



Specification of On-line Monitoring Systems for Power Transformers Based on a De-centralized Architecture

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Summary –The changes in maintenance philosophy, with migration of maintenance actions from Preventive to Predictive have led to the adoption of On-line Power Transformer Monitoring Systems as one of the main tools used in learning about equipment condition and offering diagnosis or prognosis of eventual problems. This article introduces the main aspects to be taken into account in specifying power transformer monitoring systems, including the architectures deployed in measuring variables, the means for data transmission, processing of readings to obtain either diagnosis or prognosis of equipment condition and availability of information. The concept of monitoring sub-systems using intelligent sensors (IEDs) will also be introduced, since these can create feasibility for deployment of online monitoring in small and medium scale transformers.

Keywords: transformer, specification, on-line monitoring, diagnostics, prognostics, predictive maintenance, condition based maintenance.

1. INTRODUCTION

The current scenario of electric energy markets worldwide has taken companies in the sector to operating in an unprecedented competitiveness context, forcing a permanent search for higher efficiency, better supply quality and lower costs.

This context has, in its turn, led to a change in maintenance philosophies, accelerating the migration of maintenance action from Preventive to Predictive. Some of the first equipment to operate under this new change are power transformers, since, in addition to essential for transmission and distribution grids, they are also usually the largest assets in substations.

So, On-line Monitoring Systems have been adopted as one of the main tools that afford conditions for this change without jeopardizing transformer operating safety and reliability, allowing operators to know their actual condition and diagnosing or prognosticating eventual problems.

The experience already acquired by the market through the development, specification and purchase of on-line monitoring systems, in addition to their subsequent operation and maintenance, allows the main philosophies used in building systems to be identified, as well as analyses of the practical results and the selection of the solutions that feature the best results at the lowest costs.

In this way, even though initially monitoring systems were deployed only on large scale power transformers, the choice and specification of appropriate philosophies and architectures can render feasible the application of on-line monitoring systems even on small and medium scale transformers.

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2. TYPICAL TOPOLOGY OF ON-LINE MONITORING SYSTEMS

Typically, power transformer on-line monitoring systems adopt the topology shown in the block diagram in figure 1, where the following main components can be defined:

- **Variable Measurement** – Measurement of the different variables considered to be important in order to know the condition of the equipment performed via sensors and/or transducers, in general located on the transformer. If the architecture adopted is Centralized, there will also be a measurement concentration device (PLC).
- **Data Transmission** – Consists in transmitting data from measurements taken by sensors, obtained in the preceding stage, to the stage of data storage and processing, using the most convenient physical medium for the purpose.
- **Data Storage and Processing** - Data Storage and Processing for readings issued by sensors targets obtaining useful information for asset maintenance and management, such as diagnosis and prognostics of the state of the different subsystems and overall condition of the transformer. This also avoids overloading maintenance engineering with a high volume of data, not always easily interpreted.
- **Information Availability** – For monitoring systems to deliver their objectives, information related to the state of the equipment must be made available to the different interested sector, while simultaneously maintaining data integrity and access security.

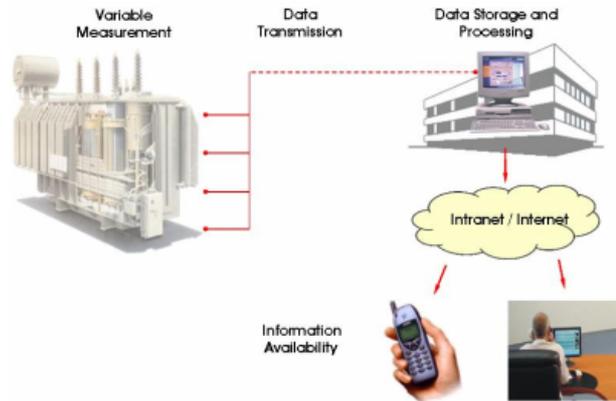


Figure 1 – Typical Topology of a Transformer Monitoring System

Specification for an on-line monitoring system must take into account the necessary characteristics and the options to meet address them in each of these. The main issues to be observed are described below.

