APPLICATION OF NEW CONDITION MONITORING TECHNOLOGIES IN THE ELECTRICITY TRANSMISSION INDUSTRY

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Abstract

In recent years a number of new devices and sensors have become available in the electricity industry that perform continuous, online monitoring of key parameters or indicators of the condition of high voltage plant. "Online condition monitoring", as it is termed, has the potential to generate significant impact in the areas of condition assessment and asset management strategies. However, these benefits will only be realised when systems are in place to manage the information returned by these devices and analysis can be performed to extract its meaning. This paper describes the steps required to effectively implement online condition monitoring, with particular focus on some of the analysis that can be performed on online monitoring information.

1. INTRODUCTION

Condition monitoring refers to the monitoring of key parameters or indicators of equipment condition in a high voltage electricity network.

Condition monitoring has traditionally been done manually by the use of various diagnostic checks. Examples include the levels and types of dissolved gases in oil-filled equipment, gas pressure checks on gas-filled equipment, and timing or operating checks on mechanical equipment.

In recent years a number of technologies have become available that enable continuous online condition monitoring, that is, continuous, in-service monitoring that returns information about key parameters or indicators.

2. BACKGROUND

Online condition monitoring is generally achieved through the use of specialised sensors or devices. Although the technologies used in these sensors have been around for some time, the extent of their application to high voltage electricity equipment is relatively recent.

With the current focus on online monitoring in the electricity industry, the market has been flooded with a plethora of online monitoring devices. These range from single-function monitors such as dissolved gas in oil and moisture in oil monitors, to more complex devices that monitor a range of parameters from plant such as tapchangers and circuit breakers. The number of devices available is continually growing, as new ones are regularly developed and marketed [1].

The range of online monitoring devices includes:

- transformer dissolved gas and moisture in oil monitors;
- transformer temperature monitors (including high accuracy optical fibre temperature sensors);
- CT and bushing dielectric dissipation factor (DDF) monitors;
- on load tapchanger monitors;
- partial discharge monitors;
- ancillary monitors such as oil level and oil flow meters for oil-filled transformers; and
- monitors for other plant including circuit breakers, batteries and backup diesel generators.

Additional information such as loadings and ambient temperature, etc can also be useful information for equipment monitoring.

Some experience worldwide has been gained with online monitoring devices including gas in oil monitors, temperature monitors, DDF monitors, tapchanger monitors and moisture monitors, with several papers published on this experience [2, 3, 4, 5]. Utilities have, in general, started to embrace these technologies to varying degrees, however it is recognised that substantially more field experience and analysis is required before the information from online monitoring devices can be broadly trusted.

To date, the establishment of integrated systems to manage information from these devices has received little attention. As such, with the plethora of online monitoring devices that can be installed in a substation, maintenance staff will require a variety of monitoring software packages on their PC or laptop just to extract information from the devices. Recognising the shortcomings of this 'piece-meal' approach, TransGrid has developed an integrated online monitoring system that manages information from a wide range of these devices across an entire high voltage network.

Additionally, in-depth analysis of data from online monitoring devices is yet to mature, with only a few instances of the application of various analysis techniques such as adaptive modelling [6]. The following sections describe TransGrid's high-level approach to online monitoring and summarise some of the research currently being carried out by TransGrid and the University of Technology, Sydney.

3. INFORMATION MANAGEMENT

A number of years ago TransGrid recognised that there would be substantial growth in the area of online monitoring, driven by its potential to impact asset management and provide business benefits. At the time, research was carried out on effective systems to manage the information provided by online monitoring devices [7, 8].

A prototype system was developed that utilised a distributed database to store and trend online monitoring information over time, and a centralised web-based user interface to provide access to this data. The system was designed in keeping with a number of principles, to be:

- integrated, that is, combining information from multiple devices across a number of substations into a common interface;
- accessible, that is, available to a range of users in a variety of locations, without the need for manufacturers' proprietary client software;
- flexible, in terms of queries that can be performed and the format and detail of information returned;
- secure, that is, not allowing changes to data or control of substation functionality;
- reliable;
- offers good performance, even with minimal infrastructure and regardless of the size of the system; and
- expandable, to potentially encompass an entire high voltage network [8].

