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Power Transformer Management through Integrated Monitoring & Diagnostics in Protection Relays

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imagination at work

Introduction

Whether in an industrial or utility application, power transformers are among the most critical assets of any power system required to maintain the reliable and efficient flow of electricity. Condition and risk assessment of these valuable assets is needed more than ever. With the average age of a transformer fleet over 40 years and new transformer fleets experiencing a greater than expected failure rate, a proactive approach to transformer monitoring is required. With 52% of transformer failures caused by insulation degradation, aging and electrical abnormalities such as through faults, extending the life of these devices through early detection or even prediction of these failure models has become a top priority for power system engineers.[1]

Traditionally, electromechanical or single function protection devices provided continuous measurement of a transformer's electrical parameters (primarily currents and voltages which lead to the detection of ground fault or overload conditions). As technology has evolved, protection relays have become more intelligent, integrating multiple protection and control functions and offering advanced communications and monitoring capabilities.

Advanced protection relays now detect and notify operators of internal or external faults, collect and record electrical data, and perform pre- and post-fault analysis using high accuracy transient records and fault reports. Transducer inputs can be added to measure temperature, pressure, cooling system characteristics, and tap changer positions, among other environmental and mechanical parameters. By combining digital inputs with various other interlocks and alarms, the relay is able to gather significantly more holistic sensor inputs from the transformer.

Integrated Approach to Asset Protection

These critical assets require more than just electrical measurement for protection and control; a transformer's insulating oil must also be monitored for abnormal conditions. Historically, this type of chemical monitoring involved asset management teams dispatching a technician to each transformer to take oil samples. These samples were sent to a lab for analysis and a condition report issued. As technology evolved, online dissolved gas analysis (DGA) devices were introduced, capable of drawing oil samples on their own on a regular basis. These devices get connected to communication networks, allowing asset managers to remotely collect and monitor the transformer's heath condition.

These two distinct systems (electrical protection and DGA devices) traditionally have not been interconnected. Yet since both systems provide much-needed asset and performance management data, there is an opportunity to bring them together to provide a more comprehensive view into the transformer's overall health condition. This integrated approach of two systems, (one protection relay with electrical functions; and the other DGA device with chemical analysis) allows the trending of incipient fault events with the same timestamps, correlation between the electrical and chemical models, and integrated asset health analysis and reporting.

This solution is one way to help bridge the gap that currently exists between the protection & control and asset management teams, allowing them to operate and monitor transformers more effectively. It also provides various tools to optimize transformer operation and maximize device life.

Recognizing this opportunity, GE's R&D team designed a transformer protection relay that is capable of integrating with DGA devices, such as GE's Kelman single and multi-gas DGAs. The protection relay imports the chemical data from the DGA device(s) at regular time intervals, which in turn provides time correlation of chemical, electrical and thermal signals for actionable intelligence to optimize asset performance and life.

The Multilin™ 845 Transformer Protection System, a member of the Multilin 8 Series protective relay platform, has been designed for the protection, control and asset management of 2- and 3-winding power and distribution transformers in both utility and industrial applications. It provides advanced functionality for a wide range of transformer applications delivering high-speed protection, customizable programmable logic, advanced transformer monitoring and diagnostics, and support for the latest communications protocols for easy integration into new or existing power systems.

The Multilin 845 also delivers comprehensive transformer health monitoring, diagnostics, and reporting with integrated connectivity to GE's composite and multiple gas transformer DGA solutions.

GE's line of advanced composite gas (single- or multi-gas) DGA devices including the Hydran, Kelman Transfix, and Multitrans, provide essential, precise on-line monitoring of fault gases within power or distribution transformers. Utilizing specifically developed photo-acoustic detection technology, GE's Kelman Transfix is capable of measuring up to 9 gases (including hydrogen, methane, ethane, ethylene, acetylene, carbon monoxide, carbon dioxide, nitrogen, and oxygen), plus moisture. Detailed diagnostics of these measured gases is provided based on IEEE & IEC standards, enabling operators to quickly assess the transformer's condition and health.

With the chemical, electrical and thermal data all available within the 845, aligned over timestamp, power engineers and asset management teams now have the ability to monitor a much broader range of factors in a transformer on a real-time, continuous basis. These teams can zoom in when there is either an internal or external fault in order to understand whether the fault event has caused or initiated a specific failure mode in the transformer. Both condition-based and event-driven monitoring is possible with this integrated protection model.