2.1. Variable Measurement

Specification of Variable Measurement for the monitoring system must take into account: (1) the variables to be measured and (2) the architecture to be adopted for these readings.

2.1.1 Variable Selection

Below is a list of the typical variables measured in on-line monitoring systems for power transformers, but it is possible to use just a part of them:

- Ambient temperature
- Oil temperature
- Winding temperatures
- Load tap changer temperature
- Condition of conservator bag/membrane
- Water content and relative saturation in transformer oil
- Water content and relative saturation in load tap changer oil
- Bushing capacitance and tangent delta
- Hydrogen in oil
- Load Currents and Voltages
- Tap changer position
- Load tap changer working instant
- Number of tap changer operations
- LTC motor currents and voltages
- Transformer oil level
- Tap changer oil level

The choice of variables to measure through the monitoring system will be conditioned to the following main factors:

- Applicability on the transformer in case of point, considering the existence or absence of accessories such as on load tap changer, oil circulation pumps, etc.
- The variables required to perform the diagnostic functions considered important for the application. This factor is directly linked to the Data Storage and Treatment block, and will be detailed in item 2.3.

2.1.2 Architecture for Variable Measurements

Measuring variables during operation of the transformer is performed by way of sensors and/or signal conditioners, which may be connected in one of two main architecture options:

- One based on a centralizer element located on the transformer casing, usually a PLC (Programmable Logic Controller), or,
- A decentralized architecture, based on IEDs (Intelligent Electronic Devices) also located on the transformer casing.

The choice of architecture to be used for measuring variables must take into account the inherent characteristics to each of the options, shown in Table 1.

Centralized Architecture	Decentralized Architecture
<ul style="list-style-type: none"> ▪ Centralized system – PLC concentrates information received from all sensors and sends them to the next block in the monitoring system. 	<ul style="list-style-type: none"> ➤ Decentralized system, where sensors are IEDs (<i>Intelligent Electronic Devices</i>) that send the information directly to the next block of the monitoring system.
<ul style="list-style-type: none"> ▪ Centralized system, expansions and maintenance more difficult. 	<ul style="list-style-type: none"> ➤ Naturally modular system, making expansions and maintenance easier.
<ul style="list-style-type: none"> ▪ Sensors must be dedicated to the connection to the PLC, resulting in the need for eventual duplication of sensors and additional costs for monitoring systems. 	<ul style="list-style-type: none"> ➤ Existing IEDs in control and protection systems can be integrated to the monitoring and data acquisition systems, avoiding the costs of additional sensors.
<ul style="list-style-type: none"> ▪ Centralizer element (PLC) represents additional costs in installing, programming and maintenance for the system. 	<ul style="list-style-type: none"> ➤ There is no centralizer element – eliminating additional costs.
<ul style="list-style-type: none"> ▪ Failure in PLC may lead to loss of all functions offered by system. 	<ul style="list-style-type: none"> ➤ Failure in one IED leads to loss of just a part of the functions – other IEDs continue in service.
<ul style="list-style-type: none"> ▪ Centralizer element (PLC) is an additional failure point for the system 	<ul style="list-style-type: none"> ➤ There is no centralizer element, thus eliminating a possible failure point.
<ul style="list-style-type: none"> ▪ Typical maximum PLC operating temperature is 55°C [1]. Installing on main equipment (ex.: transformers) is not advisable. 	<ul style="list-style-type: none"> ➤ Operating temperature -40 to +85°C, suitable for installing in yard on main equipment.
<ul style="list-style-type: none"> ▪ Installation recommended in control room – large number of connection cables between device and yard. 	<ul style="list-style-type: none"> ➤ Typical installation on main equipment, in yard – only serial communication (twisted pair or optic fiber) for link to control room.
<ul style="list-style-type: none"> ▪ Typical insulation level 500V – not suitable for high voltage substation environments [1]. 	<ul style="list-style-type: none"> ➤ Typical insulation level 2.5kV – designed for high voltage substation environment.
<ul style="list-style-type: none"> ▪ Serial communication ports do not tolerate surges, impulses and induction found in substation, mandating the use of optic fiber in communication with the control room – high installation cost. 	<ul style="list-style-type: none"> ➤ Serial communication ports designed for substation environment, allowing deployment of twisted-pair cables for communication with control room – low set up cost. Allows optional use of optic fiber cabling, with self-powered external converters.
<ul style="list-style-type: none"> ▪ Usually operate using industrial communication protocols [1]. 	<ul style="list-style-type: none"> ➤ Specific communication protocols for deployment in power systems (time-stamp, clock synchronicity, etc.).

