HYDRAN® M2 FAULT GAS AND MOISTURE MONITOR

Substation Automation Solutions

TECHNICAL SPECIFICATIONS

Specifications

General	
Specifications are subject to change without notice.	
Description	Continuous,on-line,intelligent Moisture and Gas-in-Oil transmitter
Components	Combined Dual function Sensor and electronic enclosure
Response	Relative Humidity in oil (%), Hydrogen (H2), carbon monoxide (CO), acetylene (C2H2), ethylene (C2H4)
Medium	Mineral, insulating oil for transformers
Application	Transformer monitoring; Moisture level measurement (for the evaluation of dangerous conditions, bubbling temperature and aging rate) and detection of incipient faults in oil-filled electrical equipment
Analytical Performance	
Principle	Gas: Gas-permeable membrane and combustible gas detector Moisture: Thin film Capacitive sensor
Sampling Method	Flooded port with 1 1/2-inch NPT male threads
Measurement Range	Moisture: 0 – 100 %RH Gas: 0-2000 ppm (volume/volume, H2 equivalent)
Accuracy At 35°C set point	Moisture: +/- 2% RH Gas: ± 10% of reading ± 25 ppm (H2 equivalent)
Gas Relative Sensitivity	H2: 100% of concentration CO: 18 ± 3% of concentration C2H2: 8 ± 2% of concentration C2H4: 1.5 ± 0.5% of concentration
Response Time	Moisture: 5 minutes sensor response (90% of step change) Gas: 10 minutes sensor response (90% of step change)
External Sampling Port	Designed for glass syringe with Luer stop cock; closed with 5/32-inch Allen screw

Electronic Unit	
Hardware	Microprocessor; watchdog; clock
Software	Real-time operating system; menu-driven interface
Functions	Gas level, hourly trend and daily trend readings; gas level, gas trends alarms; Moisture level (with oil temperature), hourly average and daily average reading; Moisture level and Moisture average alarms; Fail alarm; history logging; periodic sensor test; calibration, configuration and self-test; networking; remote control via H201Ci controller (optional modem); remote embedded software upgrading
Communications	One RS232 port - user selection for either local laptop connection during installation or service connection to H201 Ci controller for remote communications One RS485 port for connection to local Hydran network or remote communications
Display	Backlit liquid crystal display (LCD); graphic 128 * 64 pixels
Keypad	Eight keys: Up, Down, Right, Left, Esc and 3 context function
Alarm Contacts	Five dry contact outputs allocated as follows: Gas and Moisture High, High-High and Fail alarm contacts One NO and one NC contacts (type C) per alarm 125 VA @ 250 V a.c., 60 W @ 220 V d.c.
Optional Analog I/O	4-20 mA General purpose Input; 4-20 mA Output; 500 Ohms max loading; 1500 V RMS isolation level as follow : Gas level, %RH and Oil temperature Maximum I/O: 4; to be specified at order
Miscellaneous	
Enclosure	NEMA 4X (IP 66); aprx 10" X 8.25" X 9"
Electronic Modules	Totally encased CPU and I/O electronics
Enclosure Heating/ Cooling	Heating plate; convection cooling; maintain unit between 15 and 65°C (59 and 149°F)
Operating Temperatures	Oil at the valve: -50 to +90°C (-58 to +194°F) With optional finned, high-temperature adaptor for oil temperatures up to 105°C (221°F) Ambient: -50 to +55°C (-58 to +131°F)
Oil Pressure	0-700 kPa (0-100 psiG); no vacuum allowed
Power Supply	Universal 80-260 V a.c. , 50/60 Hz, 350 VA maximum
EMI/RFI/ESD Compatibility	Meets IEEE C37.90 and IEC 255-4, 801-2, 801-4 standards
Weight	Installed: 6 kg (13 lb) Shipping: 7.3 kg (16 lb)

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GE Power Systems

GEA-13516

GE
Energy

Hydran* M2 “All-In-One”

Fault Gas, Moisture, Transformer Monitor with Transformer Models

fact sheet

Overview

Based on field-proven technology, the new Hydran M2 adds transformer mathematical models based on IEEE® and IEC® standards to provide real-time information on the overall performance of the transformer. This extends the monitoring to more failure modes than by dissolved gas and moisture monitoring alone.

When an unexpected failure of a transformer occurs, the operational and economic impacts are substantial. Today, many existing oil-insulated transformers used by electrical utilities and other industries are approaching the end of their design life and are exposed to significantly higher probabilities of failures. Stringent regulations on the supply of energy, the reduction of capital investment and operation expense budgets, and the shortage of specialized personnel are also increasing the need to extend the lifespan of these transformers.

Description

The Hydran M2 is an economical, yet powerful all-in-one transformer monitoring device that allows utilities and other customers to deploy transformer monitoring to a large number of transformers that will benefit from its advanced features.

The Hydran M2 with models is an early warning device for detection of primary faults at transformers and other oil-filled equipment with its on-line fault gas and moisture sensors. Additional analog and digital inputs allow the monitoring of other important transformer variables. The new transformer models extend the monitoring power and asset management capability of the Hydran M2, bringing more decision power to operation and maintenance personnel.

Key Benefits

Monitoring and performing real-time transformer modeling can help reduce the risk of unexpected and sometimes catastrophic failures. This also helps to avoid expensive clean-up, replacement, and unplanned downtime. Early detection of potential transformer problems is vital to the lifespan extension of critical transformers and provides significant business and operational benefits that will:

- Reduce inspection and maintenance costs by stretching out the time between routine maintenance activities
- Reduce unplanned outages with continuous condition monitoring and early detection of primary faults
- Provide greater lifespan confidence through the use of on-line model computations providing real-time transformer condition information
- Defer major replacement costs by optimizing the transformer’s performance and extending its lifespan

System Features

- Real-time fault-gas and moisture-in-oil measurement system
- Vacuum-resistant gas extraction membrane
- Single-valve installation with no pumps or moving parts
- Microprocessor-based intelligent electronic device
- Full system self-test and self-diagnostics
- Type NEMA® 4X (IP 66) enclosure
- Alphanumeric display with scrolling control
- Four programmable relay contacts for alarms
- One relay contact for self-diagnostics
- Four I/O expansion plug-in connectors for a combination of:
    - Isolated 4-20 mA analog input card
    - Isolated dual-channel digital input card
    - Isolated 4-20 mA analog output card
- One communication expansion plug-in connector for:
    - Ethernet 10-100BaseT card
    - Analog modem
- Local isolated RS-232 serial port
- Isolated RS-485 serial port for remote communications
- Support to DNP3 protocol (serial or TCP/IP)
- Expanded logging of data and events at adjustable rates

- Adjustable alarms on gas, moisture, analog inputs and values calculated by transformer models based on levels or trends
- User-friendly client/server graphical user interface software (GUI) permitting multi-client access to transformer data via TCP/IP

Transformer Models

State-of-the-art on-line models based on the Hydran sensor inputs and additional transformer inputs via I/O expansion plug-in cards. (Please consult table for required inputs per transformer model.)

- MVA model computes apparent power on each winding where load current is measured
- Winding hot-spot temperature computes the hot-spot on each winding where load current is measured
- Insulation aging computes insulation loss of life from IEEE® or IEC® guidelines
- Moisture in paper and bubbling computes moisture in winding insulation and the critical temperature for gas bubble inception
- Moisture in the main insulation pressboard barriers is computed
- Cooling efficiency model monitors the actual efficiency of the cooling system
- Cooling bank status computes the cumulative operation time of each cooling bank
- Tap changer position tracking records each operation and provides history of operations of the tap changer
- Tap changer thermal model computes temperature difference between the OLTC tank and the main transformer tank

Required and optional analog and digital inputs per transformer model (maximum of 4 expansion slots)

- Each optional analog input module supports one 4-20 mA input
- Each optional digital input module supports two "dry-contact" inputs
- Appropriate sensors are required
- GE offers temperature and current sensors

(R = Required; O = Optional)

	Std Hydran Readings		Analog Inputs								Digital Inputs	
	Relative Humidity (%RH)	Sensor Temperature (°C)	Top Oil Temperature (°C)	Load Current Winding H (A)	Load Current Winding X (A)	Load Current Winding Y (A)	OLTC Tap Position	OLTC Tank Temperature (°C)	Ambient Temperature (°C)	Bottom Oil Temperature (°C)	Status of Cooling Banks #1 and #2	Transformer Energized
Winding H Apparent Power				R								
Winding X Apparent Power					R							
Winding Y Apparent Power						R						
Winding H Hot-Spot Temperature			R	R								
Winding X Hot-Spot Temperature			R		R							
Winding Y Hot-Spot Temperature			R			R						
Insulation Aging	R	R	R	R								
Moisture in Paper and Bubbling	R	R	R	R								
Moisture in Pressboard Barriers	R	R	R	R						R	O	
Cooling Efficiency			R	R					R		R	O
Cooling Bank Status											R	
OLTC Position Tracking							R					
OLTC Temperature Differential			R					R				

