Trends in continuous on-line condition monitoring

ABSTRACT

The article describes new trends in the field of continuous on-line condition monitoring of transformers. These trends are related to the following topics: the monitoring system itself and new requirements for, for instance, HVDC and offshore transformers; growing importance of the implementation of continuous on-line monitoring of bushings, dissolved gases and new ultra-high frequency technology for partial discharge monitoring; and finally, the new trend of using IEC 61850 [1] data model and communication protocol in digital substations.

KEYWORDS

comprehensive monitoring, IEC 61850, asset management, DGA monitoring, partial discharge

From measurements to information for decisions

1. Introduction

Today, utilities are focusing on improving or maintaining system security by preventing outages on the one hand, and on the other, on reducing operation and maintenance costs of their assets. Both objectives rely on information about asset conditions. As such, an increasing number of power transmission and power generation utilities are equipping their power transformers with continuous on-line monitoring systems. Step by step, this equipment is becoming a standard configuration of power transformers.

Comprehensive monitoring solutions are becoming a part of standard configuration of power transformers

2. New trends for continuous on-line monitoring

Special applications such as HVDC transformers and new applications in offshore environments require a permanent improvement and further development of comprehensive monitoring systems for continuous on-line condition monitoring. There are also new trends involving advanced sensors, such as on-line bushing monitoring, dissolved gas analysing devices and partial discharge detectors. Furthermore, new requirements have to be fulfilled regarding information interchange among sensors, Intelligent Electronic Devices (IED) and monitoring systems by using, for instance, IEC 61850 data model and communication protocol.

2.1 Comprehensive continuous on-line monitoring systems

A power transformer consists of several components: transformer tank with active part and oil-paper insulation, conservator, cooling unit, on-load tap changer and bushings, to mention a few. These components can be fitted with various sensors which are integrated into one monitoring IED by means of analogue or digital signals and protocols, building a comprehensive condition monitoring and expert system, see Fig. 1.

Raw data, acquired from a wide range of demand-specific selectable sensors, is analysed by means of implemented models and stored in the on-line condition monitoring and expert system. This requires a highly flexible and modular design of comprehensive monitoring systems to provide tailor-made solutions adjusted to the application, rating, relevance, condition, operating mode and maintenance of the transformer protection/maintenance scheme. For example, offshore applications have specific requirements regarding mechanical durability, whereas HVDC applications require new analytic models, such as the bushing monitoring model which is impacted by the connected DC converter station. The application of field bus and process control technology offers a very high degree of flexibility concerning the system architecture, possible functionality and future expandability. This concept allows monitoring of all of the transformers at one substation or power plant with only one IED and is, moreover, an important component of higher-level asset management systems.

Data acquisition and processing alone, however accurate, are of limited value if operators cannot prioritise and exploit the masses of generated information. An expert system included in the monitoring device becomes a useful tool to accomplish this. Configurable report generators automatically create user-friendly reports providing information about the status of the transformer and its main components, upon request or to be sent periodically by email.

Expert systems also provide recommendations and information concerning transformer operation and service/maintenance.

Figure 1. Example of transformer continuous on-line monitoring module to collect and analyse data from various sensors placed at strategic points of the transformer

a) Bushing adaptor

b) Voltage sensor

Figure 2. A solution for bushing monitoring

They also allow to program alarms according to data values and can be correlated to other data impacting the identified problem. Messages, including necessary actions, are displayed in a status window. The processed data is stored in the expert system, becoming a knowledgeable database.

2.2 Continuous bushing monitoring

High voltage condenser bushings of power transformers, depending on their construction and age, are amongst the most endangered components from all operating equipment used.

In the past, off-line measurements (like the measurement of bushing insulator capacitances and measurement of the dissipation factor) were carried out to define their operational status. Today, modern microprocessor and computer technology makes it possible to perform continuous measurements and analysis as an integral part of a monitoring system.

Monitoring of the electrical measurement quantities is achieved by a voltage measurement consisting of a bushing adaptor directly connected to the measurement tap of the bushing and the connected voltage sensor, see Fig. 2.