Table 1 – Comparison of Centralized and Decentralized Architecture Characteristics

Monitoring system topologies using centralized and decentralized architectures can be seen in the examples of figures 2 and 3. Figure 2 shows, for example, the duplication of oil temperature and load current sensors, which does not occur in figure 3.

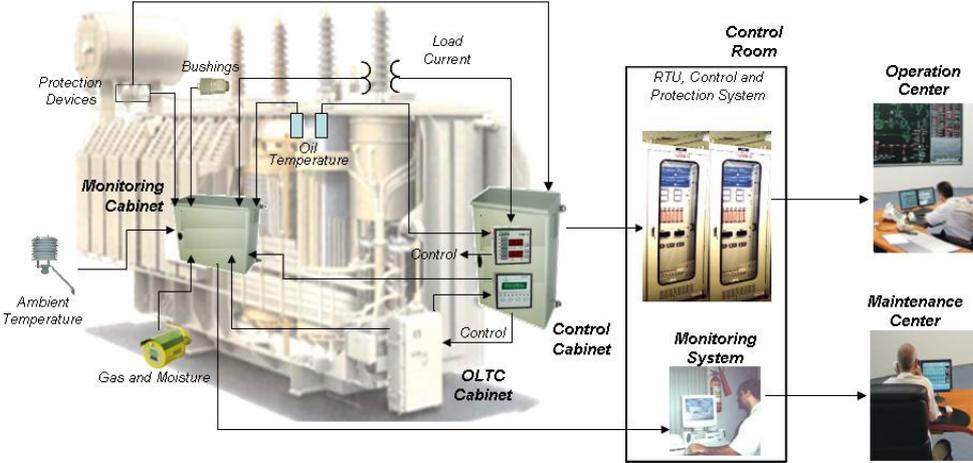


Figure 2 – Topology using Centralized Architecture

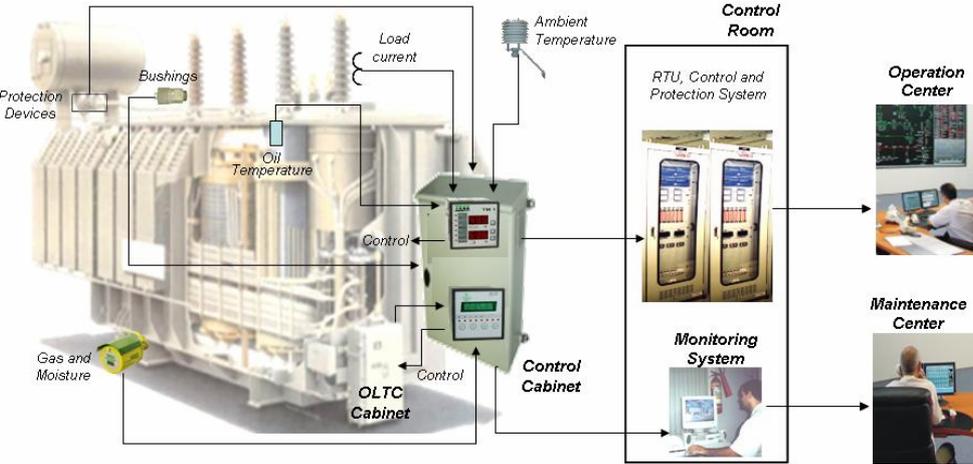


Figure 3 – Topology using Decentralized Architecture

The different benefits obtained from the use of decentralized architecture make it advisable, therefore, in monitoring system specifications, given the higher level of reliability and lower maintenance costs, in addition to the ease in specifying for small scale monitoring systems and reduced costs. To this end, a contribution is made by the possibility in deploying existing IEDs already installed on the transformer for supervision and control functions as data sources (sensors) for the monitoring system. In some cases, like the examples shown in item 3, monitoring systems can actually have zero sensor acquisition costs.