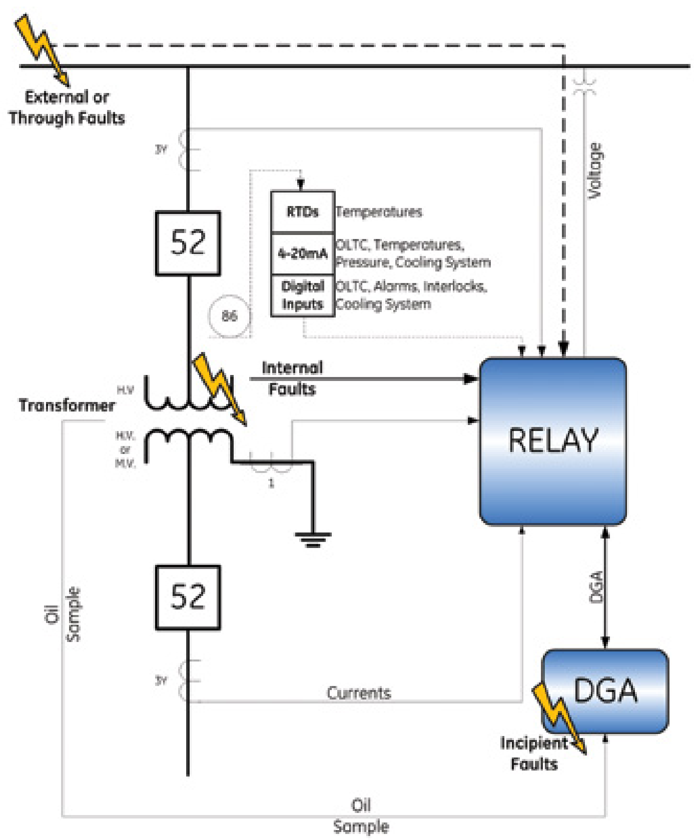


Figure 1: Convergence of electrical protection and chemical monitoring.

Applying Monitoring and Diagnostic Capabilities to a Wide Range of Transformers

Transformer monitoring and diagnosis is scalable, depending on the type of transformer. For small dry-type transformers, basic monitoring is likely all that is required, including breaker monitoring, harmonics, THD and RTD. For medium-sized oil-filled transformers, there's a need for more standardized IEEE®/IEC®-based modelling of hot spot temperature, aging factor or degradation of life in the transformer.

However, for larger size mid- to high-end power transformers, distribution transformers, and critical assets, operators require all standard monitoring, plus additional elements. These include historical records, energization characteristics, transformer health reports and transformer models, as well as integrated DGA analysis. Again, the additional functionalities available in today's Multilin 845 can provide this more comprehensive data collection, allowing greater scalability of the monitoring and diagnostic solution.

The applications that can be built on this more holistic, integrated approach include electrical models, DGA models, energization records, integrated fault report and health reports.

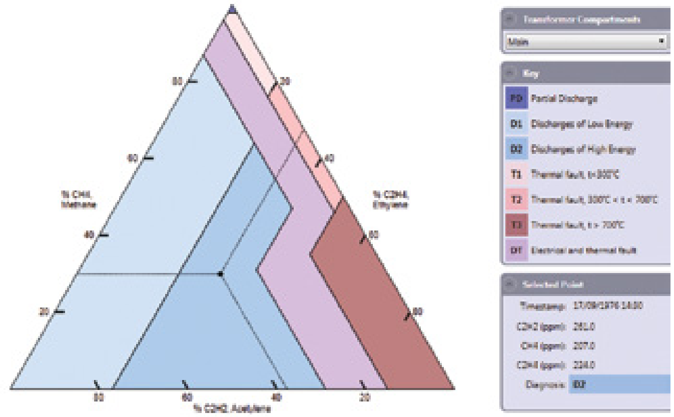
Electrical models

In addition to continuously measuring voltages and current, protection relays such as the 845 measure numerous critical electrical parameters, including over-excitation and flux conditions. This allows operators to see loading imbalances and averages, including seasonal averages, average loading from one particular condition to another, or average loading for parallel or unparalleled conditions. For each of these different operational scenarios, the 845 relay captures the electrical characteristics of the transformer and stores this data for a short- or long-term view. Data can be stored for up to one year of data within the relay, creating a repository of transformer behavior and modeling it. These models depict specific behaviors and help in correlating various electrical data sources to identify trends.