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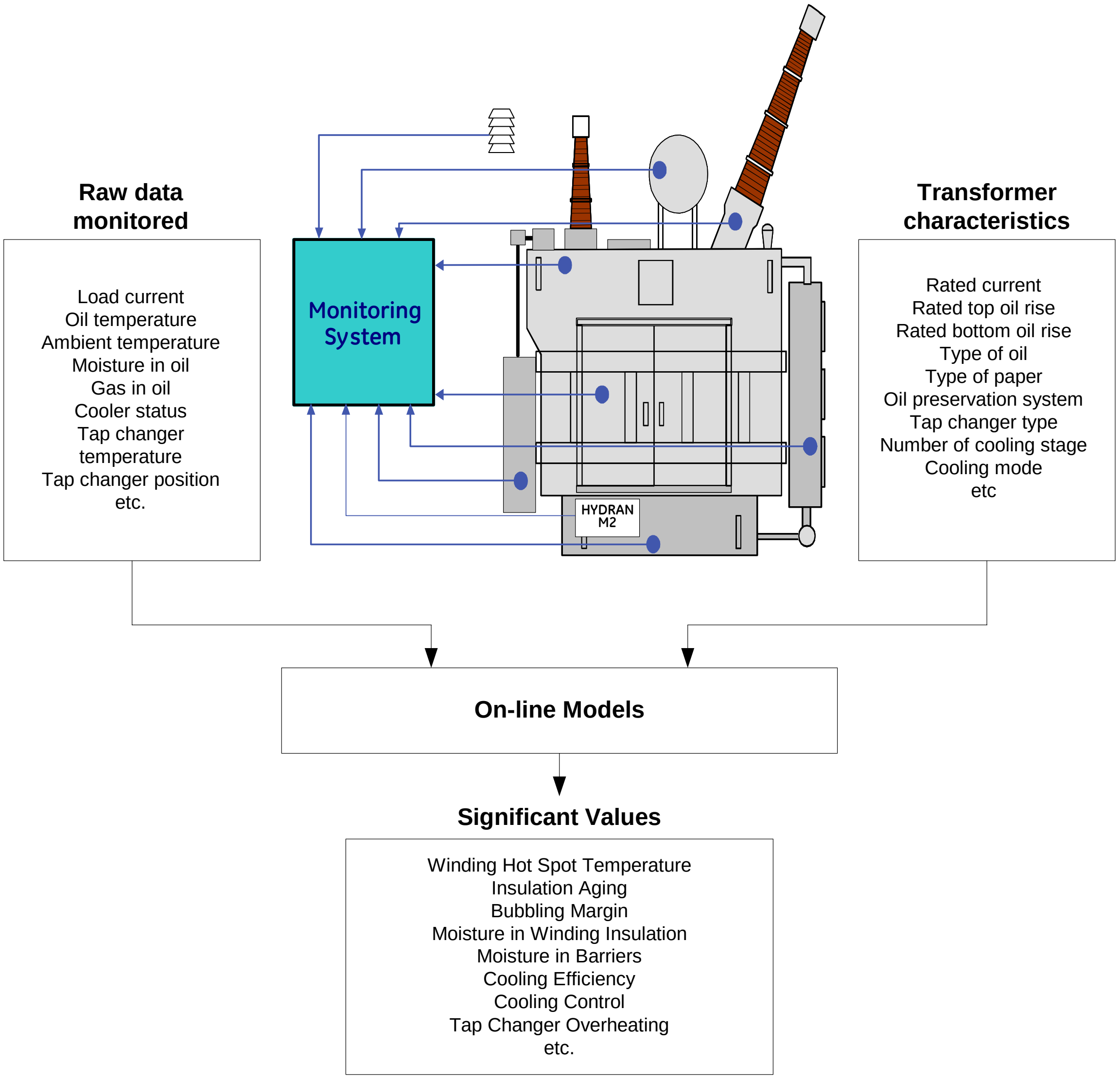
For more information, please visit our web site at ge.com/energy.

GEA-14810 (11/06)

Transformer Management Models

Power transformers are one of the most critical components of power systems. The cost of such units and the consequences of unexpected failure has always been a concern for system operators. It is no wonder that monitoring devices such as Buchholz gas relay and winding temperature indicators have been used for many years. More recently, the availability of microprocessors, ruggedized for high voltage substation environment, had made it possible to monitor a large number of parameters. With large memory capability and communication facilities it is tempting to record all these data for future usage.

However experience has shown that the monitored values are of limited interest by themselves. They gain there value when compared with rated values and combined among themselves to generated more significant information. This is the purpose of transformer models provided with Hydran M2 and Intellix MO150. In the following pages, these models are described along with the benefit to the user the user.



Raw data monitored

Load current
Oil temperature
Ambient temperature
Moisture in oil
Gas in oil
Cooler status
Tap changer temperature
Tap changer position
etc.

Transformer characteristics

Rated current
Rated top oil rise
Rated bottom oil rise
Type of oil
Type of paper
Oil preservation system
Tap changer type
Number of cooling stage
Cooling mode
etc

On-line Models

Significant Values

Winding Hot Spot Temperature
Insulation Aging
Bubbling Margin
Moisture in Winding Insulation
Moisture in Barriers
Cooling Efficiency
Cooling Control
Tap Changer Overheating
etc.

Winding Hot Spot Temperature

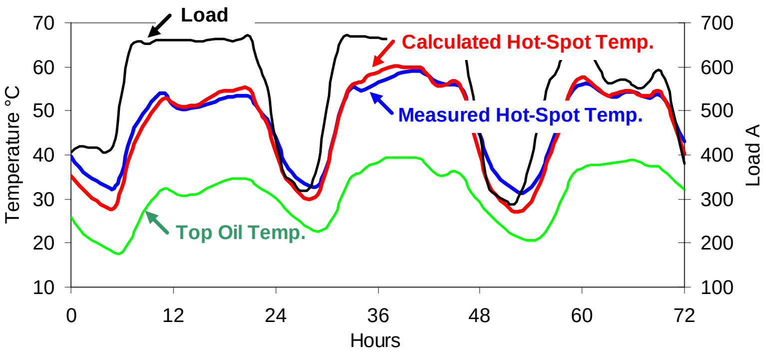
The rating of a transformer is closely linked with the winding temperature. In fact the rated power of a transformer is the amount of MVA the transformer can carry without exceeding the average winding temperature rise of 65°C. The temperature limits are defined as “temperature rise” above the ambient air temperature.

The average temperature rise of a winding is measured during the temperature rise test carried out on the completed unit, before delivery. However it is not the average winding temperature that is of interest but rather the temperature in the hottest area (so called “hot-spot temperature”). This temperature cannot be measured directly except with fiber optic sensor installed in the winding at time of manufacturing. Simplified calculation methods are provided in IEEE and IEC loading guides. They relies on the following values:

Measured values
- Top oil temperature
- Load current in each winding to be monitored

Transformer characteristics
- Rated hot spot rise above top oil for each winding to be monitored
- Rated current on each winding
- Winding thermal time constant
- Winding exponent relating winding temperature to load

This model has been validated with test on a large transformer equipped with fibre optic sensors. It can be seen that for normal load fluctuation this model provide sufficient accuracy especially under high loading conditions.



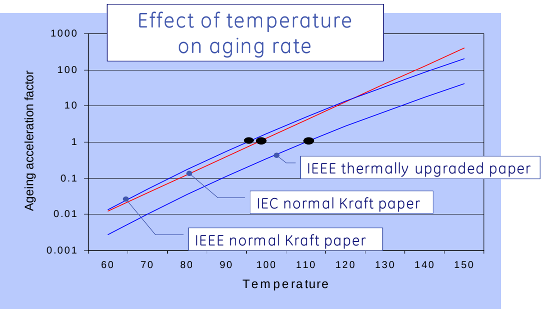
The temperature of the winding insulation is one of the most critical factors in a transformer. This calculated value is an essential input for several functions:

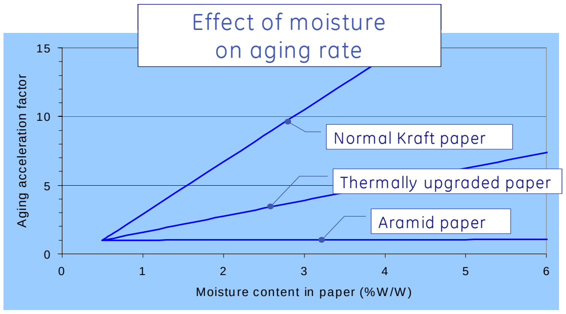
- Allows computation of insulation aging (see Aging Model)
- Allows control of the cooling system (see Cooling Control Model)
- Allows evaluation of the risk of bubbling (see Moisture and Bubbling Model)
- Provide warnings and alarms

Insulation aging

With time, temperature and moisture, all cellulose material undergoes a “depolymerization” process; i.e. cellulose chains breaking down into smaller chains and the paper loses some of its mechanical strength and becomes brittle. The aging process is irreversible and defines the end of life of a transformer. This model takes into account the type of paper used in winding insulation; it can be normal Kraft paper (for older transformers) or thermally upgraded paper. The Hydran M2 and Intellix MO150 can also handle high temperature Aramid paper (Nomex).

The **winding hot spot temperature** is the main aging acceleration factor (also call aging rate). When the paper is operating at its rated temperature, we say that the aging acceleration factor is 1. This temperature differs depending on the type of paper and the standard applicable for the transformer. The graph below shows the sensitivity of paper to temperature. In fact, increases of about 7°C will double the aging rate. The insulation temperature in the hottest spot area is calculated in the previous model.