2.2. Data Transmission

Transmission of data from the measurement equipment (item 2.1) to the substation control room can be achieved via a range of different means of communication, obviously addressing the requirements of the type of architecture deployed in measuring the variables, as shown in table 1. In systems with centralized architecture for measuring variables, optic fiber cables are usually deployed.

In systems with decentralized architecture, on the other hand, in addition to the option for optic fiber cabling, it is possible to use RS485 serial communication standard cables, with the advantage of the lower costs and shorter installation times, thus contributing to reducing costs and increasing financial feasibility for monitoring systems in small scale transformers. Thus, under this aspect also, deploying decentralized architecture becomes advisable in specifying monitoring systems.

Other communication options can also be studied, depending on the characteristics of the facility, such as for example, dedicated radio links or wi-fi wireless networks.

If the computer that stores and treats the data (item 2.3) is located in the substation control room, the equipment data transmission connection can be direct. However, if the computer is in another remote facility, transmissions of measurement data can also be done via the company intranet, by internet or even by cellular phone modem GPRS.

2.3. Data Storage and Processing

The data supplied by the IEDs located on the transformer, both raw readings and those supplied resulting from the pre-treatment of the data, are received by a computer, which can be located in the substation control room or at a remote location, running the monitoring software.

More than a system for simple digitizing of sensor measurements, a monitoring system must be able to transform these data into useful information for transformer maintenance, which are equipment condition diagnosis and prognosis. In order to comply with this function the monitoring system must be equipped with an “Engineering Module”, which contains the algorithms and mathematical models for diagnostics and prognostics.

Table 2 summarizes the main diagnostic modules that can be specified for a monitoring system, as well as the variables needed for their operation [2], [3].

Diagnostic Module	Variables Necessary
- Insulation Loss of Life	- Winding temperatures (hot-spot) - Water content in paper (from the diagnostic module)
- Forecast of future temperatures - Cooling system efficiency	- Ambient temperature - Top oil temperature - Percent load - Cooling stage in operation
- Cooling Maintenance Assistant	- Cooling stage in operation
- Water in Oil and in Paper - Bubbling temperature - Free water formation temperature	- Percent relative water saturation in oil - Water content in oil in ppm - Oil temperature at the point of measurement - Winding temperatures - Ambient temperature
- Gas in transformer oil	- Hydrogen in oil concentration - Concentration of combustible gases in oil (off-line or on-line)
- Load tap changer temperature differential	- Top oil temperature - Tap changer oil temperature - Tap position
- Load tap changer operation time	- Tap position - Tap changer in operation
- LTC motor torque	- Tap position - Tap changer in operation - Tap changer motor current - Tap changer motor voltage (optional)
- LTC Maintenance Assistant	- Tap position - Tap changer in operation - Load current
- Water in LTC oil	- Percent relative water saturation in oil - Water content in oil in ppm - Oil temperature at the point of measurement

Table 2 – Examples of Diagnostic Modules and Variable Measurements Needed

In systems with decentralized architecture, the modularity of the IED sensors is extended to the diagnostic modules to be used, since modules can be specified to cover just the variables listed in the column “Variables Required” in table 2.

This contributes to reducing costs and increasing financial feasibility for monitoring systems in small scale transformers. Thus, under this aspect also, deploying decentralized architecture becomes advisable in specifying monitoring systems. In item 3, a few examples of monitoring subsystems are given where, deploying few sensors, it is possible to diagnose the different transformer functions.