The output signal of one phase is compared with the two remaining phases. Hence the influence of temperature is compensated by the three-phase measurement principle. Short and long term grid unbalances can be filtered by a proven algorithm.

> **An active use of the bushing monitoring functionality may prevent a major failure and unscheduled outages**

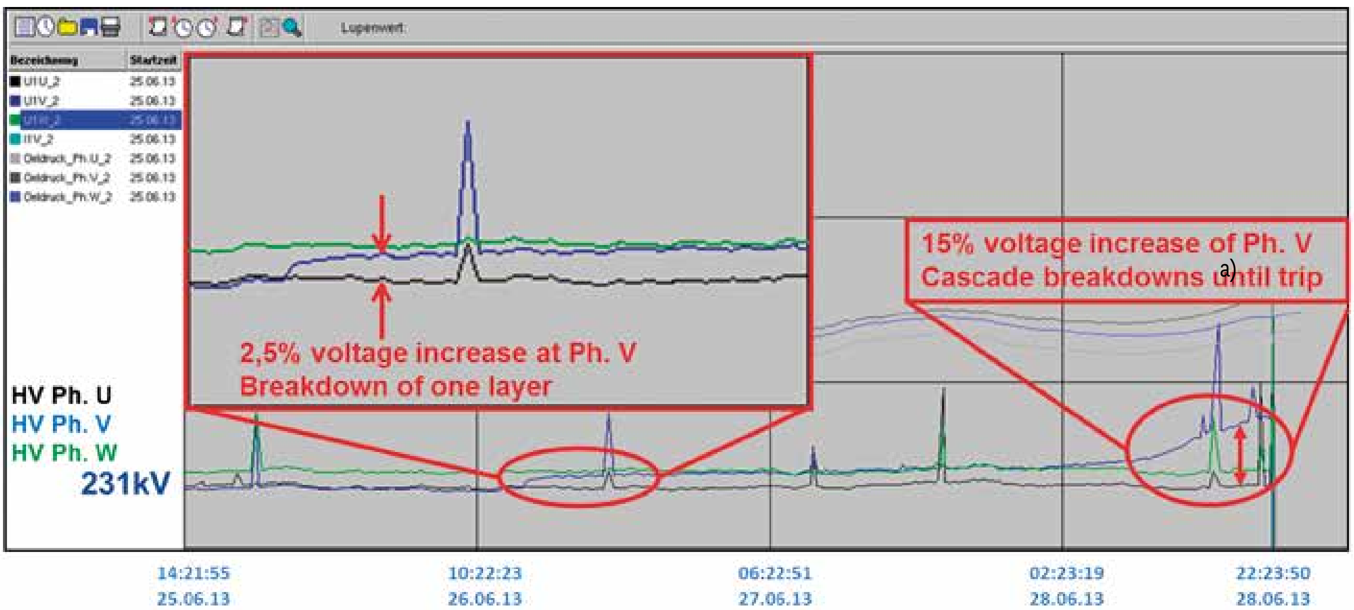

Figure 3. Increase of measured voltage (phase to ground voltage measurement on bushing test tap at high voltage side) on a failed bushing of an 850 MVA transformer

Application of continuous on-line dissolved gas analysis techniques supplements laboratory analyses

Case Study

Comprehensive monitoring systems offer the advantage of collecting all the important information about the condition of a transformer and thereby allow a thorough investigation of failures. It is important to correlate the data with the various measurements to partly distinguish root causes of transformer failures.

The following case study demonstrates the benefit of comprehensive monitoring solutions and shows the capability of such a solution. Even if the monitoring system is able to detect incipient bushing failures, the utility of this case study did not use it actively to monitor and operate the 850 MVA, 400/27 kV transformer, manufactured in 2000. In the evening of the 28th of June 2013, it tripped due to a catastrophic bushing failure at the high voltage side in phase L2. The measurement data of the monitoring system revealed that the catastrophic failure was detectable approximately 3 days in advance, see Fig. 3.

On the 26th of June, the voltage measurement on phase L2 showed a voltage rise of approximately 2.5 %, which correlates to one layer breakdown in the condenser bushing. A cascade breakdown inside the bushing occurred approximately 6 hours before the trip, rising up the nominal voltage to additional 15 %. An active use of the bushing monitoring functionality would have prevented that major failure and therefore, the unscheduled outage. Due to this experience, the utility decided to implement the bushing monitoring into the active alarm management.