The system was installed on a prototype basis at several sites with online monitoring devices fitted to substation plant.

Figure 1 shows an example of the output of the system, in this case for gas pressures in circuit breakers in multiple substations.

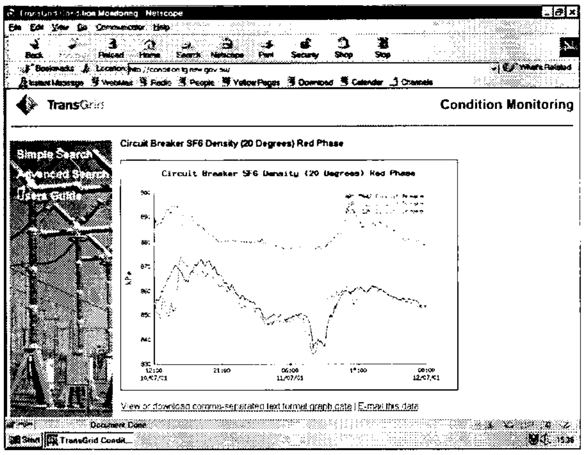

Figure 1 - Example of results from the system

The system is able to handle the following types of information:

- analog quantities, such as DGA and moisture;
- digital quantities, such as extended circuit breaker alarms;
- records from protection relays, circuit breakers, tapchangers and battery tests; and
- plain text information, such as flag information from modern protection relays.

Even in its early stages the system has been able to provide a range of information on a variety of equipment, which has served a number of purposes. The main advantages TransGrid has found with this system are easy and flexible access to online monitoring data, and the ability to then use this data for automated analysis as required.

4. ANALYSIS OF INFORMATION

With a system in place to manage online monitoring data, analysis can be both easy and comprehensive and the need for human involvement can be reduced. This application of online monitoring is the topic of a current research project being carried out by TransGrid in conjunction with the University of Technology, Sydney.

A number of analyses on online monitoring data are possible, but are subject to a few difficulties. Firstly, the accuracy of online monitoring devices is generally not as good as that attainable by traditional diagnostics. This poses some limitations on the accuracy of quantifying key equipment indicators via online monitoring. (In some instances there are exceptions to this generalisation, in which online monitoring can provide potentially greater accuracy of readings than traditional methods.)

Secondly, online monitoring information is often less comprehensive than that obtained by traditional diagnostics, being a subset of the condition information that may be available through traditional means.

This factor gives rise to the third difficulty, which is the accurate correlation of readings from online monitoring devices with specific plant conditions, due to the potentially wide range of reasons for a particular trend or pattern being evident in online monitoring results, more so than with traditional monitoring.

The purpose of the research project is to determine the analysis that can effectively be carried out based on online monitoring information, and implement some of this analysis as an extension of TransGrid's existing prototype information system.

4.1 A methodology

To provide some direction to the research, a methodology to approach the topic was adopted. One type of substation plant, power transformers, was selected as the initial subject of the research.

The methodology adopted was:

1. Model the high voltage equipment under consideration. These will initially be a descriptive model, and due to equipment complexity requires some degree of simplification (and consideration of accuracy) to translate into a mathematical model.
2. Identify all possible failure modes of the equipment under consideration, and also known indicators of fatigue, failure or degradation. Also determine diagnostics or monitored quantities that can track these indicators.
3. Review known online monitoring sensors, they quantities they are able to monitor, the place of these quantities in the model and their fit with the indicators determined above.
4. Determine quantitative and qualitative rules that can be used to determine condition or other useful information based on indicators and online monitoring data.
5. Implement these rules, review their performance and consider further analysis that may be possible.

For the purposes of the research, only a few indicators and failure modes were selected for application of this methodology.

