Condition Based Monitoring Concept for Transformers and Other Network Components Using a Web-Based Application

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ABSTRACT

In this paper hot spot temperature monitoring and cumulative life consumption calculation methods for transformers are shortly presented. The methods can be utilized e.g. for condition-based maintenance. Methods are based on the simple calculation of winding hot-spot temperature and cumulative life consumption of a transformer using the load and temperature data provided by different metering devices. Methods are inexpensive and simple for monitoring the ageing and the degree of utilization of transformers and can be used with both oil-immersed and dry-type transformers.

The studied methods are integrated in a Web-based pilot application. The measurement system consists of power quality meters, their remote reading software, database server, web server and client (i.e. web browser). The application can be used e.g. to optimise the time-period between planned maintenance actions and to control the loading and rating of transformers based on the proper data available from the network.

The concept can be utilized for condition based maintenance (CBM) also in a wider scale. It could offer huge benefits by giving more information of the critical network components without any extra measurements. The proposed extensive condition monitoring concept could be implemented as ASP -service to present information for customers, subcontractors and the utility itself.

1. INTRODUCTION

Nowadays many network utilities endeavour to optimise the total life cycle costs of their network components. This could be done by adjusting the ratings of the high voltage components and by planning maintenance actions carefully, which in the best case increases reliability, lowers the total costs caused by the components and also extend the equipment service time. However, if the utilities do not have adequate information of the network components and a properly planned maintenance program, the network components could sometimes fail e.g. due to wrongly scheduled maintenance or replace actions.

From the condition monitoring point of view e.g. distribution transformers are problematic. The cost of a sophisticated condition monitoring system is high compared to the cost of a distribution transformer. Due to the lack of inexpensive measuring techniques the temperatures as well as the degree of utilisation of distribution transformers are seldom known. Because of this monitoring of distribution transformers is traditionally based on regular inspections and occasional checking of the maximum load and temperature readings. The information obtained this way is inadequate to determine the condition and ageing of the distribution transformer properly. If the values seem to be too high, the transformers are replaced with larger ones because there is usually no information available of the actual frequency of occurrence and duration of the overloading situations. Also the high amount of distribution transformers makes the determination of the optimum time to replace an aged transformer more difficult and it is a question of great economical importance.

Overall, the condition monitoring of the network components is difficult task and better methods are needed. In the future measurements from the network will increase e.g. because of increasing interest for power quality. From this point of view utilising measurement data for transformer and other condition monitoring purposes could offer network utilities cost effective ways also for a large scale condition monitoring purposes.

2. HOT-SPOT TEMPERATURE AND CUMULATIVE LIFE CONSUMPTION CALCULATION METHODS

The technical life of oil immersed distribution transformers is determined by the thermally activated chemical process, which slowly deteriorates the insulation. The ageing of oil-paper insulation has been thoroughly studied and the ageing mechanisms are fairly well known. The most important factor determining the rate of ageing of the insulation is the temperature of the hottest point in the winding area, the hot spot temperature.

Loading guides IEC 354 [1], IEEE C57.91 [2] and IEC 905 [3] give guidance for the hot spot temperature and ageing calculations and the selection of right transformer ratings for certain loading and cooling conditions. In the standards ageing mechanisms are described to depend directly on the hot spot temperature. The reference value for hot spot temperature for normal ageing is defined in [3] to be 98 ^{o}C. If the hot spot temperature rises much higher during overload situations, the transformer should be disconnected instantly because harmful gas bubbles can develop in insulation liquid.

Sometimes the content of current harmonics can be quite high in a distribution network. In that case the hot spot temperature calculated with conventional methods adopted from loading guides [1], [2] and [3] can differ quite a lot from the real hot spot temperature. Guidance for taking into account the harmonic losses with simple calculation equations can be found e.g. from CENELEC HD 428.4 [4]. The equations can be utilized for transformer condition monitoring purposes as well if the information of the content of the current harmonics is available. More information of the standards [1-4] can be found from [5].

With the methods considered here the actual value of the hot spot temperature is not measured; instead it is evaluated using empirical equations. The calculated values of cumulative life consumption cannot be strictly accurate because of the possible sources of error in the calculation. However, there are unquestionable benefits to be achieved with the methods presented in this paper. Even an inaccurate value of cumulative life consumption makes it possible to monitor the degree of utilization of a large population of distribution transformers. In addition to the calculation of cumulative life consumption, the methods enable on-line monitoring of the winding hot-spot temperatures of transformers in some accuracy. The methods can also be utilized in a planning application when selecting appropriate transformer ratings.

3. EARLIER APPLICATION DEVELOPMENT

Tampere University of Technology (TUT) has studied different possibilities to utilize the methods described in standards [1-4]. An advanced distribution automation system provides new possibilities to develop inexpensive applications for condition monitoring and asset management purposes also for distribution transformers. The monitoring functions can be integrated into existing distribution automation systems. Also the information collected from the network can be used as a basis for the external applications.

The calculation methods can be implemented as part of secondary substation automation, which may provide local monitoring and protection and possible connection to remote control system. This implementation requires a lot of data processing capability in the automation device, but only limited capacity for data transfer (only warning and alarm signals). One example to utilize the calculation methods in medium voltage network in this way is to integrate the functions as part of a relays operational code. This has been done during the earlier research work. In the implemented case, information of calculated values is sent to control centre with supervisory control and data acquisition (SCADA) system. The implementation offers tools to monitor calculated temperature values continuously and in this way to control the loading level of the transformer. The application is presented in more detail in publication [6].