In Fig. 3 it can be seen that overvoltages have been detected prior to the fault, which might have been a possible root cause for the bushing failure. The benefit of comprehensive monitoring systems is the correlation of transient overvoltages and capacity change of bushings for a deeper understanding of those additional dielectric stresses.

2.3 Continuous Dissolved Gas Analyses (DGA)

In addition to transformer monitoring via periodic oil sampling and oil analyses in a laboratory, it is increasingly requested to apply continuous on-line Dissolved Gas Analysis (DGA) techniques. There are different technologies to measure it. The best possible utilization of DGA raw data can be achieved by incorporating DGA sensors and DGA interpretation algorithms into a comprehensive monitoring system. Depending on the user and region, the interpretation of DGA is supported by different methods: IEC 60599 [2], Doernenburg, Rogers, extended Rogers, MSS (Müller, Schliesing, Soldner), key gas and Duval.

The correlation with other electrical and thermal data, even across various transformers, allows a deeper analysis of the transformer condition compared to just using DGA data alone.

2.4 Partial discharge monitoring

Today, there are numerous important diagnostic approaches for condition assessment of power transformers. One in particular is the Partial Discharge (PD) measurement in Ultra-High Frequency (UHF) range [3]. The development of the new UHF PD monitoring module follows the trend to use diagnostic technology for continuous on-line monitoring. The UHF PD module consists of an UHF sensor to be installed in the transformer and the measuring electronics for capturing UHF PD impulses, see Fig. 4.

a) UHF sensor and electronics

b) Monitoring system with UHF sensor

Figure 4. Ultra-High Frequency (UHF) partial discharge monitoring

Power transformer on-line monitoring system

> **Partial discharge monitoring in ultra-high frequency spectrum is establishing as an important diagnostic approach for transformer monitoring**

The UHF PD module measures electromagnetic emission of internal PD pulses in the UHF frequency range from 300 MHz to 3 GHz. The UHF sensor uses the transformer tank as a "Faraday Cage" and allows the detection of PD activity from inside the transformer only. The Phase Resolved Partial Discharge pattern (PRPD) evaluation provides typical characteristic PD pattern which can be used for the interpretation of possible PD sources. The UHF PD data can be correlated to all measured and analysed values of the monitoring system on the transformer, including for instance, load condition, On-Load Tap Changer (OLTC) operation or DGA, and hence allows further condition and risk assessment of PD effects.

2.5 IEC 61850

The IEC 61850 series of standards for communication in substations is increasingly accepted worldwide. The main advantage of the new standard is the interoperability and compatibility between IEDs and devices independent of the manufacturer [4]. This means that multiple electronic devices can communicate and share information, without detailed knowledge of the equipment or protocols. Based on the standard IEC 61850, a comprehensive modelling of power transformers, including advanced on-line monitoring functions, can be built and the derived data can be easily transferred to the station automation system. As such, measurements on transformers can be correlated to other transformers in one substation or even across a wider range.

3. Conclusion

Continuous on-line condition monitoring systems need to cover conventional transformers as well as the new requirements arising from new applications such as HVDC transformer stations, and new environment conditions such as offshore surroundings. Another new trend is the correlation of continuous on-line bushing monitoring, dissolved gas measurement devices and partial discharge detectors, and their individual interpretation of measurement data.

> **IEC 61850 communication standard is gaining increasing acceptance worldwide for higher interoperability and compatibility**

Following these trends, monitoring systems need to support operators in obtaining and efficiently prioritising information via expert systems with appropriate report generators. State of the art monitoring systems have the capability to be integrated within higher level asset management tools.

Sensitive bushing monitoring can be achieved by voltage measurements correlating to change of capacitance. The bushing structure, with its number of layers, defines clear criteria to identify main bushing problems, thus enabling major failure prevention in certain cases.

Finally, the trend is evolving to standardise the communication of sensors, IEDs and monitoring systems by use of the IEC 61850 data model and communication protocol.

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