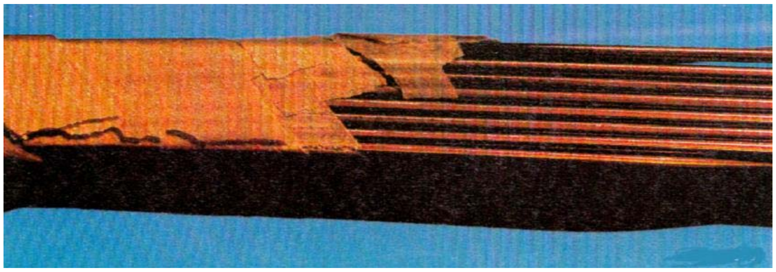




Temperature is not the only factor promoting accelerated aging. **Moisture** content is also an important factor. The graph above show the additional aging acceleration factor that is applied as a function of the moisture content in winding insulation. A new transformer, completely dry has about 0.5% moisture and in this condition the additional aging factor is 1. Older transformers use to be made of “Normal Kraft paper” and for those, a high moisture content of 3% will lead to an additional aging acceleration factor of about 10. Thermally upgraded paper is less sensitive to moisture and Aramid paper is practically insensitive to moisture. Moisture content in insulating paper is calculated in a separate model.

A third factor of importance is the **oxygen content** of insulating oil. It has been shown that oxygen can promote significantly the depolymerization process. Transformers with seal tank (and nitrogen blanket) are free from oxygen and this is also true for transformer with a membrane in the conservator. But normal conservator allows the air to be in contact with insulating oil. With time the oil become saturated with oxygen and this will affect the aging by an additional factor of 2.5 The amount of oxygen dissolved in oil does not need to be measured as it is assumed to depend on the type of oil preservation system.

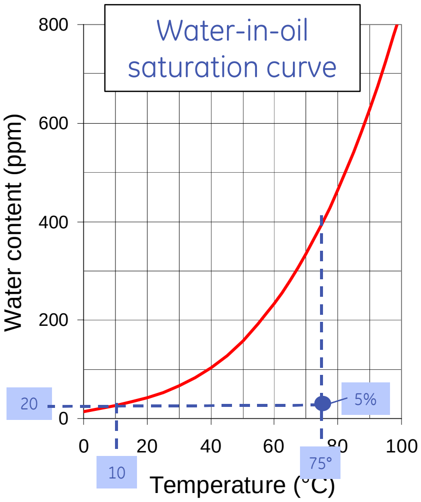
In the Hydran M2 and Intellix MO150 all these factors are considered in the calculation of insulation aging. The user interface indicates the current global aging acceleration factors and the contribution related to temperature and moisture. The cumulative aging is also provided. The remaining life of the insulation can be assessed by comparing the cumulative aging with the “normal life duration” as recommended by the applicable standard.



Moisture content in winding insulation

Moisture is one of the worst enemies of transformers. Wet insulation will suffer accelerated insulation aging, risk of bubbling during overload and severe reduction of effect on dielectric strength. However in practice, only moisture in oil can be measured and the moisture in paper has to be calculated considering the water absorption characteristics of both oil and paper and also the migration characteristics of water under variable temperature conditions.

Measurement of **water dissolve in oil** is carried out with a capacitive moisture sensor located near the membrane of the Hydran M2. As all capacitive sensors, it measures the relative saturation; i.e. the ratio between actual water content and the amount of water the oil could carry at saturation.

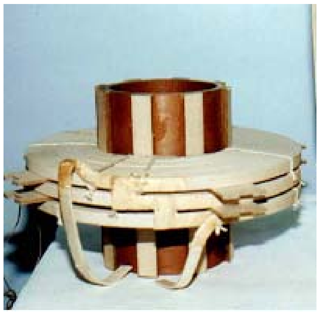


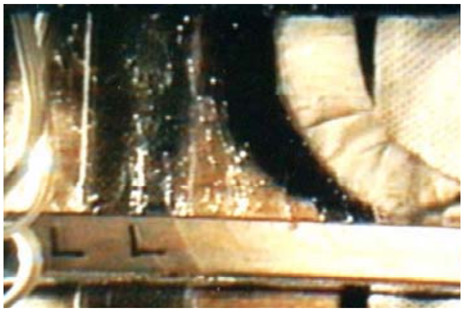
Consider this saturation curve for naphthenic oil. It shows that if the oil temperature is 40°C the oil can hold up to 100 ppm of water (part per million). But if the oil is heated to 100°C then it can carry up to 800ppm. Now assume that the moisture sensor indicate a relative saturation of 5% with a local oil temperature of 75°C. at that temperature the saturation is 400 ppm therefore the absolute water content in oil is 20 ppm.

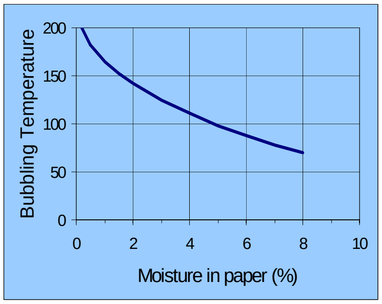
Now, 20 ppm is no problem at 75°C but if this transformer is allowed to cool down to ambient temperature, the oil may reach saturation. In this example, the saturation temperature is 10°C, meaning that if the transformer cool down below that point, water in oil will precipitate in the form of small droplets and these droplets will eventually drop to the bottom of the tank or deposit on any surface it meets. This situation should be avoided in all cases as free water will deposit everywhere and may endanger critical insulation when the transformer is reenergized. With the moisture model the operator is continuously aware of the condensation temperature and an alarm can be set to alert the operator if the condensation temperature rise above the coolest ambient temperature to be expected.

Moisture in winding insulation can be evaluated from relative saturation at the sensor, considering sensor temperature, winding hot spot temperature and the equilibrium function between oil and paper. Because of the long time required to exchange water between these two elements it is not possible to run his calculation from a single sampling of oil. The temperature variation has to be observed over several weeks before a realistic value can be stated.

Beside the accelerating affect on aging, the water content in winding insulation can also trigger generation of free gas bubbles should a wet winding be submitted to sudden overload. Several researchers testing wet coils under controlled conditions have identified this effect. This tests have shows that for a new and dry transformer, with about 0.5% Water Content in Paper, the bubbling temperature is about 180 °C But for a wet transformer with 4% moisture content, this bubbling temperature can be as low as 110 °C One conclusion is that wet transformers should never be allowed to operate under overload condition.

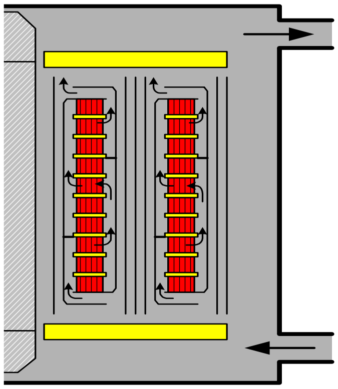


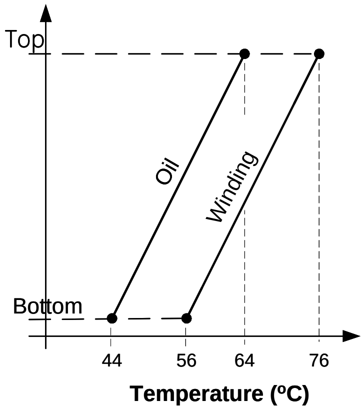


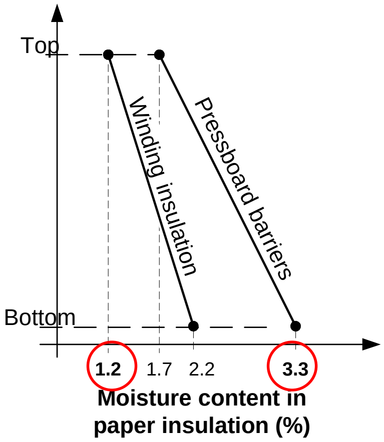


Moisture in pressboard barriers can be significantly higher than moisture in winding paper because of the temperature difference. The top of the winding is the hottest part while the bottom part of pressboard barriers is at the temperature of the bottom oil. Because of water absorption characteristics, the water content in the barrier can be surprisingly higher than the water content in winding paper.

For example we may consider a naturally cooled transformer with a temperature drop of 20 °C between top oil and bottom oil at full load. Assuming an ambient temperature of 20 °C and thermal equilibrium, the temperatures shown below for oil and winding are typical. If a moisture sensor, installed at the bottom oil temperature, shows a relative saturation of 22 %, we can calculate, for winding hot spot area a moisture content of 1.2% which is still acceptable, while the lower part of pressboard barrier being at 44°C will show a moisture content of 3.3% which imply a severe reduction of the dielectric strength in this area







The parameters of the moisture management model can be summarized as follows

Measured values:
Moisture content in oil
Temperature of the moisture sensor
Top oil temperature
Load current
Bottom oil temperature

Transformer characteristics used in the calculation:
Rated hot spot rise above top oil for each winding to be monitored
Rated current
Winding thermal time constant
Winding exponent relating winding temperature to load
Type of oil
Height of oil above hot spot area

Benefits derived from this model:

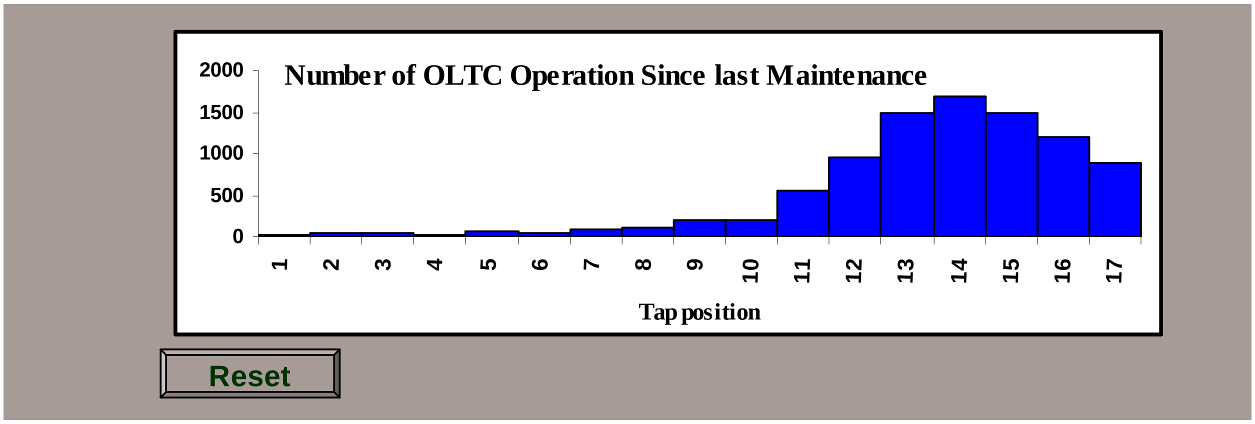
- Avoid risk of water-in-oil condensation at low ambient temperature
- Evaluate the effect of water content on aging rate
- Avoid risk of bubbling at high load.
- Assess the moisture content in insulation to determine need for drying of solid insulation.

