Smart grid solutions for transformer monitoring and diagnostics

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Transformers form an integral part of the power system value chain. They are used at different voltage levels throughout the power delivery process, starting from step-up operation at the generation power plant and going through various step-down operations to different voltage levels along the way down to distribution voltage levels. Obviously, the degree of transformer criticality depends on the intended purpose of operation. For example, generator step-up (GSU) transformers are extremely critical, as any unplanned outage would mean service interruption to a wide area of customers and possible system-wide instability resulting in unfavourable consequences.

Likewise, some industrial transformers could be small in size but yet very critical for the continuity of the process, and an unplanned outage might entail a big loss of revenue. Therefore, continuous monitoring, full diagnostics and protection of critical transformers are critical and unavoidable tasks for utilities and industries alike in order to maintain availability, avoid damage to life and property, protect the asset and environment, preserve the image of the organisation, and sustain profitability.

Power system faults are unpredictable, and are typically accompanied by increased currents flowing through transformer coils, which would heat up the oil in the transformer tank. Depending on the severity of the fault, the temperature rise in the oil varies, thus giving rise to a mix of dissolved gases of different concentrations. Maintaining good dielectric characteristics of the insulating oil is extremely important.

Dissolved gas analysis (DGA)

DGA has been the method of choice for transformer monitoring and diagnostics (M&D), the goal of which is to detect the levels of dissolved gases and associate them with fault severity. DGA can also help the utility make an informed decision on the level of loadability of transformers after fault clearance by the protection system. It can also offer early detection of moisture and partial discharge, thus helping the utility avoid fast degradation of dielectric strength of the oil that could lead to imminent faults. In this paper we will briefly talk about two methods for DGA.

Gas chromatography method

The traditional method for transformer M&D is based on chemistry of gas chromatography (GC), (see Fig. 1) whereby an oil sample is fed into the analyser, and the constituent gas concentrations are given at the end of the process. Fig. 2 shows the basic components, while Fig. 3 shows the lab setup of the GC system. A typical gas chromatograph consists of an injection port, a column, carrier gas flow control equipment, ovens and heaters for maintaining temperatures of the injection port and the column, an integrator chart recorder and a detector [1].

To separate the compounds in gas-liquid chromatography, a solution sample that contains organic compounds of interest is injected into the sample port where it will be vapourised. The vapourised samples that are injected are then carried by an inert gas, typically helium or nitrogen. This inert gas goes through a glass column packed with silica that is coated with a liquid.

This technique, although very popular and accurate, has been in existence for a long time, and has some drawbacks. First, it is laboratory-based, due to the fact that it requires controlled temperature, pressure regulators, gauges, and flow meters; it also requires an extremely accurate and chemically inert gas that is used to carry the oil sample through the analyser. Inert gases used include helium, argon, and nitrogen. GC is a very sophisticated analytical technique, as gas separation is performed in a very precisely controlled environment where any fluctuation in temperature is disastrous. Detectors used in the analysis process must be maintained at an extremely stable temperature, and the technique is sensitive to vibration, movement, slight changes in flow rates, etc. For these reasons, GC is a bench-top technique and is less suited to applications requiring portability or autonomous operation in a remote location.

Photo acoustic spectroscopy (PAS) method [2]

In contrast, the photo acoustic spectroscopy (PAS) technique has proven very suitable for portable DGA in the field. Fig. 4 shows the basic components of the PAS system. The oil sample to be analysed is irradiated by modulated infrared (IR) light of a pre-selected wavelength. As the gas absorbs energy, it is heated and therefore expands and causes a pressure rise. As the light is chopped, the pressure will alternately increase and decrease, and an acoustic signal is thus generated. The produced acoustic signal is detected by two microphones. The electrical output signals from the two microphones are added in an amplifier, before they are processed.

The merits of PAS for DGA are numerous. This technique has been used to develop
portable M&D equipment that can be used to quickly conduct the analysis in the field, without having to wait for the sample to be sent to the lab for analysis. Furthermore, several M&D products have been developed based on the PAS technique to do unattended M&D for transformers. These devices are mounted on transformers, and automatically draw an oil sample that is analysed. The same technique is now being explored to be used for partial discharge analysis, and for cable and switchgear monitoring. Since the technology uses advanced techniques in doing signal processing with communications capabilities, it becomes an easy task to report results continuously to the control room via wired or wireless communications infrastructure.