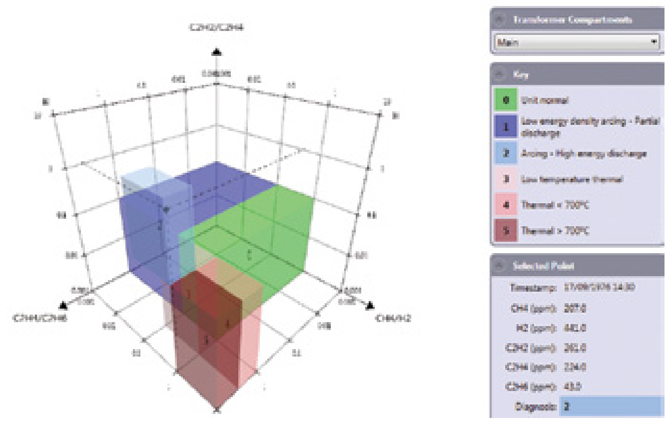
Dissolved Gas Analysis models

The 845 can be connected to many of GE's DGA devices – Hydran, Mini Trans, DGA 500 and Transfix. Depending on whether the DGA device is a single gas or multi-gas analyzer, several standard gas analyzer models exist that conform to IEC and IEEE standards, including the Duval triangle, gas ratios, and key gas, as illustrated in Figure 2. These allow data to be extracted from the DGA device and imported into the protective relay for storage, historical data and representation using these standard tools. Regardless of the model or combination of models used, this data can detect the nature of an incipient fault condition that is evolving inside a transformer.

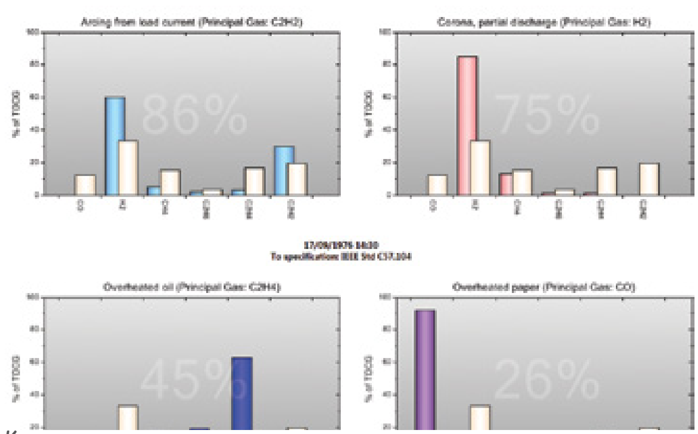
The integrated approach offered by the 845 eliminates the need for offline DGA analysis. When the DGA device is connected to the 845, the relay imports the chemical data on an ongoing basis, compiling reports, and presenting the analysis back in a practical, actionable fashion. This reduces reliance on offline experts and laboratories; the data is readily available in the system. This type of continuous monitoring can show a transformer fault's characteristics moving from one point to another, as well as the rate of change of gas concentrations. This is a powerful tool in understanding the speed at which degradation or a fault condition is evolving.



Duval triangle



Gas ratios



Key gas

Figure 2: DGA models help provide clear indication of changes that may signal an evolving incipient fault condition in transformers.