Tap changer position tracking

Most network transformers have a tap changer to change the turn ratio and regulate the voltage as dictated from transmission system conditions. These tap changers are an important cause of transformer failure and deserve special monitoring to improve the overall reliability.

Several important data can be derived for the monitoring of tap changer operation. This model provides several counters where the number of operation on each tap is displayed. A first counter, resettable by maintenance personnel, provides detailed information on the number of operation since least maintenance thus allowing better planning of maintenance activity. It will be reset typically every 3 or 4 years when an inspection activity is preformed on the unit.

A second counter can be reset any time by the operator, to monitor the number of operation over a given period of time, when it become advisable to validate the proper setting of the voltage regulation device. The third counter is defined as “Not resetable” and is intended to cumulate all operations since commissioning of the system.



Some tap changers tend to operate always toward one end of the voltage control range. This situation tends to maintain the reversing switch on a fix position thus leading to premature overheating of that contact. This model will monitor the reversing switch activity and raise a warning if this set of contact remains inactive for a period of time longer than a preset value.

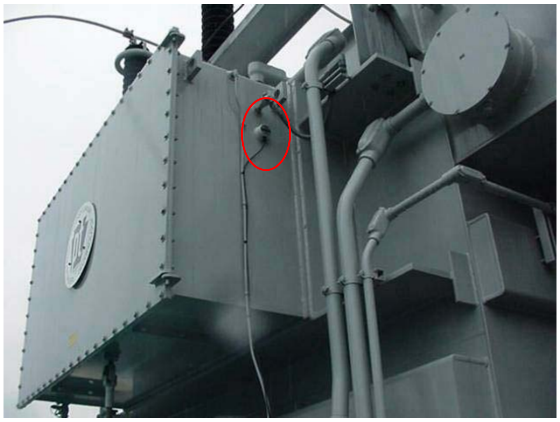
The tap changer operation frequency needs to be monitored to minimize contact wear. Maladjustment of the voltage control system or insufficient dead band can lead to excessive number of tap changer operation. This model will raise a warning if the rate of operation for a given period of time exceeds a preset value.

A tap position indicator, located in the Motor-Drive Unit is to be supplied by the User to provide a 4-20mA signal proportional to the tap changer position.

Benefits derived from this model:

- Provides a count of operations on each contact and the total number of operations
- Three separate counters for different use: Operation, Maintenance, Permanent count
- Provide time elapse and number of operation since last maintenance
- Issue warning if excessive time elapse since last operation of reversing switch
- Issue warning in case of excessive number of tap change over a given time period

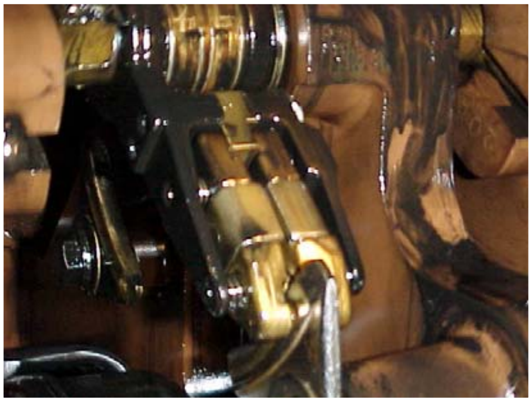
Tap changer temperature



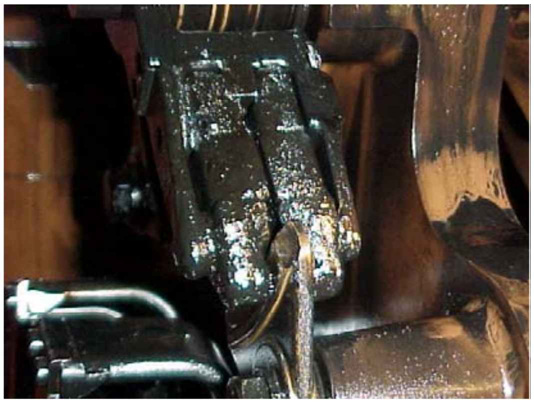
Several tap-changer problems leads to temperature rise in the tap-changer compartment. Among frequent problem is the lack of operation of the reversing switch or progressive misalignment or loosening of contacts. Any failure mode involving an unusual temperature rise in the tap changer compartment can be conveniently detected by monitoring tap-changer temperature.

In this model, the temperature of the tap changer compartment is continuously compared with the main tank temperature. The difference is averaged over several days to eliminate effects of sunshine and weather. A warning will be issued if the temperature of the tap changer compartment starts to rise significantly.

In the example below we can see overheating of reversing switch contacts. High temperature decomposes oil and a coat of carbon eventually builds up on the contact surface. This failure mode known as "contact coking" has lead to several cases of flashover in the tap changer compartment which in turn lead to a short circuit of the regulation winding, that often cause a mechanical collapse of the winding, and ensuing major transformer failure.



Normal contact



Overheated contact

Benefits derived from this model:

- Temperature of aging tap changer in separate compartment can be monitored conveniently
- Thermal fault on tap changer contacts can be virtually eliminated.

Cooling System Monitoring and Control

Transformer cooling system is an essential component of a transformer. Although the transformer is seldom operating at rated load, the system operator need to ensure that full cooling capacity is available all the time, in case of unexpected loading condition. Several aspect of the cooling system can be monitored to improve availability of the transformer.

Cooling Bank Status

The status of individual cooling banks can be monitored using the digital input available on the Hydran M2 and the Intellix MO150. These monitoring systems will provide the current cooling status and the cumulative operating time for each cooling bank. The cumulative duty on each cooling bank is useful to plan maintenance activity on the cooling system.

User interface provides continuously the following information:

- Current status of each cooling bank
- Cumulative operating time on each cooling bank

Cooling Efficiency

Effectiveness of the cooling system is demonstrated as part of the temperature rise test on new units. In service, the cooling capacity can loss some of it performance due to fan failure or clogging of coolers by pollen or dust. Although the actual load might be lower than rated value, it is advisable to check that the cooling system is working as expected. It would be unwise to wait until an emergency load occurs to discover that the cooling is not in full running order.

This model computes continuously the temperature that the top oil should have, considering load, ambient temperature, cooling mode, oil time constant and other transformer characteristics. This theoretical top oil temperature is then compares to the measured value of top oil temperature. The difference is weighted and averaged over time to generate a cooling efficiency index. When this value exceeds a configured threshold, a warning is issued.

This model requires an ambient temperature sensor. It provides the following benefit:

- Raise a warning if the transformer is running warmer than it should.

Cooling Control

This model is available on Intellix MO150 only. It complements the control features provided by the transformer manufacturer. Beside the traditional control by top oil temperature and winding temperature, it is now possible to link cooler initiation to the load current thus providing an earlier start when a sudden overload occurs. Moreover the load current rating can be adjusted to follow the seasonal variation of ambient temperature and altitude of the site where the transformer is installed.

For transformers with two cooling banks, a duty sharing function can be initiated to alternate the usage of cooling banks to equalize the wear on bearings and extend the period between fan motor maintenance. A time delay function is available to avoid the two cooling banks from starting at the same time. Moreover, a cooler exercising routine can be used to run the units for a few minutes every week.

Proper operation of the cooling system is also monitored with continuous measurement of pump motor and fan motor current draw by each cooling bank. A malfunction of some elements is to be suspected when the current is significantly below or significantly above the normal value.

This model requires cooling bank current sensors. It provides the following benefits:

- Intelligent cooling control based on, top oil temperature, winding temperature, or load current.
- Cost saving on fan and pumps motor maintenance with duty sharing function.
- Detection of pumps and fans malfunction.

Models in Hydran M2

A model is defined as a specific computation or algorithm, following industry-recognized standards (such as the IEEE and IEC Loading Guides), from which valuable information about the real-time operating conditions of the transformer can be derived.

Each model uses the data received from the sensors connected to the transformer, and makes computations to produce useful transformer information. The model gives results that can be compared with user configurable alarm levels.