2.4. Information Availability

In order to create availability of the information from the monitoring system, usually the computer used to run the monitoring software will be connected to the company Intranet or even the Internet. In order to allow access to the monitoring system without the need to install specific software in all remote computers, the solution usually employed is access via internet browsers.

In addition, in order to avoid the need for ongoing follow up of the system, which would lead to major time consumption (and respective cost) for maintenance engineering, the monitoring system can be specified with an automatic alert message sending functionality in the event any abnormality is registered. Alerts can be sent by email or by SMS text messages on cell phones, according to definitions previously recorded on the system.

3. EXAMPLES OF MONITORING SYSTEM CONFIGURATION

In order to illustrate the specification of different configurations for monitoring systems, below a few examples of application using monitoring modules with relatively few variables are given.

Examples consider the use of decentralized architecture, taking advantage of supervision and control equipment already found on many transformers with sensors for variable measurement for the monitoring system.

3.1. Temperature Monitoring Subsystems

Figure 4 brings an example of a Temperature monitoring sub-system that uses as sensor for measurement of variables only one temperature monitor, frequently already found on transformers for the functions of forced ventilation supervision and control. With this simple configuration, several monitoring functions are possible, as shown in the list found in the figure.

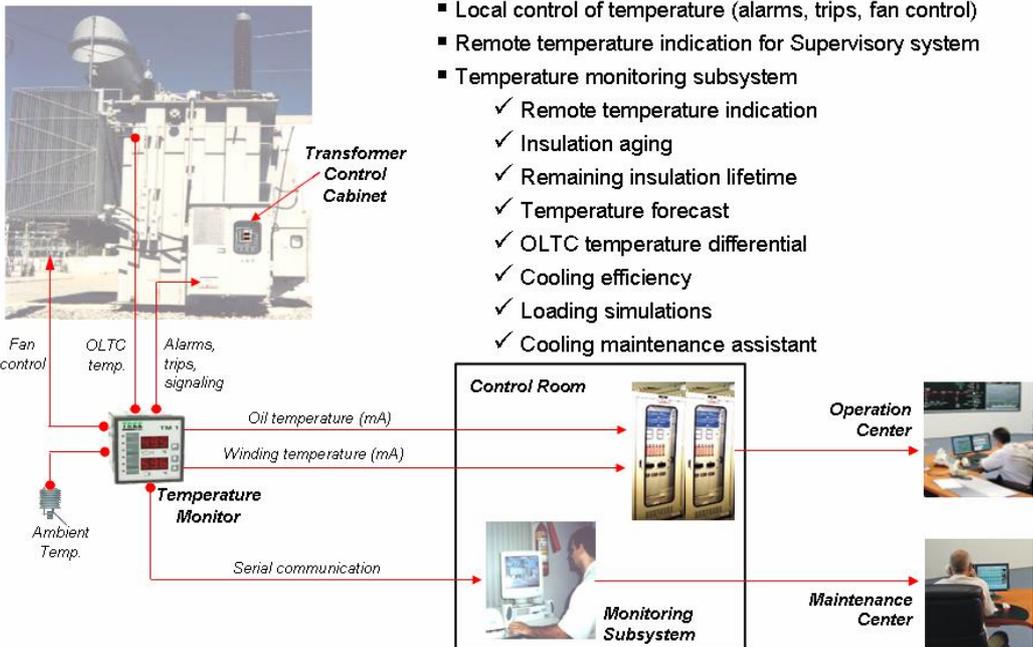


Figure 4 – Temperature Monitoring Subsystem

3.2. Temperature and Moisture Monitoring Subsystems

Figure 5 brings an example of Temperatures and Moisture monitoring subsystem that uses as sensors for measuring variables a temperature monitor, frequently already found on transformers for the functions of forced ventilation supervision, and control, and one moisture in oil sensor of relatively low cost. With this simple configuration, several monitoring functions are possible, as shown in the list found in the figure 4, with addition of the functions of the moisture monitoring subsystem listed in figure 5.