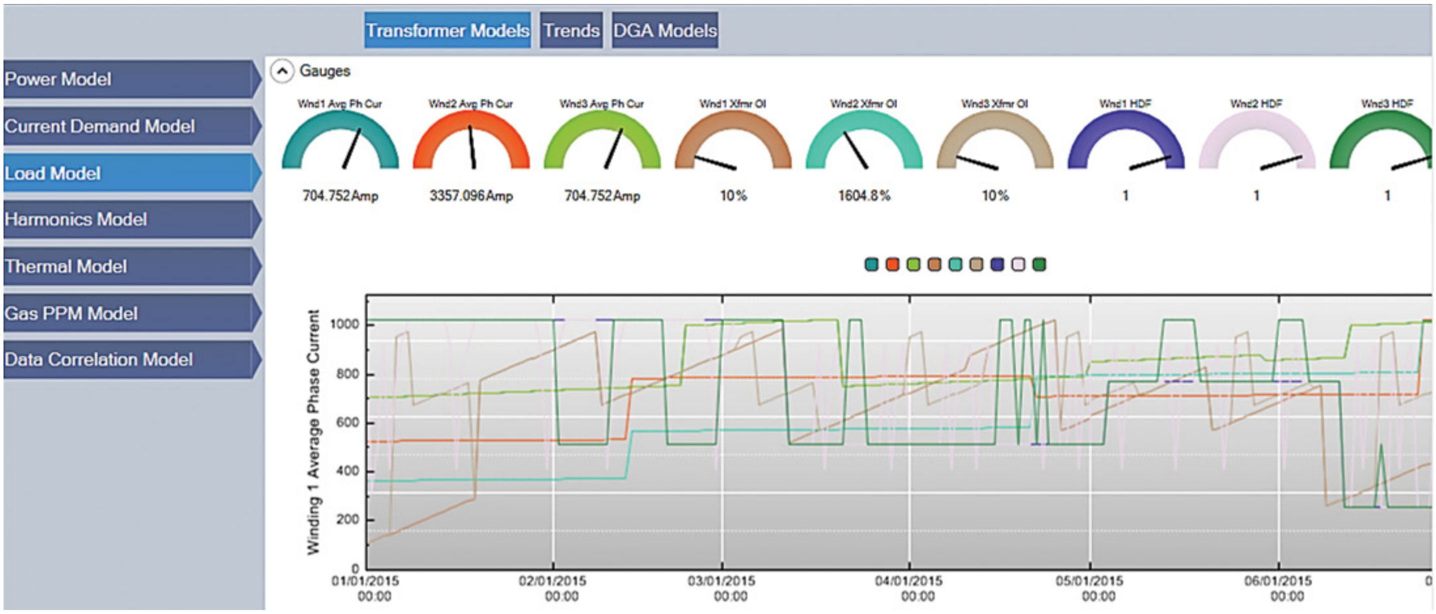


Figure 3: The 845 protection transformer relay tracks and models numerous critical electrical parameters, providing simplified data analytics from ready-to-read monitoring data.

Data correlation models

These models provide the ability to correlate electrical, chemical and thermal data, allowing for the creation of individual trending models. Such models help identify correlations between different but inter-related sets of data, such as a record of transformer loads compared to gas concentration data. A correlation model will help spot, for example, that a gas concentration is occurring every time a transformer is loaded in a particular way. This model can then be used to track transformer load, temperature, and gas concentration changes in order to identify any relationship between one measure and another. This in turns allows operators to proactively safeguard transformer assets, extending the time before a shut-down for maintenance or decommissioning is required.

Energization record

During energization, a transformer goes through tremendous stress, experiencing significant inrush current and application of voltage. Every time a transformer is energized, the 845 protection relay captures a snapshot view of what is happening inside the transformer during the event. That data is assembled into an energization record that includes such measures as:

- Current and voltage samples for initial cycles as shown in Figure 4
- Inrush parameters:
  - Peak inrush current
  - Max voltage dip
  - Volts/hertz
  - 2nd and 5th harmonics

This is a particularly valuable tool when working with aged transformers. In this type of transformer, incipient fault conditions can start developing when the asset is energized. A protection relay can provide an accurate representation of energization behavior of the various inrush parameters. This allows the benchmarking of a healthy energization condition that helps determine any deviations from one event to another. In addition to being an invaluable instrument in the commissioning of new transformers, this record is an excellent recommissioning tool, capturing and analyzing data for a transformer after repair. In addition, energization data acts as baseline data during specific operational cycles until next energization event.

Integrated transformer fault report

When a protective relay detects an internal fault, it trips the transformer. External or through faults, however, can result in high current flow through the transformer prior to the fault being cleared, causing significant stress on the transformer. A typical distribution utility experiences about 15 to 20 through faults each year, even in advanced distribution systems. Research demonstrates that many transformers that fail catastrophically start showing indications of problems immediately following a through-fault event.[2] Developing situations such as these are more easily detected with visibility into pre- and post-fault electrical, chemical and thermal data. In the 845, this data is delivered via the user-friendly integrated transformer fault report (Figure 5). This graphical fault report can provide clear visual indication of the fault condition and any changes to the transformer's health.