4.2 Initial analyses

There are a number of types of fairly simple and straightforward analysis that can be done on online data, which may subsequently lead to more complex analysis. These include:

- analysis of dissolved gas results and variations, even on monitors that detect a weighted sum of gases;
- transformer loss of life and overload in real-time;
- calculation of moisture in oil and moisture in paper at times when transformers are close to equilibrium of temperature and load [9];
- comparison of online condition monitoring results with offline results obtained via traditional methods;
- compensation of oil level for oil temperature;
- transformer temperature rise above ambient; and
- comparison of results from like transformers (transformers that are supplied under the same contract or from the same factory that are of similar design).

These analyses focus mainly on the oil/paper insulation systems of the transformer.

4.2.1 Dissolved gas analysis

Monitors are available that measure the level of dissolved gases in transformer oil. This is significant because the level, ratios and types of gases that are generated in the oil are indicative of various internal conditions of the transformer.

Some monitors on the market measure single gases, such as hydrogen, for which significant features may include the absolute value of the gas reading, changes over periods of time, and its immediate rate of change.

However, other monitors on the market monitor a weighted sum of key gases. For example, one commonly available sensor provides a reading which is a sum of the following:

  100% of H_2 dissolved in oil
\+ 18% of CO dissolved in oil (±3%)
\+ 8% of C_2H_2 dissolved in oil (±2%)
\+ 1.5% of C_2H_4 dissolved in oil (±0.4%)

with overall accuracy of ±10% ±25ppm [10].

Thus the reading of the monitor may indicate a number of different scenarios, because it is not possible to determine from the reading which gases are contributing and in which proportions.

Further, because each of the gases indicate a different condition within the transformer, an attempt to determine the transformer's condition from online results alone is potentially difficult.

The usual response to a rising online dissolved gas trend would be to arrange for a traditional oil sample and analysis to be carried out. However, there is some analysis that can be performed on the online information alone. This is based on a number of assumptions, which in most practical situations are reasonable, and is briefly described here.

Acetylene and ethylene (C_2H_2 and C_2H_4) indicate substantial arcing or hot spots respectively in a transformer, and in normal operation should not be present at all or at most in very small quantities. Because the monitor is very insensitive to these gases, they will have a very small contribution to the weighted sum. In most cases this will hold even in the case of an internal fault in the transformer, as even the levels of these gases associated with a serious fault would be insignificant compared to the weightings of the other gases in the reading.

Of the remaining gases, hydrogen and carbon monoxide (H_2 and CO), the absolute value of the weighted sum is only useful in new transformers where gas levels are low. In these cases it is sufficiently reliable to accept the sensor's reading as the maximum possible quantities of these gases (from field experience), and this provides information on how low the levels of these gases must therefore be in the transformer, which can be quite useful.

It is likely that in any immediate increases of total gases in the transformer, only one gas will be predominately generated at any one time, with the possibility of secondary gases accompanying it in smaller quantities. This is because each gas detected by the sensor is due to a different type of fault. Thus it is possible to short-term changes in gas level to one of two types of faults: partial discharge (which generates H_2) or fast ageing of the paper insulation (which generates CO). This can be further investigated by traditional diagnostics.

Online monitoring data, taken together with known theory on equipment behaviour, can be used to narrow down information on a transformer's condition to a few possible causes. This is one of the desired outcomes of analysis on online monitoring data.

4.2.2 Transformer loss of life & overload

According to the standard IEC354, it is possible to calculate the relative ageing of the transformer from temperature and load information over time.

When transformers are designed, manufacturers provide an estimate of the life of the transformer based on constant operation at a particular temperature (usually 98°C) [11]. According to the standard, operation at higher temperatures will decrease the expected life of the transformer and at lower temperatures will increase the expected life of the transformer (halve or double the expected life for every 6°C difference).

The standard also provides a means of calculating the relative "used life" of the transformer, which can be calculated based on actual temperatures where online monitoring is provided. It is also possible to calculate the length of time an operator can safely run the transformer into overload for, based on the thermal characteristics of the transformer as measured at time of manufacture.