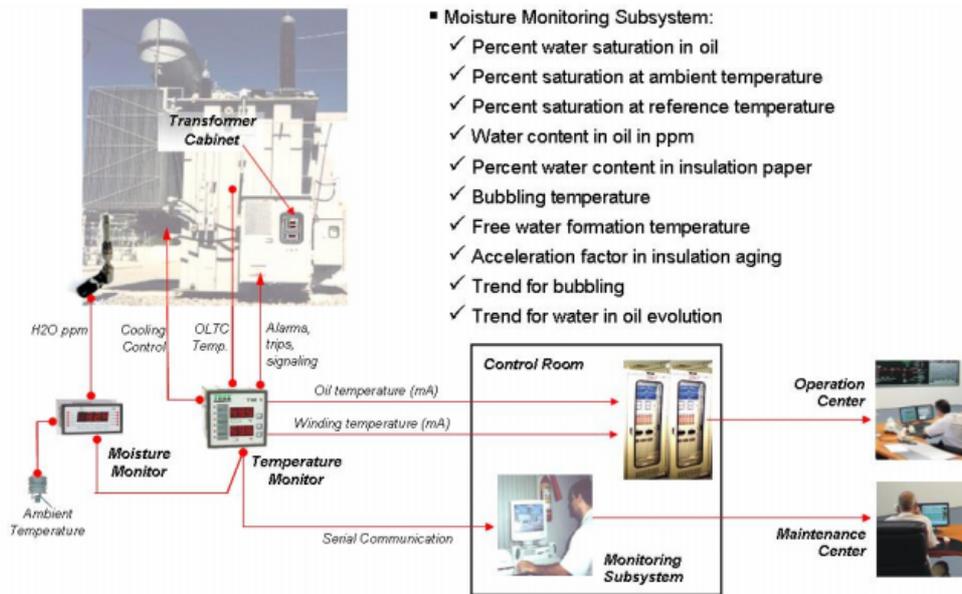


Figure 5 – Temperature and Moisture Monitoring Subsystems

3.3. Temperature, Moisture and Bushing Monitoring Subsystems

Figure 6 brings an example of a monitoring subsystem for Temperatures, Moisture and Bushings that uses as sensors for measuring variables a temperature monitor, frequently already found on transformers for the functions of forced ventilation supervision and control, one moisture in oil sensor and a bushing monitor. This configuration allows all the functions of the temperatures and moisture monitoring subsystems shown in figure 5, plus the functions of the bushing monitoring subsystem listed in figure 6.