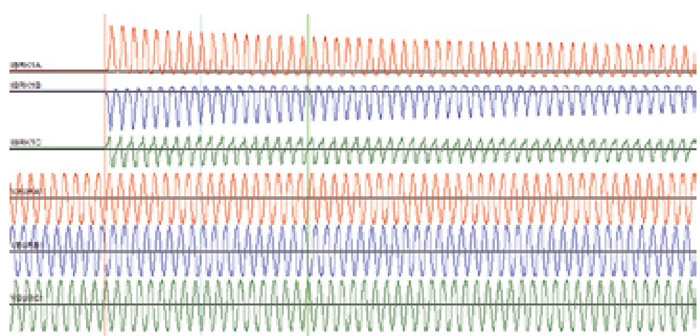
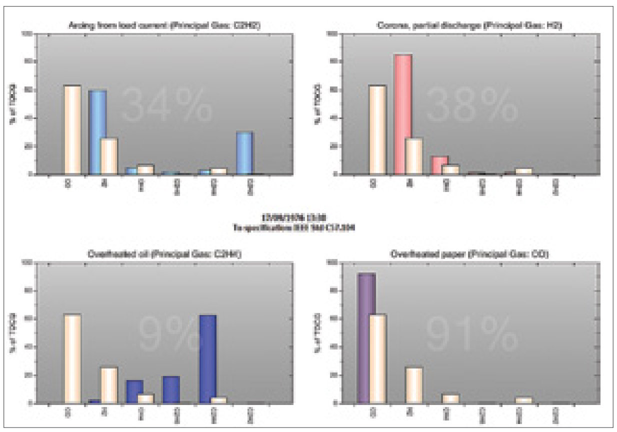


Figure 4: The energization report provides an accurate capture of transformer energization, allowing operators to see baseline behavior in a transformer and compare it throughout the operational life of the asset.

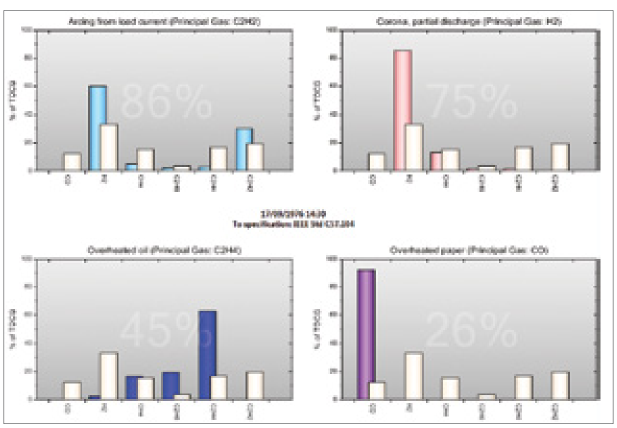
For example, analysis of the data provided during through-fault conditions allows the transformer protection device to estimate the amount of electrical stress applied to the transformer during the event. This estimate - which takes into account cumulative through fault stress, thermal and insulation condition monitoring and incipient fault detection during the event - is provided within the detailed fault report. DGA data collected during through fault conditions is also integrated into the report, providing more accurate visibility into the transformer's health.

This report can help in two ways. First, it provides greater visibility into the safety of a transformer after it has been tripped, allowing operators to make judgments about whether it is safe to put the device back into operation. Second, it allows for proper diagnosis of any new conditions that have started evolving in that transformer, such as an increase in a gas concentration, shortly after a fault event.

This integrated solution provides a heightened level of visibility, allowing the data to be applied in a meaningful way to maintenance or troubleshooting needs.