This analysis can be carried out several times an hour, thus giving the utilities the ability to do continuous monitoring and diagnostics on their transformers. Using PAS, no regular recalibration is needed. This technique is accurate, robust over long timeframes, operates in ambient air, and requires no cylinders of carrier or reference gasses. It is inherently easy to use, with no user interaction required to complete results calculation, and uses minimal serviceable parts. PAS is capable of measuring at very low detection levels (e.g. 0.5 ppm for acetylene) and very high detection levels (>50,000 ppm). PAS is also capable of measuring individual gases in a mixture, and has the ability to move from high gas levels to lower gas levels without cross contamination. It can also give direct measurements of both CO and CO₂, vital gases for understanding cellulose condition of insulating paper, giving increased accuracy and repeatability. Finally, PAS can be used to do measurements on multiple tanks, such as the main tank plus the tap changer tank. Recent advancement in technology has allowed the integration of PAS for DGA with other important transformer monitoring signals such as pressure, Bucholz and temperature to list a few, for an overall monitoring, diagnostic and protection of this very important asset of the power system.

**Smart grid integration**

Smart grid (SG) vision aims to modernise the power grid and optimise its operation. A holistic vision should address the entire value chain of the power grid in order to reap the real benefits of such modernisation effort. This includes solutions for transmission grid, distribution grid, demand side, work force, and asset protection. The ultimate goal of a smart grid deployment is to make the grid more efficient and more reliable, facilitate renewable integration, increase productivity, empower consumers, and extend the life of critical assets. The underlying platform for all of these solutions is an advanced metering infrastructure (AMI) which comprises smart meters equipped with two-way high speed communications. This is a major transformation of the antiquated grid that is based on one-way power and communications flows. The availability of a high speed communications channel for data transmission paves the way for integration of transformer M&D solutions into the holistic SG framework. Thus, M&D devices deployed at critical transformers in the field can perform frequent collections of DGA data and send it via the communications channel (typically wireless) to the control centre, where advanced software solutions can be used to analyse and interpret this data to assess the health of transformer oil and come up with appropriate decisions and recommendations for an action plan. This closed-loop approach for M&D of critical transformer assets is one of the major attributes of SG solutions, and adds great value to the utility and industrial operations through life extension of such assets. The main feature of the SG asset optimisation solution is that it moves the utility from time-based maintenance approach to condition-based approach, resulting in huge savings on transformer purchases. As such, using advanced M&D devices and solutions within a holistic SG framework and vision will result in better utilisation and life extension of critical transformers.

**Hosted asset optimisation solution**

Smart grid deployment requires huge investment, which many utilities find difficult to allocate money for. A viable route that could be beneficial to utilities seeking SG deployment is to consider a “hosted” transformer monitoring system (TMS) solution. In a hosted TMS solution framework, the solution provider assumes all the upfront cost of system and equipment deployment, and the end user will be charged a monthly payment over an agreed – upon period of time, e.g. 20 years.
There are two types of transformer monitoring systems available in the marketplace. Centralised systems composed normally by an acquisition unit that is installed close to the transformer and a PC that centralises most of the intelligence, calculations, and communications in addition to the human machine interface (HMI) functionality. The other type of TMS is distributed systems whereby the intelligence is distributed throughout the intelligent monitoring equipment. In the distributed intelligence principle, each of the proposed monitoring devices is an electronic intelligent device (IED) that is capable of executing the online diagnostics pertaining to its functionality, generating the alarms, communicating with other equipment and reporting to operation and analysis software. The TMS IED components are powerful electronic devices with capacity to store data, manage alarms, drive a local HMI through displays and also offer digital communications with open industry protocols. The distributed intelligence of the system and the capacity of the IEDs to support different protocols allow an independence from a central PC. The operations and analysis software is installed on a PC and, through its scheduler, it interrogates each component and stores the data in a centralised database for expert visualisation and analysis. The distributed TMS continues to monitor other functions of the transformer in the event of component faults.

In a hosted TMS solution framework, the end user gets the benefit of mitigated deployment risk, extended asset life, and investment deferral, while the solution provider collects revenues for an extended period of time.

References:

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