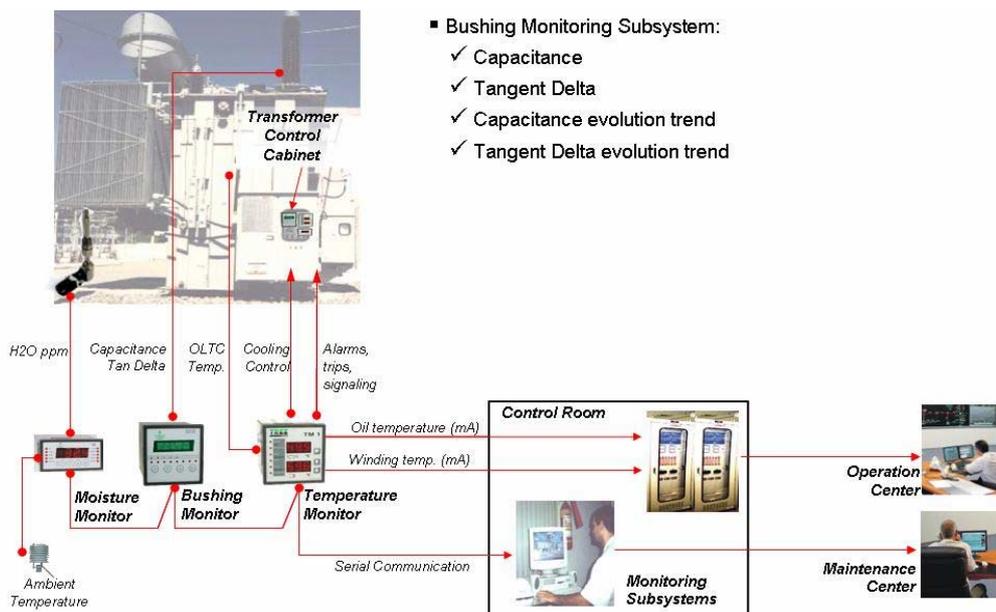


Figure 6 – Temperature, Moisture and Bushing Monitoring Subsystems

3.4. Temperature and Load Tap Changer Monitoring Subsystems

Figure 7 brings an example of a Temperatures and On Load Tap Changer monitoring subsystem that uses as sensors for measurement of variables a temperature monitor and a voltage regulation, frequently already found on transformers for the functions of forced ventilation supervision and control and of the tap changer. This configuration allows all the functions of the temperatures monitoring subsystems shown in figure 4, plus the functions of the on load tap changer monitoring subsystem listed in figure 7.

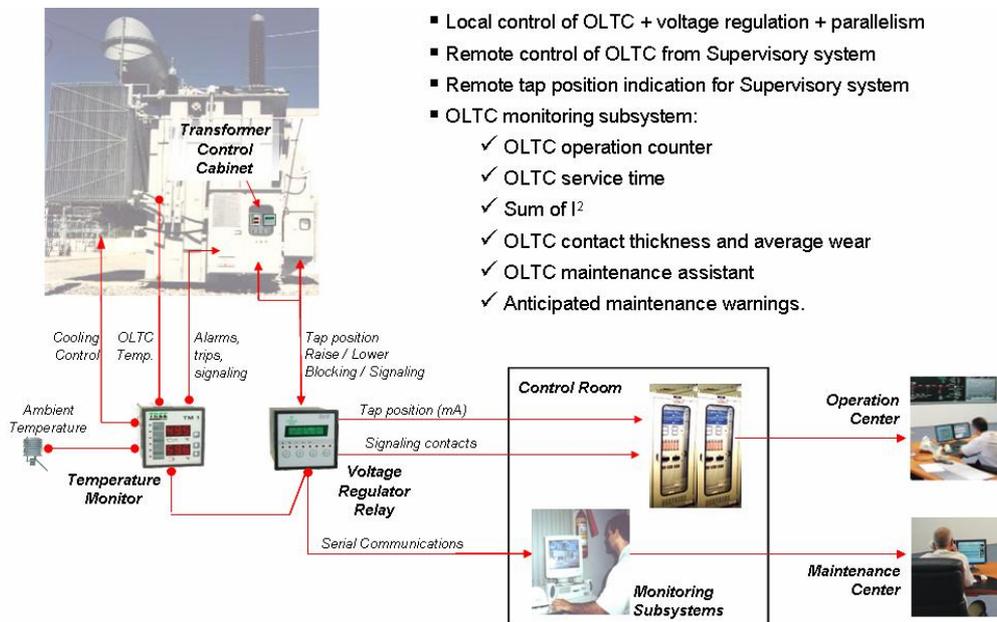


Figure 7 – Temperature and Load Tap Changer Monitoring Subsystems

4. CONCLUSIONS

In order to achieve the expected outcomes for using power transformer on-line monitoring systems, special care must be taken in drafting the specifications for the features of the system, such as the variables to measure, the architecture that will be used in measuring the variables and the desired diagnostic modules.

By specifying a decentralized architecture for measuring variables, based on intelligent devices (IEDs), it is possible to deploy specific diagnostic modules, as shown in the examples given in item 3, taking advantage of the IEDs already installed on the transformer for supervision and control functions as data sources (sensors) and at a zero cost for the monitoring system. This architecture also allows the gradual implementation and expansion of the monitoring system, respected the availability of company resources and allowing their implementation on a larger number of transformers.

Thus, the deployment of online monitoring systems, in the past usually limited to large scale transformers due to their high costs, also becomes possible in small and medium scale transformers.

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