While overload calculations have traditionally been done as a table of figures calculated from ambient conditions and loadings, online monitoring also enables overload capability to be calculated based on real-time temperature and loading information. This provides a truer indication of the transformer's capabilities than is otherwise possible, and can be used to assist operators in their decision making in real-time.

4.2.3 Active moisture in oil and paper

Moisture can cause a number of problems within the transformer dielectric (oil & paper) system. These include:

- the presence of free water which reduces the dielectric strength of insulating oil and at worst case can lead to electrical breakdown;
- dissolved water in oil, which also reduces dielectric strength;
- dissolved water in paper, which significantly increases the ageing rate; and
- some water dissolved in pressboard and blocks used in transformer construction [12].

All of the above presences of water have a component of 'active' moisture. This term refers to the amount of moisture that is available for transfer between the oil, paper, pressboard and blocks at any given time (there is some level of moisture in the components of any transformer that will not transfer).

The level of moisture in the insulation system can have an impact on the ability of the transformer to handle high temperatures and loads.

When transformer temperature and loadings are steady, the active moisture in the paper insulation on the windings and in the oil will move towards equilibrium. However, this process has a time constant which can vary from a few hours to several weeks, and the moisture transfer will never practically reach equilibrium [9]. For this reason it is very difficult to obtain an accurate reading of moisture in oil and subsequently calculate moisture in paper.

Online monitoring can be used to improve the accuracy of these readings, by monitoring the required quantities simultaneously and performing calculations to determine when the moisture transfer between oil and paper is closest to equilibrium. It also provides a moisture and temperature history of the transformer, which can be taken into account for greater accuracy in these calculations. It also reduces the inaccuracies that can arise in traditional oil sampling and testing for moisture.

Due to the difficulty in accurate measurement of moisture using traditional means, and the contribution of moisture in oil to several types of faults and transformer failures, online moisture monitors and the analysis that can be performed on their data, taken together with other monitored data, can provide useful information on this aspect of a transformer's condition.

4.2.4 Offline results

Offline or traditional condition monitoring results are useful due to the greater level of information they provide, which can also be useful in interpreting online monitoring trends. Offline results can be integrated into the same system as is used for managing online monitoring data and as well as being subject to the same analysis as online results, the greater level of information provided by offline results can be used to interpret online results (such as oil analysis for dissolved gases).

4.2.5 Oil level vs oil temperature

It is known that oil level in a transformer or reactor undergoes the similar changes to oil temperature as the oil expands and contracts with heat. It is possible to determine an algorithm that will correlate oil level with oil temperature, and can be used to track slow oil leaks over time (which would otherwise be difficult with the usual variations in oil level through the course of a day and loading peaks).

4.2.6 Transformer temperature rise

The transformer temperature rise is a simple subtraction of ambient temperature from transformer oil or winding temperature, which gives a temperature differential between the tank of the transformer and the hottest oil or winding. While it is a simple quantity, it can provide some valuable information on the thermal dynamics of the transformer.

4.2.7 Comparison of results from like transformers

One of the methods used to determine equipment condition is to compare results for like (or "brother") equipment within an electricity network. This can be done by simple comparison of absolute values (such as dissolved gas levels), or more complex statistical analysis using methods such as standard deviations.

While this can be done manually from traditional results, it is also possible to undertake this analysis automatically using online results. This means that comparisons can be performed regularly and discrepancies noted automatically, for further investigation.

In this analysis, there are a number of external factors that must also be taken into account including system conditions at different sites on the network, and a history of events (such as through faults) that will affect individual transformers.

5. CONCLUSION

The above analyses, based on online monitoring data and incorporating other information as it becomes available, can be used to provide information on high voltage equipment that is valuable for its use and management. Because online monitoring is continuous, it is more likely to pick up serious problems before traditional diagnostics (which are carried out at regular intervals), and can be used to attain business benefits in the electricity industry.