Limitation of Models Running Concurrently on Hydran M2

The Hydran M2 is limited to four plug-in ports for 4-20 mA or digital inputs. Thus, at any given time, the total number of models that can run simultaneously on the Hydran M2 is limited based on the four configured inputs. It should be noted that the digital input card is a dual input, thus two of the digital inputs can be configured on one card.

In this matrix, the first three inputs, namely Hydran gas level, Relative Humidity, and Sensor Temperature are included as part of the functionality of the Hydran M2. Of the eleven remaining analog and digital inputs, up to four can be configured to enable models.

	Analog Input											**Digital Input**		
	Hydran gas level (ppm)	Relative Humidity (%RH)	Sensor Temperature (°C)	Top Oil Temperature (°C)	Load Current Winding H (A)	Load Current Winding X (A)	Load Current Winding Y (A)	OLTC Tap Position	OLTC Tank Temperature (°C)	Ambient Temperature (°C)	Bottom Oil Temperature (°C)	Status of Cooling bank #1	Status of Cooling bank #2	Transformer Energized
Transformer Insulation Models														
Winding H Apparent Power					X									
Winding H Apparent Power						X								
Winding H Apparent Power							X							
Winding H Hot-Spot Temperature				X	X									
Winding X Hot-Spot Temperature				X		X								
Winding Y Hot-Spot Temperature				X			X							
Insulation Aging		X	X	X	X									
Water-Oil Condensation Temperature		X	X	X	X									
Moisture Content in Winding Paper		X	X	X	X									
Winding Bubbling Temperature		X	X	X	X									
Winding Bubbling Temperature Margin		X	X	X	X									
Moisture Content in Insulating Barrier		X	X	X	X						X	(X)	(X)	
Cooling System Models														
Cooling System Status												X	X	
Cumulative Operation Time												X	X	
Cooling Efficiency				X	X					X		X	X	(X)
Tap Changer Models														
OLTC Tap Position Tracking								X						
OLTC Temperature Differential				X					X					

Assigning Inputs

The models are dynamically enabled based on the inputs configured.

The inputs to activate the models can be selected from a predefined list during input configuration. The list of analog inputs include:

- Top Oil Temperature
- OLTC Tank Temperature
- Tap Position
- Winding H Current
- Winding X Current
- Winding Y Current
- Ambient Temperature
- Bottom Oil Temperature
- User Defined

The list of digital inputs include:

- Feedback status of cooling bank #1
- Feedback status of cooling bank #2
- Transformer Energized status
- User Defined

Input Alarms:

The inputs top oil, bottom oil and ambient temperature all have input fault alarms that can be enabled or disabled. A lost input connection will produce N/A values for the inputs as well as the corresponding models, thus the input fault alarms will alert the user that the input signal is unavailable.

Available Models

Apparent Power:

The primary function of this model is to continuously monitor the load carried by the transformer in MVA (Mega Volt-Amperes). The Apparent Power can be computed on the Primary, Secondary, and Tertiary windings, depending on the input configuration. The historic maximum MVA value is retained with a timestamp and can be reset by the user.

The current signal is a mandatory input, whereas the voltage signal is configured as a fixed value. Since voltage variations occurring in service and tap changer operations are not taken into consideration, the MVA is an approximate reading, and used only for display.

Required Inputs:

- Load current on Winding H
- Load current on Winding X (optional)
- Load current on Winding Y (optional)

Outputs:

- Winding H MVA
- Historic Maximum Value of load on H winding with a time stamp. Load is expressed in Per Unit of rated current (P.U.) This value is resettable by the user
    - o
- Winding X MVA (if load current X is configured as an input)
- Historic Maximum Value of load on X winding with a time stamp. Load is expressed in Per Unit of rated current (P.U.) This value is resettable by the user
    - o
- Winding Y MVA (if load current Y is configured as an input)
- Historic Maximum Value of load on Y winding with a time stamp. Load is expressed in Per Unit of rated current (P.U.) This value is resettable by the user

Winding Hot-Spot Temperature Model:

The rating of a transformer is closely linked with the winding temperature as it governs the insulation-aging rate and bubbling release threshold. The winding temperature can also raise alarm if excessive values are taking place. In the industry standards, the winding temperature limits is defined as a temperature rise above the ambient air temperature. The cooling system is design to insure that at full load, the average winding temperature rise do not exceed the value accepted in the industry (usually 65°C).

However it is not the average winding temperature that is of most interest but rather the temperature in the hottest area (so called "hot-spot temperature"). This temperature cannot be measured directly as it is not possible to insert thermocouples in a winding that is to be put in service. It is possible to use fiber optic temperature sensors that do not interfere with dielectric strength but this procedure is costly and is usually limited to the validation of the manufacturer calculation methods. Therefore the traditional method was to use a Winding Temperature Indicator to fulfill that function.

Using the equations provided in IEEE and IEC loading guides, a more accurate and reliable evaluation of the hot spot temperature can be provided.

A key value is the temperature difference between winding hot spot and top oil at rated condition. The transformer manufacturer normally provides this value after suitable validation of their calculation method. In the Winding Hot Spot model, this rated value is corrected to account for actual load current and winding thermal time constant. The calculated hot spot temperature rise is then added to the measured top oil temperature to provide the actual winding hottest spot temperature.

The winding hot-spot temperature is calculated separately for each winding. The highest value of Winding Hot-Spot Temperature is identified and used to raise alarm signal on the transformer and also to control stage 2 and stage 3 of the cooling system. The hottest winding might not always be the same, depending on the load on the tertiary winding and on the position of the tap changer.
For Autotransformers the Winding Hot Spot Temperature is calculated for Series Winding (H), Common Winding (C) and Tertiary Winding (Y). The current in the common winding is calculated by subtracting secondary load current minus primary load current

Required Inputs:

- Top Oil Temperature
- Load current on Winding H

- Load current on Winding X (optional)
- Load current on Winding Y (optional)

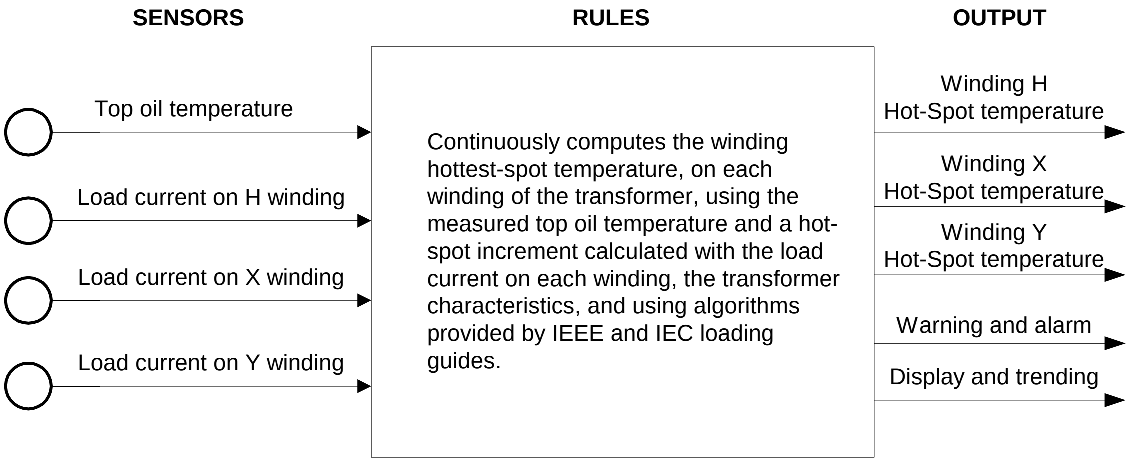
Outputs:

- Winding Hot-Spot Temperature in Winding H
    - Historic Maximum for Winding H Hot-Spot Temperature
    - Timestamp of Historic Maximum for Winding H Hot-Spot Temperature
- Winding Hot-Spot Temperature in Winding X (if load current X is configured as an input)
    - Historic Maximum for Winding X Hot-Spot Temperature
    - Timestamp of Historic Maximum for Winding X Hot-Spot Temperature
- Winding Hot-Spot Temperature in Winding Y (if load current Y is configured as an input)
    - Historic Maximum for Winding Y Hot-Spot Temperature
    - Timestamp of Historic Maximum for Winding Y Hot-Spot Temperature
- Winding Hot-Spot Temperature in Winding C (if load current C is configured as an input and Transformer type is Autotransformer)
    - Historic Maximum for Winding C Hot-Spot Temperature
    - Timestamp of Historic Maximum for Winding C Hot-Spot Temperature
- Highest Winding Hot-Spot Temperature
- Highest Winding Hot-Spot Temperature Source Winding

Alarms:

- Winding Hot Spot Hi Alarm
  A Hi alarm is available on the calculated winding hot spot temperature. This alarm is sensitive to all winding being monitored and will react to the hottest winding temperature. This value is configurable from 70 to 170°C and the system default value is 110°C, as this is the rated temperature for thermally upgraded paper. This alarm comes with a dead band configurable from 0 to 15°C (default: 2°C) to avoid oscillation of alarm signal. A time delay, configurable from 0 to 30 minutes (default: 1 min) is also provide for the same purpose.

- Winding Hot Spot Hi-Hi Alarm
  A Hi-Hi alarm is available on the calculated winding hot spot temperature. This alarm is sensitive to all winding being monitored and will react to the hottest winding temperature. This value is configurable from 70 to 170°C and the system default value is 120°C. This alarm comes with a dead band configurable from 0 to 15°C (default: 2°C) to avoid oscillation of alarm signal. A time delay, configurable from 0 to 30 minutes (default: 1 min) is also provide for the same purpose.