Pre-fault *Principal gas: CO Overheated paper*



Post-fault *Principal gas: C_2H_2 Arcing fault*

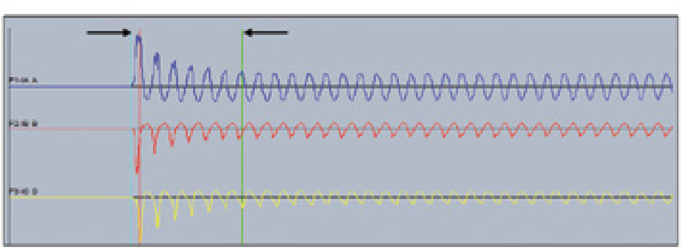


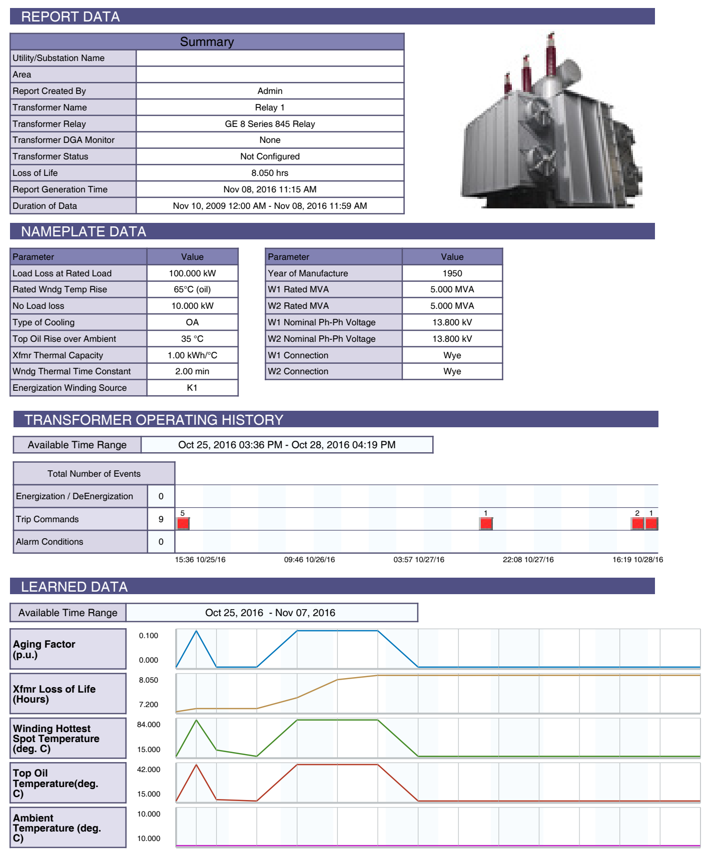
Figure 5: The integrated fault report provides a comprehensive view of transformer condition both pre- and post-fault, allowing operators to identify a greater range of health issues and enabling a proactive maintenance approach.

Transformer health report

The 845's transformer health report shown in Figure 6 is a compilation of operational and fault data, allowing benchmarking and identification of deviations from the normal operating conditions. Asset management teams can utilize this readily available report for post-event analysis and record archival. It provides a snapshot of tripping alarm events on a transformer, including the following:

- Name plate data
- Trend in energization behaviors
- One year learned data
- Historic maximums
- DGA data
- DGA models
- Alarm/trip history

Having all this data in a single device helps eliminate multi-layered monitoring and recording devices, providing one-stop operational, monitoring and fault analytics. The simple and intuitive analytics can be archived for reference and future comparison.



REPORT DATA

Summary	
Utility/Substation Name	
Area	
Report Created By	Admin
Transformer Name	Relay 1
Transformer Relay	GE 8 Series 845 Relay
Transformer DGA Monitor	None
Transformer Status	Not Configured
Loss of Life	8.050 hrs
Report Generation Time	Nov 08, 2016 11:15 AM
Duration of Data	Nov 10, 2009 12:00 AM - Nov 08, 2016 11:59 AM

NAMEPLATE DATA

Parameter	Value
Load Loss at Rated Load	100.000 kW
Rated Wndg Temp Rise	65°C (oil)
No Load loss	10.000 kW
Type of Cooling	OA
Top Oil Rise over Ambient	35 °C
Xfmr Thermal Capacity	1.00 kWh/°C
Wndg Thermal Time Constant	2.00 min
Energization Winding Source	K1

Parameter	Value
Year of Manufacture	1950
W1 Rated MVA	5.000 MVA
W2 Rated MVA	5.000 MVA
W1 Nominal Ph-Ph Voltage	13.800 kV
W2 Nominal Ph-Ph Voltage	13.800 kV
W1 Connection	Wye
W2 Connection	Wye

TRANSFORMER OPERATING HISTORY

Available Time Range	Oct 25, 2016 03:36 PM - Oct 28, 2016 04:19 PM

Total Number of Events	
Energization / DeEnergization	0
Trip Commands	9
Alarm Conditions	0

LEARNED DATA

Available Time Range	Oct 25, 2016 - Nov 07, 2016

Figure 6: The transformer health report compiles operational and fault data, providing a one-stop operational, monitoring and fault report with intuitive analytics.