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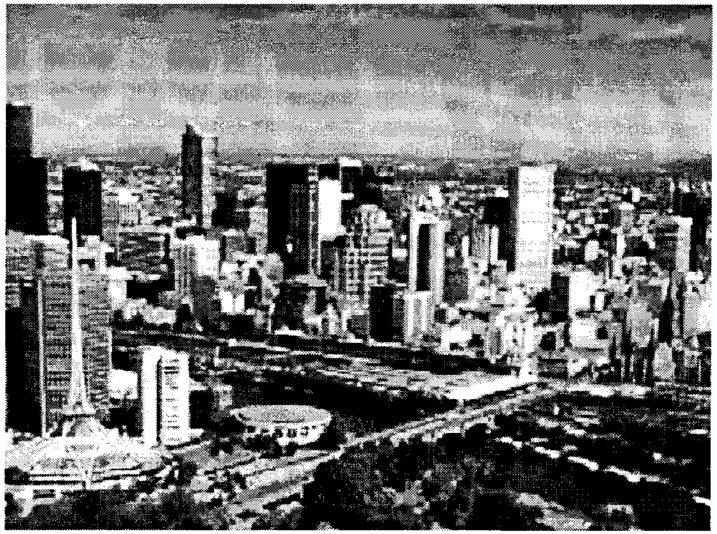

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Message from the Conference Chairman

It gives me great pleasure to welcome you all to the Australasian Universities Power Engineering Conference (AUPEC 2002). AUPEC traditionally rotates among the venues in the Australasian region and we are delighted to host the 2002 conference at Monash University, Melbourne Australia.

AUPEC is the only annual conference organised by the Australasian Committee for Power Engineering (ACPE). The primary aim of this conference is to provide a national forum for academia and industry to share innovation, development and experiences in a friendly environment. The other key aim of AUPEC is to provide postgraduate students with the opportunity to present their research findings in front of experts from both academia and industry for scholarly feedback. It also provides university academics and Industry the opportunity to interact with the technical community, to share experiences and gain the benefit from the latest developments in technology presented at the conference.

We were very pleased with the response received from our call for papers. The conference secretariat received more than 180 abstracts from prospective authors from various countries including Australia, New Zealand, Canada, Malaysia, Singapore, Japan, India, China, Finland, Egypt, Czech Republic and Iran. Members of the organizing committee selected 158 abstracts suitable for presentation at the AUPEC conference. Papers were reviewed by 60 independent reviewers from around the world. Finally, after a two-stage independent peer review process, 138 papers successfully passed the process and were accepted for presentation and discussion at the 27 technical sessions of the conference. All papers published in the conference proceedings for AUPEC 2002 have been fully refereed, having satisfied the requirements of this peer review process. My sincere thanks to all the reviewers for their time and effort toward the review process.

We are also very pleased to put forward four outstanding keynote speakers in the mornings of day one and day two of the conference.

Finally, I would like to thank all the members of the AUPEC 2002 organizing committee for their dedication and effort, without which the conference would not have been possible.

On behalf of the conference committee let me welcome you to AUPEC 2002, which is all set to be a rewarding experience in all respects.

Dr. A. Zahedi
Chairman - AUPEC 2002
29 September 2002

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D Thoroughgood, M Al-Dabbagh, I Bates

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Francis. K. Rault, A. Zahedi and Nolan D. Caliao

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H. Kazemi Karegar, H. Askarian Abyaneh, A. Zahedi, A. M. Ahmadi, M. Khalaji, G. Taleghani

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DEVELOPMENT OF AN ALKALINE FUEL CELL POWER CONDITIONER
Tony Rocco, Richard Duke, Simon Round, Roger Brough

4. High Voltage, Condition Monitoring

APPLICATION OF NEW CONDITION MONITORING TECHNOLOGIES IN THE ELECTRICITY TRANSMISSION INDUSTRY
A Kingsmill, S Jones, JG Zhu

ANALYSIS AND CLASSIFICATION OF PARTIAL DISCHARGE DATA
T. Pawlowski, T. Czaszejko

STUDY OF PARTIAL DISCHARGES USING KIRLIAN IMAGES
B.T. Phung, T.R. Blackburn, J. Hsu and H.P. Lee