block “Data Repository” represents the place of lifetime data and information storage, which could be, for example, a relational database.

The block "Analysis System" represents the computational routines in which the data and information are processed, aiming to the taking of defect evidences and the performing of prognostics, diagnostics and risk analysis, possibly using Data Mining tools and Artificial Intelligence.

The block "Parameterization" allows the remote access to the systems in lower layers, for adjustments and configurations.

The introduction of the "Common Format for Data Presentation" block allows the use of any available user interface or the creation of automated reports, as it happens with the user interface of HTML pages on the Worldwide WEB.

In the fourth layer one finds the "Access Security" block, generally supplied by the Database Manager itself, which has access control, backup and cryptography tools. However, with the advent of the computer networks, there is, frequently, the need of using of specific products to guarantee the information confidentiality and security, like package filtering (Firewall).

In the fifth and last layer in the diagram one finds the "Graphical User Interface" block, where are the visualization products used to show raw and processed data, generally including the generation of reports, summaries and structured search of information.

10.4.3 Data Transfer Layer: Common Data Transfer Archive Format and Layout

It was identified in previous sections that the interaction among software products can be implemented from a "Common Format for Data Transfer". Based on the computation history, some characteristics of that format must be considered:

- Use of the ASCII format;
- Creation of a variable standardization dictionary (e.g. IEC 61850);
- Structuralized formatting;
- Possibility of transformation between formats.

The impact for the software developers would be limited to the building of connectivity plug-ins based on that common format, where the several collected data, including equipment identification, field measurements data, laboratory tests data, date and time, acquisition rate, sensor type, signal type, etc can be transmitted. The "Common Format" considered here still does not exist but it can be developed if the IEC 61850 model is adopted.

10.5 TLDM vs. conventional approaches

A comparison between the frequently encountered current utility practices and a possible future situation with applied transformer lifetime data management TLDM and a dedicated Transformer information system is shown in Table 2.

Table 2 Comparison between the current and an alternative situation with applied TLDM and TIS

Item	Without TLDM and TIS	With TLDM and TIS
Computing systems	Closed, little flexible systems, based on isolated treatment of the data.	Open modular systems, based on integration of functionalities and centered treatment of data.
Computer networks	The use is still restricted to some analysis and diagnosis systems. Different monitoring systems use and create data. No common view on transformer data.	Indispensable to all analysis and diagnosis systems. Use of a common view and a transformer lifetime data model.
TFO Data availability	Data are available in most cases but with heterogeneous formats or support for older transformer equipment.	Systematic lifetime data information available. Computational systems transform data into information useful for maintenance and operation crews.
TFO Data storage	On paper or in data archives in computers or isolated systems, with little use of databases.	Minimum on paper. Full use of historical and corporative big sized databases.
TFO Lifetime data	Incomplete historical data and with difficult access by remote users.	Relevant data historically organized and with easy access from inside the companies corporative environment.
Analysis Methods	Diagnosis results with high uncertainty. Slow optimization process, sometimes impracticable.	Diagnosis optimization based on the data consolidation and the proposed modular structure, which allows easy evaluation of the methods and quantification of uncertainties.
Output Standardization	Not standardized outputs, generally without evaluation of uncertainties.	Standardized outputs.
Visualization of Results	Incomplete, slow and, sometimes, laborious	More complete, fast and straightforward.
TFO Test and measurement/diagnosis support	Slow access to test results.	Systematical and rapid access to test results
TFO monitoring support	Individual monitoring systems.	Individual monitoring systems plus fleet information analysis.
TFO Data re-use and sharing	Limited capabilities.	More complete and systematical.
Systematization of the Analyses	In general, it doesn't exist in a complete form. The most traditional techniques and the specialists' intuition are applied.	The analyses and the most important actions are previously systematized and defined from the application of a RCM or similar process.
Execution of the Analyses	Companies' specialists separately analyze the few available data (generally, on paper) from diverse tests. Using, then, their experience and the not standardized results from the traditional methods, they request new confirmation tests to come to conclusions.	Companies' specialists analyze the available data over all the transformer history, consolidated in a corporative database, using the support of computational systems with standardized analysis methods, optimized over time. Using their experience and the emitted recommendations, they try to come to conclusions.
Analysis capabilities	Analysis of data with limitations.	Improved data analysis capabilities and background.
Decision support	Generally slow. Difficult in most of the cases. Very intuitive and not supported by consolidated data. Limited and costly.	Faster. Difficult in some cases. Less intuitive and based on more complete data, standardized degrees and valuation of losses.