Continuously computes the winding hottest-spot temperature, on each winding of the transformer, using the measured top oil temperature and a hot-spot increment calculated with the load current on each winding, the transformer characteristics, and using algorithms provided by IEEE and IEC loading guides.

Insulation Aging Model:

Winding insulation is made of oil-impregnated cellulose material in order to properly fulfill its function, this material needs to have a certain mechanical strength and flexibility. These properties are dependent on the length of the cellulose chain constituent of the paper and pressboard. With time and temperature, these long polymer chains break down into shorter segments, a process called depolymerization. The practical effect is that the paper loses its flexibility and tensile strength to become a brittle material. The winding is continuously submitted to clamping forces and vibrations. Moreover, during short-circuit on the system, these forces are increased tremendously and if the insulating paper is too brittle, it may rupture under the pressure and create a weak point in the insulation that will later allow flashover between adjacent turns when a voltage surge occurs on the transformer.

This insulation aging process is irreversible. It is also the main factor determining transformer end of life. The rate of aging of cellulose insulation material is a function of the following factors:

- Insulation temperature at the hot spot
- Water content in the winding insulation paper
- Oxygen content of insulating oil

The effect of temperature is the most important, as described in the IEEE and IEC loading guides. The effect of temperature on aging is a function of the type of paper. It is therefore important to state in the configuration page the type of paper used for winding insulation.

A second factor affecting insulation aging is the moisture content. It is assumed that the aging acceleration factor is directly proportional to the water content with 0.5% as reference value for dry paper. The water content in winding insulation is calculated in the Moisture Content in Insulation Model. The effect is more severe on the normal Kraft paper than on Thermally Upgraded paper and it can be practically neglected on Aramid paper.

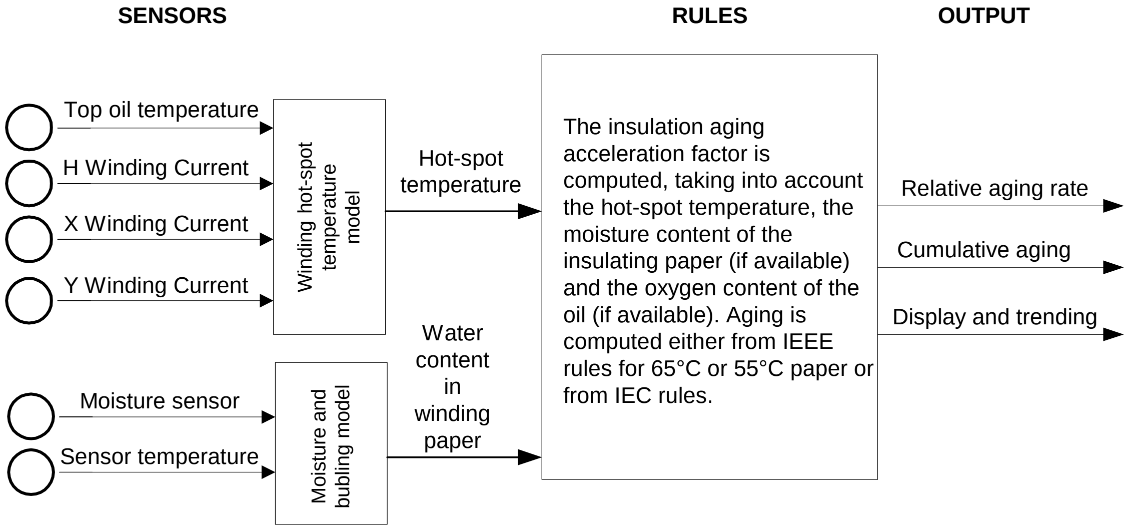
The third factor is the oxygen content of insulating oil. This oxygen content can be inferred from the type of oil preservation system. IEEE loading guide recommend using an aging acceleration factor of 2.5 for free breathing conservators while the sealed type transformers and those with a membrane in the conservator are practically oxygen free

Required Inputs:

- Top Oil Temperature
- Load current on Winding H
- Load current on Winding X (optional)
- Load current on Winding Y (optional)

Outputs:

- Thermal Aging Acceleration Factor
- Moisture Aging Acceleration Factor
- Global Aging Acceleration Factor
- Cumulative Aging



The insulation aging acceleration factor is computed, taking into account the hot-spot temperature, the moisture content of the insulating paper (if available) and the oxygen content of the oil (if available). Aging is computed either from IEEE rules for 65°C or 55°C paper or from IEC rules.

Moisture and Bubbling:

Moisture content of oil and solid insulation is a serious concern for power transformers especially for aging units. Extensive drying procedures are applied at the manufacturing stage and sustained efforts are deployed in service to maintain a high level of dryness. However with time, water can penetrate through various paths such as air breather and leaky gaskets. Aging of cellulose also release some water. Moisture tends to accumulate in solid insulation and leads to several detrimental consequences, namely:

Acceleration of insulation aging
Risk of water vapour bubbles being released from the winding insulation
Reductions of dielectric strength of insulating barriers
Risk of water condensation in transformer oil at low temperature

Moisture content assessment is often derived from a single oil sample submitted to a Karl Fischer test in laboratory. This is a valid approach for oil evaluation but it do not allows evaluation of moisture content in solid insulation as the rate of water exchange between oil and paper as to be taken into account. On-line monitoring of moisture in oil allows integration of temperature variations and the computation of a dependable value for moisture content in the various components of the solid insulation system even if they are at different temperatures and characterized by different diffusion rates.

The most critical part of the winding insulation is the top of the winding that operate at the hot-spot temperature. This is the area where the aging is most severe and the effect of water content can be computed. The determination of critical temperature for bubble evolution takes into account atmospheric pressure, oil pressure above hot-spot area and the amount of gas dissolved in oil.
The moisture sensor continuously monitors the relative moisture saturation in the oil and the temperature of oil at the sensor location. A filtering is applied to remove effect of cyclic heating created by the sensor to ensure oil circulation. This filtered value is used to calculate the absolute value of water content in oil, the temperature of water condensation and the relative saturation at the reference temperature.

Since oil and winding temperature varies continuously, this moving target is used with an integrating algorithm taking into account diffusion time constant and temperature.
The calculated value of water content in winding insulation allows prediction of bubbling temperature. It is also used in the insulation-aging model.

Required Inputs:

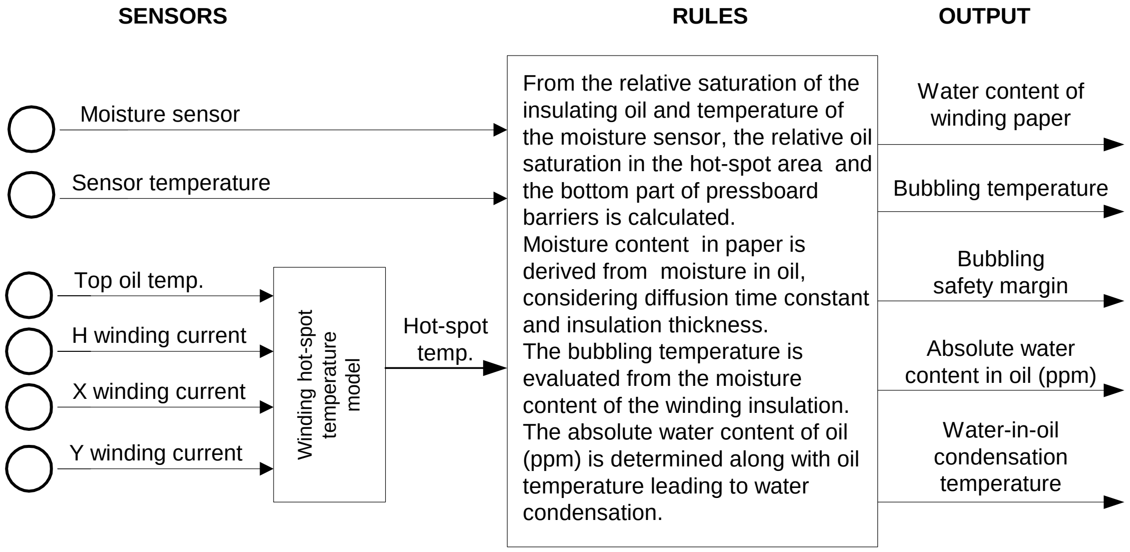
- Top Oil Temperature
- Load current on Winding

Outputs:

- Water-Oil Condensation Temperature
  This is the critical temperature (°C)for the formation of free water in insulating oil when a wet transformer is allowed to cool down rapidly. If the water dissolved in the oil does not have sufficient time to migrate back to the cellulose insulation, droplets of free water may precipitate in the oil. This create a hazard for dielectric failure should the transformer be reenergized in this condition.
- Moisture Content in Winding Paper
  This value is expressed in percentage weigh by weight.
- Moisture Content in Winding Paper Valid Delay
  Migration of moisture between oil and paper is a slow process governed by moisture content, and diffusion time constant. At system commissioning it is not possible to provide immediately a value of moisture content in paper. Data may need to be integrated over several days or week before a reliable value can be displayed. This delay is calculated considering current temperature conditions and time elapsed since the system was commissioned.
- Winding Bubbling Temperature
  Residual moisture in the winding insulation can release free gas bubbles if the hot-spot temperature is too high or increasing rapidly. The bubble inception temperature is function of moisture content in paper and also oil pressure and partial vapour pressure in the area of the winding hot spot.
- Winding Bubbling Temperature Margin
  This is the difference between the bubbling inception temperature and the actual winding hot spot temperature.