Communication Aspects with DGA Devices

Both the 845 and the monitoring and diagnostic devices must be connected and operated in the client-server mode of operation using Modbus® TCP/IP protocol. Communication settings for configuration of the 845 and DGA integration is done via the DGA monitoring screen of EnerVista™ software. The 845 and Kelman DGA devices require TCP/IP support on Modbus protocol for communicating and should be connected to the network through an Ethernet switch or direct point-point fiber-optic Ethernet communication where feasible. With support for multiple communication protocols and ports, the protection device is able to maintain communications between the DGA and a supervisory system such as SCADA or DCS.

When separate network ports for primary and secondary LANs are required, ports 4 and 5 in the 845 relay can be applied as depicted in Figure 7. One example of primary and secondary LANs includes the protection network (time critical) and M&D network (less time critical) within a utility.

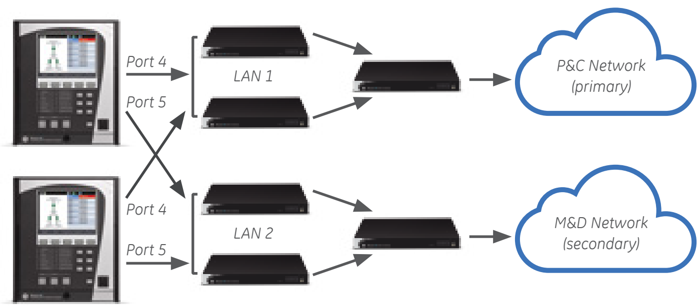


Figure 7: Primary and secondary LAN connections.

EnerVista and Perception® Software

Transformer monitoring software systems such as GE's Perception help in the condition-based monitoring of transformers with large volumes of historical data. They are used for the long-term health assessment of transformers, fleet monitoring, risk analysis and maintenance scheduling using historical data.

GE's Perception Fleet provides a holistic approach to transformer fleet management assessments for utility and industrial applications. Designed as a standards-based software system, the application utilizes real-time DGA data from monitors/sensors in the field to evaluate the condition of each asset and establishes their risk of failure. The software tool is then able to prioritize and rank each asset within the fleet to enable a proactive maintenance approach that is targeted and more cost-effective. This ensures the customer focuses limited resources where they are needed most, reducing operational expenses.

For short term health assessment of transformers, a system such as EnerVista should fulfill the following:

- helps with fault analysis after a major or critical event
- assists with commissioning
- provides time synchronized data correlation between electrical, thermal and mechanical parameters for proactive transformer condition monitoring
- performs historical events analysis

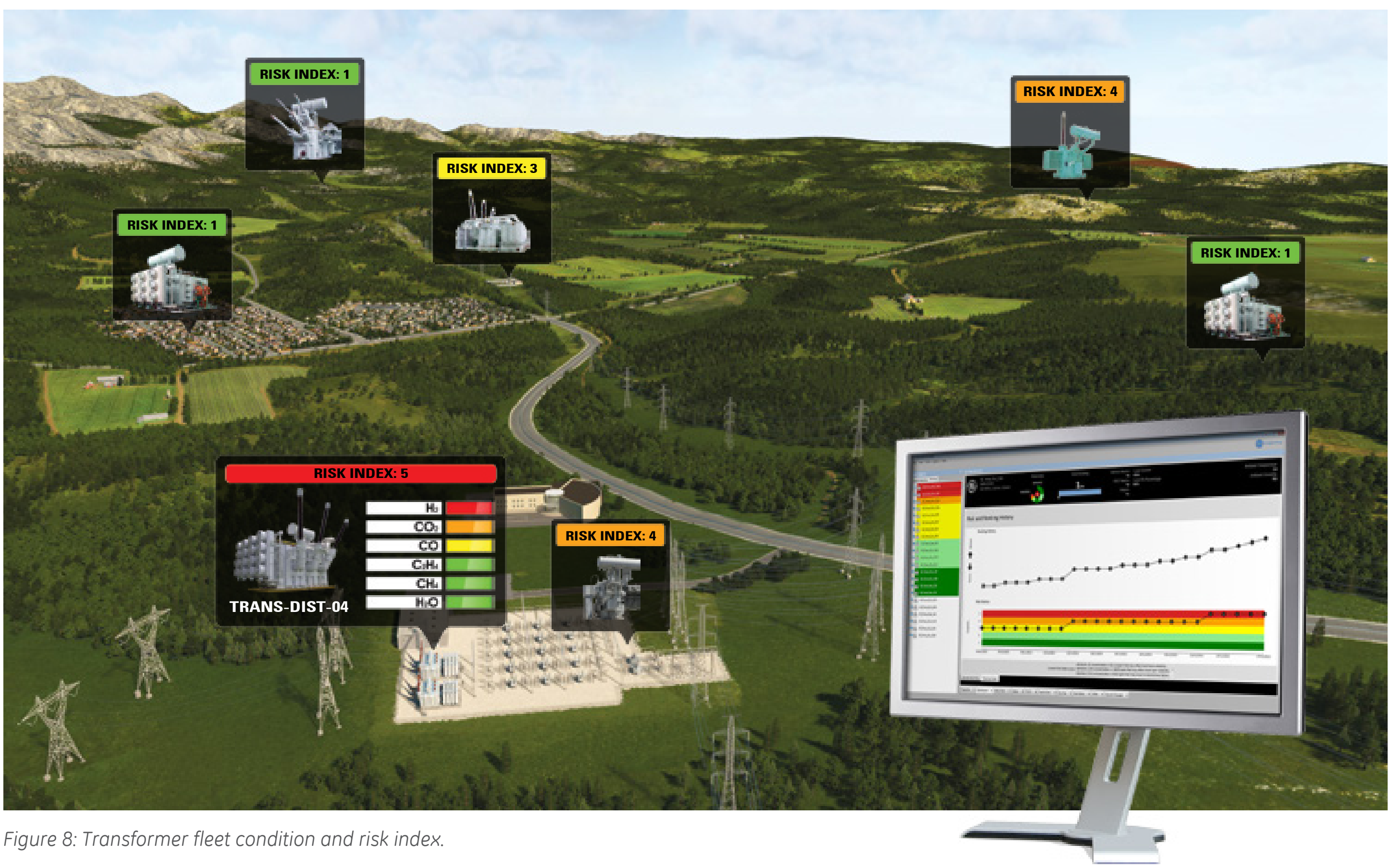


Figure 8: Transformer fleet condition and risk index.

Enervista is a tool with analytics for one asset at a time while Perception offers the benefit of total asset management on a fleet-wide basis. In a typical power utility, protection engineers work with relays (EnerVista), and asset or maintenance engineers work with DGA devices (Perception). This solution helps these two teams collaborate and monitor the transformer more effectively, better utilizing mutual skills and experience. However, in industrial or captive power plants, the same engineer might look after protection and monitoring of transformer. This solution also provides a good value proposition in this scenario by offering simple tools for analyzing transformer condition.

In the near future, Perception software will deploy integrated analytics by combining data from 845 and DGA devices such that an increased level of situational awareness for the complete fleet of assets can be accomplished using Perception software.

Conclusion

Today's power engineers and asset managers need transformer monitoring and diagnostics solutions that provide clear, actionable intelligence through a combination of electrical, chemical and thermal data. In unifying these different types of data, the Multilin 845 protection relay provides a holistic view into multiple aspects of transformer health, including overloading and gassing, over-voltage and bushing problems, hotspots and DGA, and tap changer and cooling system monitoring.

Data correlation models are time-aligned and trended among electrical, chemical and thermal characteristics through a range of transformer conditions. Reports from the 845 – including the energization record, integrated transformer fault report and transformer health report – allow capturing the key operational dynamics that provide insights around both internal and through fault conditions.

Critical transformer data is compiled into reports and models that are easy to interpret, supporting informed decision-making. This ultimately delivers actionable analytics for asset optimization and transformer life extension, enabling operators to reduce capital and operational expenditures while maintaining the power system reliability demanded by today's market.[3]

References

1. "Electric grid large power transformers take up to 2 years to build", http://energyskeptic.com/2015/power-transformers-that-take-up-to-2-years-to-build January 21, 2015.

2. Kipp Yule, Duane Brock, and Jim Purdy. "Accountability and Evaluation of Aggregate Effects of Through Faults On Power Transformers", White paper [Open Source].

3. Giesecke, Jon L. "Transformer Lifecycle and Risk Management" http://reliabilityweb.com/articles/entry/transformer_lifecycle_and_risk_management

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