Alarms:

- Water-Oil Condensation Temperature Alarm
  This alarm is normally set to alert the operator when the condensation temperature is above the minimum temperature that can be observed on the transformer, should it be suddenly remove from service. This value can be configured from -40°C to +20°C with a default value of -20°C.
- Bubbling Temperature Margin Alarm
  A significant margin should be maintained at all time to avoid occurrence of free bubbles circulation in the cooling oil. This margin can be configured from 0 to 50°C with a default value of 20°C



Moisture Content in Insulating Barrier:

Moisture content in solid insulation can reduce significantly the dielectric strength of components submitted to high electric field. This effect is especially critical for partial discharges inception on barriers that provide insulation between windings and that can be submitted to tangential electric field.
The most critical pressboard barriers are at the bottom oil temperature because this is the coolest area and this is where the moisture content in solid insulation will be the highest. A sensor providing a measured value of the bottom-oil-temperature must be connected as an input.

Knowing the bottom oil temperature, the relative oil saturation in this area can be calculated and the oil to paper equilibrium curves provide an ultimate value of moisture in paper is those condition would be maintained continuously.

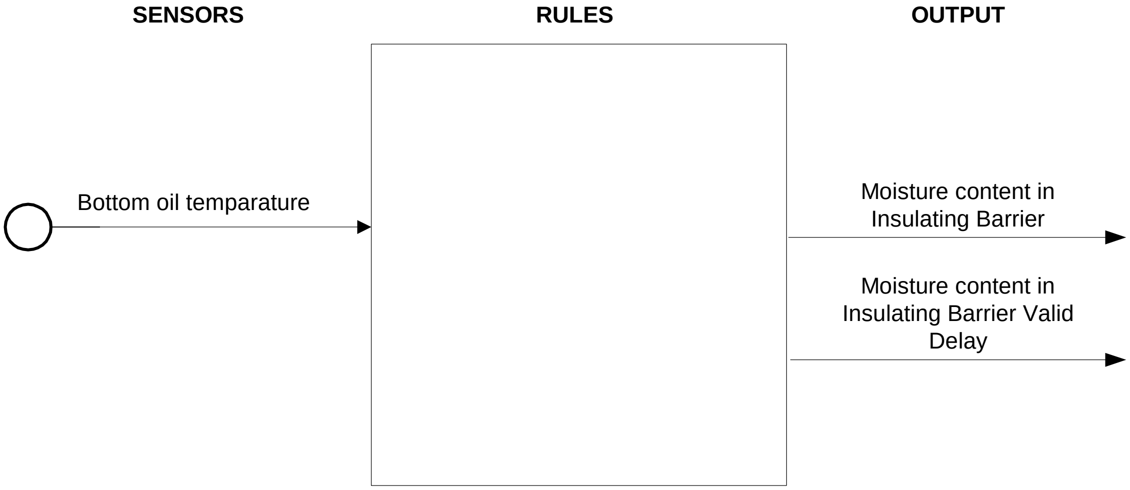
The value of water content in pressboard barriers can be used to evaluate reduction of dielectric strength of this component.

Required Inputs:

- Bottom Oil Temperature

Outputs:

- Moisture Content in Insulating Barrier
- Moisture Content in Insulating Barrier Valid Delay



Cooling Efficiency:

This model computes the top-oil temperature that should be expected considering the load current, the ambient temperature, the cooling mode, the oil time constant and the altitude. The calculated value is then compared with the measured value and an alarm will be raised if the transformer is found to be overheating. This calculation allows for the detection of obstructions, such as dirt on the coolers, which could be a limiting factor when the transformer is required to operate at full load or under overload conditions.

During the initial model computation, the measured values of top-oil temperature and ambient temperature are used to provide a starting point for the calculated value of top oil temperature rise. From then on, the calculated temperature at the end of the time interval is used as the initial temperature for the next time interval. This calculation is run with load current in the H winding only. The rated current for each cooling stage is calculated from rated power on each stage and rated current on top cooling stage.

Ultimate temperature rise and current temperature rise are calculated considering the actual cooling stage and the actual oil time constant. This value is added to the ambient temperature to provide a calculated top oil temperature. This value is subtracted from the measured top oil temperature and

the difference is averaged over a configurable period. An alarm is raised when the difference exceeds a configured value for a period of time that is also configurable.
The model can accommodate a transformer with one, two or three cooling stages.

In the calculation of top oil temperature it is important to remove the core losses from calculation if the transformer is not energized. Otherwise a false alarm could be generated.

Required Inputs:

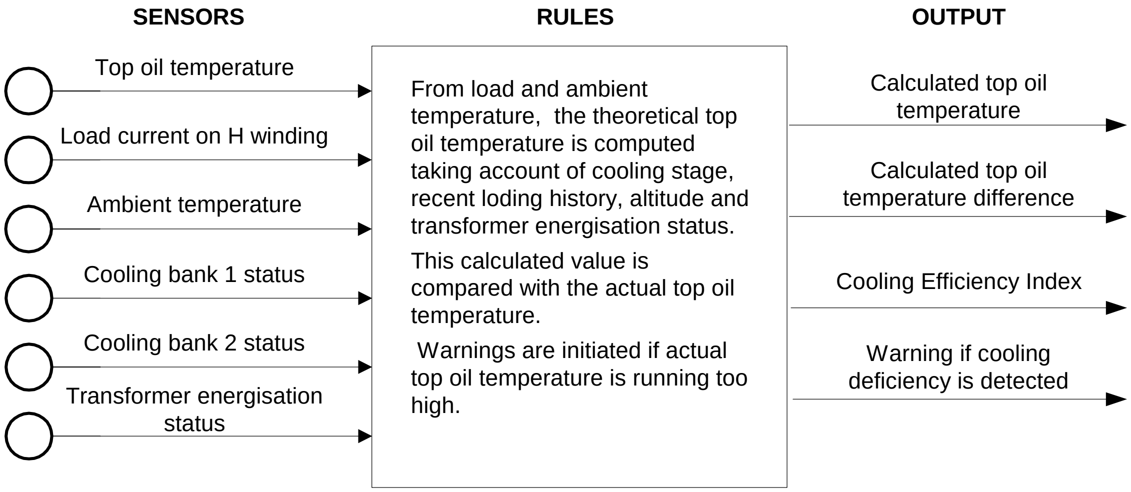
- Top Oil Temperature
- Load current on Winding H
- Ambient Temperature
- Feedback status of cooling bank #1
- Feedback status of cooling bank #2
- Transformer Energized status

Outputs:

- Calculated Top Oil Temperature
- Calculated Top Oil Difference
- Calculated Bottom Oil Temperature (if bottom oil temperature not available as input)
- Cooling Efficiency Index

Alarm:

- Cooling Efficiency Index Hi alarm
  This alarm indicates that the transformer is operating at higher temperature than it should, considering the recent load and recent ambient conditions. Although it does not present an immediate threats for transformer life duration, it indicate that the cooling system is not performing as it should and could mean excessive temperature if the transformer is requested to operate at full load or under overload condition.



From load and ambient temperature, the theoretical top oil temperature is computed taking account of cooling stage, recent loding history, altitude and transformer energisation status.

This calculated value is compared with the actual top oil temperature.

Warnings are initiated if actual top oil temperature is running too high.

Cooling Status:

The digital indication of cooling bank status can be used as prime source of information. Transformers usually have two or three ratings related to the three different cooling modes. The lowest rating is defined as “Cooling Stage 0” and usually applies to the natural cooling of the transformer tank without any fan or pump. Similarly, cooling stages 1 and 2 implies the starting of fans or pump that increase the cooling capacity.

Since permutation of fan operation is intended, activating either Bank 1 or Bank 2 enables Cooling Stage 1. The Cooling Stage 2 implies that both Bank 1 and Bank 2 fans are activated.

Some transformers (such as GSU indoor) have only one cooling mode i.e. whenever the transformer is energized, the full cooling is automatically initiated. These units are treated as having only Cooling Stage 0.

Required Inputs:

- Feedback status of cooling bank #1
- Feedback status of cooling bank #2
- Transformer Energized status

Outputs:

- Current Type of Cooling
  Display the type of cooling (cooling mode)presently in service.
- Cooling Status on (Present Cooling Stage)
  Displays the cooling stage presently in service
- Cooling Bank1 Feedback Status
  Current status of cooling bank no 1
- Cooling Bank2 Feedback Status
  Current status of cooling bank no 2
- Cooling Stage 0 Total Activity Time
  This output value shows the total cumulative time (since system commissioning) that the transformer has been operated without any cooling bank.
- Cooling Bank1 Total Activity Time
  This output value shows the total cumulative time (since system commissioning) that the transformer has been operated without any cooling bank.
- Cooling Bank2 Total Activity Time
  This output value shows the total cumulative time (since system commissioning) that the transformer has been operated without any cooling bank.
- Cooling Stage Activated
  Displays the cooling stage presently in service
- Cooling Bank1 Activated
  Indicate whether bank 1 is currently activated
- Cooling Bank2 Activated
  Indicate whether bank 1 is currently activated

OLTC Position Tracking:

Tap changer driving mechanisms are always provided with a visual tap-position indicator and a counter indicating the total number of operations. This model provides additional information that is useful to monitor the proper operation of this critical device, such as:

- The cumulative number of visit to each tap since commissioning
- Resettable variables for operation and maintenance counts
- Warnings for excessive number of operations over a certain period
- Time spent since last operation of the reversing switch and a warning to avoid contact cooking because of insufficient operation

A position transducer, driven by the visual indicator shaft (also called Geneva shaft), provides a 4-20mA signal that is proportional to the tap changer mechanical position. The multi position switch can be equipped with jumpers (instead of resistors) in the "Through Positions" where the tap position indicator will stay only momentarily during operation of the reversing switch. In this case, the potentiometer provides an indication of the electric position of the tap changer. When the tap changer operates, the signal should remain steady, until it changes to a new value without falling to zero.

It is assumed that the Geneva shaft rotates by a fix value for each step on the transducer. The signal from the Geneva shaft position transducer is read at a regular interval and is analyzed to determine the actual position of the visual position indicator.
The position generated may refer to the mechanical position of the Geneva gear or the electrical position. In the first case, the conversion from mechanical to electrical position is done considering the number of through positions specific to this tap changer when it moves to the neutral position.

The number of visit to each tap position is presented by histograms using the tap position denomination configured by the user. The system provides three separate registers to record the number of operations carried out by the tap-changer.

The Permanent Tap Position Transition Count is intended to be the summation of all operations since the commissioning of the system. However, if the monitoring system is moved to a different transformer, the system administrator can reset this value to zero.
This counter provides the number of operations on each tap position; the total number of operations and the date when the system was put is service. The total number of operations performed prior to the commissioning of the system can also be taken into account.

The Operator Tap Position Transition Count can be reset by the operator when there is need to check the number of operations in one or several days to demonstrate that the tap changer control unit is operating properly. This counter provides the number of operations on each tap position, and the maximum and minimum position visited by the tap changer since the last reset, as well as the date of last reset.

This Maintenance Tap Position Transition Count is used by maintenance personnel to assess the need for maintenance and to plan maintenance schedules. It will be typically reset every 3 or 4 years when an inspection activity is preformed on the unit. This counter provides the number of operations on each tap position, and the maximum and minimum position visited by the tap changer since the last reset, as well as the date of last reset.

Required Inputs:

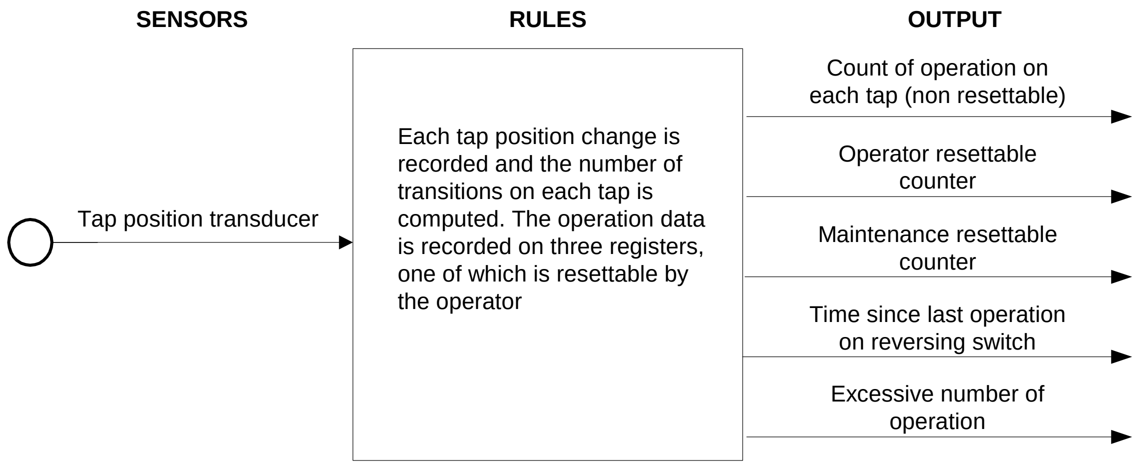
- Tap Position Indication Signal

Outputs:

- Actual Tap Position
- Elapsed Time since last Maintenance reset
- Elapsed days since last Reversing switch operation
- Last Hour Operation Count
- Last Day Operation Count
- Last Permanent Tap Position Reset Time Stamp
- Permanent Tap Position Transition Count
- Permanent Count for Positions 1-35
- Last Operator Tap Position Reset Time Stamp
- Operator Tap Position Transition Count
  - Historic Min for Tap Position
  - Historic Min Timestamp for Tap Position
  - Historic Max for Tap Position
  - Historic Max Timestamp for Tap Position
- Resettable Count for Positions 1-35
- Last Maintenance Tap Position Reset Time Stamp
- Maintenance Tap Position Transition Count
  - Historic Min for Maintenance Tap Position
  - Historic Min Timestamp for Maintenance Tap Position
  - Historic Max for Maintenance Tap Position
  - Historic Max Timestamp for Maintenance Tap Position
- Maintenance Count for Positions 1-35

Alarms:

- Number of operations since last Maintenance
  This alarm indicate that the number of operation since the last maintenance has exceeded the set point
- Elapsed Time since last Maintenance
  This alarm indicates that the time elapsed since the last maintenance has exceeded the set point.
- Days Elapsed since last Reversing Switch Operation
  This alarm indicate that the time elapsed since the last operation of the reversing switch has exceeded the set point
- Maximum Number of Tap Operations per Hour
  This alarm indicate that the number of operation per hour has exceeded the set point
- Maximum Number of Tap Operations per Day
  This alarm indicate that the number of operation per day has exceeded the set point



OLTC Temperature Differential:

The On-Load Tap Changer (OLTC) Temperature model continuously compares the top oil temperature in the main tank with the tap changer compartment temperature. Monitoring of tap changer temperature is a recognized method of detecting abnormal operating conditions in the tap changer. This monitoring method is intended for tap changers mounted on a separate compartment on the transformer tank. The tap changer temperature is normally lower than the main tank because no heat source is expected in the tap changer. If the tap changer temperature rises above the main tank temperature it is indicative of an overheating contact.

The temperature difference is calculated by subtracting the tap changer temperature minus the main tank temperature, thus yielding a negative value. This method allows for setting of the alarm on a positive threshold value rather than a negative value. This temperature difference is averaged with a low pass filter to eliminate normal variations arising from sunshine and wind.

A short-term averaged value is generated with a configurable filtering factor typically set at 60 minutes. This short term average is intended to detect severe heat sources such as resistor overheating when the mechanical links break while the switches is in-between two contacts.

A long-term averaged value is generated with a configurable filtering factor typically set at 7 days. This long-term average is intended to detect slow evolving thermal problems such as contact overheating. The measured temperature difference is averaged over a round number of days to filter out the daily temperature variation.

Required Inputs:

- Top Oil Temperature
- OLTC Main Tank Temperature

Outputs:

- OLTC Differential Temperature
- Short Term Average of Tap Changer Temperature Differential
- Long Term Average of Tap Changer Temperature Differential

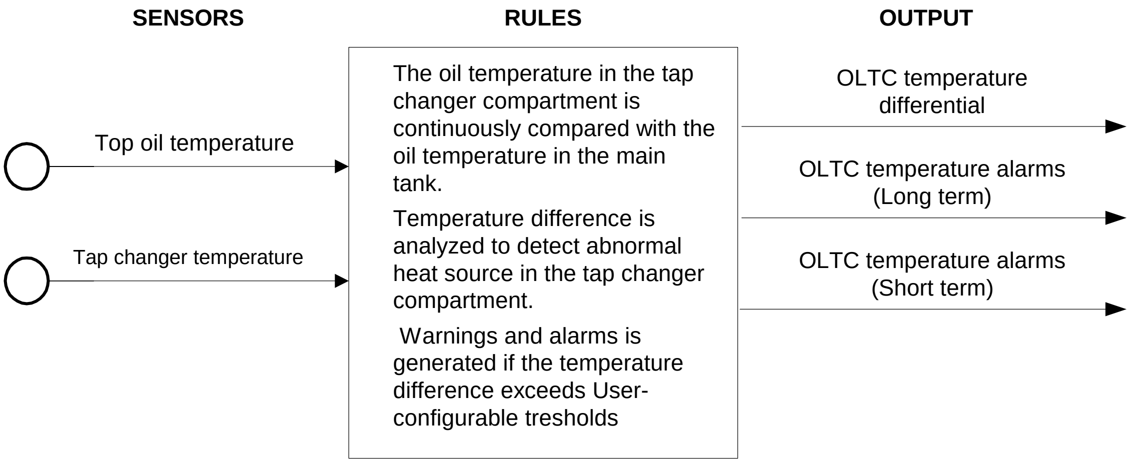
Alarms:

- OLTC Short Term Temperature Differential Hi Alarm
  A tap changer running 5°C above the main tank should be closely monitored. This value is configurable from 0°C to 30°C.

- OLTC Short Term Temperature Differential Hi-Hi Alarm
  A tap changer running 15°C above the main tank is a serious concern. This value is configurable from 0°C to 40°C.

- OLTC Long Term Temperature Differential Hi Alarm
  A tap changer running continuously 3°C above the main tank should be closely monitored. This value is configurable from 0°C to 20°C.

- OLTC Long Term Temperature Differential Hi-Hi Alarm
  A tap changer running continuously at 10°C above the main tank is serious concern. This value is configurable from 0°C to 30°C.



The oil temperature in the tap changer compartment is continuously compared with the oil temperature in the main tank.

Temperature difference is analyzed to detect abnormal heat source in the tap changer compartment.

Warnings and alarms is generated if the temperature difference exceeds User-configurable tresholds