During the research work done, the calculation methods have also been implemented in a Windows -application, which uses external databases to store the measured and calculated data. This kind of application offers valuable information for rating new transformer and deciding the optimal time for maintenance actions. The application is developed to calculate values for multiple transformers and to show the information of measured and calculated quantities. The application is not so far integrated in existing measurement systems, which makes the utilisation of the application a bit difficult. More information about the application is presented in [5].

The developed monitoring applications show that there are several ways to utilize the information collected from the medium voltage network for transformer condition monitoring purposes. The next step in the development work has already been implemented, which means utilizing WWW for offering the measured and calculated information also for transformer monitoring purposes trough the Internet.

4. THE CONCEPT OF DATA MANAGEMENT AND TRANSFORMER MONITORING SYSTEM

The data management and monitoring system for the web-based application consists of metering device, the remote reading software, database server, web application, web server and client (i.e. web-browser). Fig. 1 illustrates the architecture of the developed system. The metering device used is a fairly cheap smart kWh-meter with power quality monitoring functions. In the developed system the meter is remotely read with a modem, which could use either GSM or local phone network. The meter utilizes so called sparse sampling methods described in reference [7]. With the meter it is also possible to utilise external probes to measure e.g. ambient temperature and to store measured temperature data. The temperature data can be read similar to the other quantities. Overall 24 quantities can be measured at the same time and the measurement period can be selected between couple of seconds to several hours. If the measurement period is selected to be 10 minutes, the metering device can store the data approximately three days. Ten-minute time period is adequate also for transformers condition monitoring purposes.

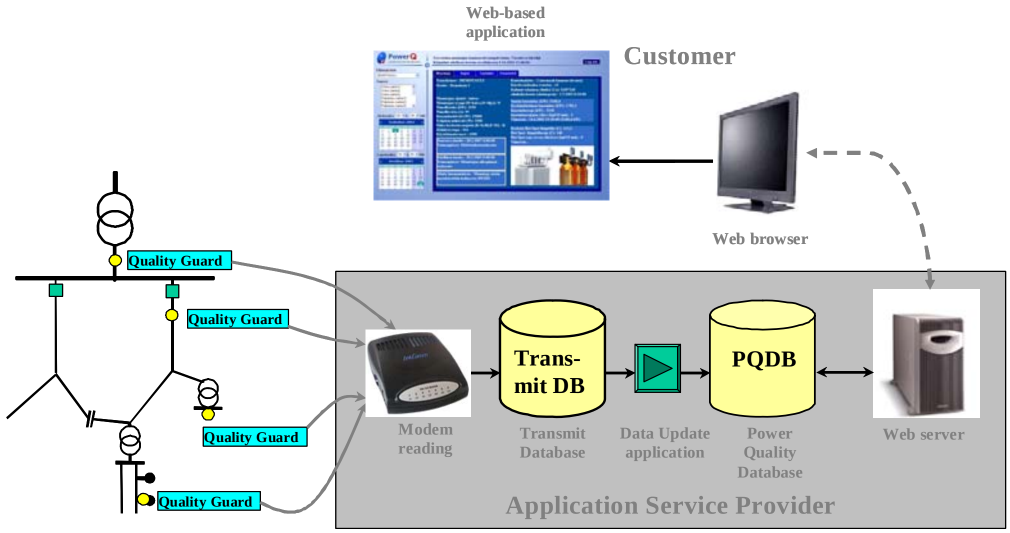

Fig. 1 Developed concept for data transmission and handling

Measurement data is stored with Transmit system, which is a remote reading system of the metering equipment used. The Transmit system consists of reading applications, timer applications and a database. The Transmit database is used only for contemporary data storing because of the shortcomings of the database structure. For more effective data storing purposes, a new kind of database (PQDB) is being developed. The structure of the database is suitable for long-term data storing and for different applications. In the structure each measuring point has its own table where measured values with same timestamp are stored in the same row. The database structure is also designed for multiple users. More information of the meter used can be found from [8].

For mapping the Transmit-database data, the Data Update-application has been developed. The application converts and stores the measured data from Transmit database to PQDB database. At the same time the data is reorganised to PQDB, the developed application also calculates transformer condition monitoring quantities from the measured current and ambient temperature values for selected measuring points. The measurement points, which are included for condition monitoring, are defined in the PQDB database. For the calculation also nameplate information from the transformer is stored in PQDB database. The application determines calculational top oil and hot spot temperature of the transformer, ageing factors in detected time period and the total metering period. For oil-immersed transformers standard IEC 354 and for dry-type transformers IEC 905 are utilised. The selected metering device can also be trimmed to measure existing current harmonics. If measured, current harmonics can be taken into account in ageing calculations. The calculation methods given in CENELEC standard 428.4 can be utilised for this purpose.

Data stored and calculated during the mapping operation is analysed and presented by using a web-based application. Implementation of the developed pilot application is carried out using Microsoft Visual Studio .NET architecture. The developed graphical user interface is presented in Fig. 2.

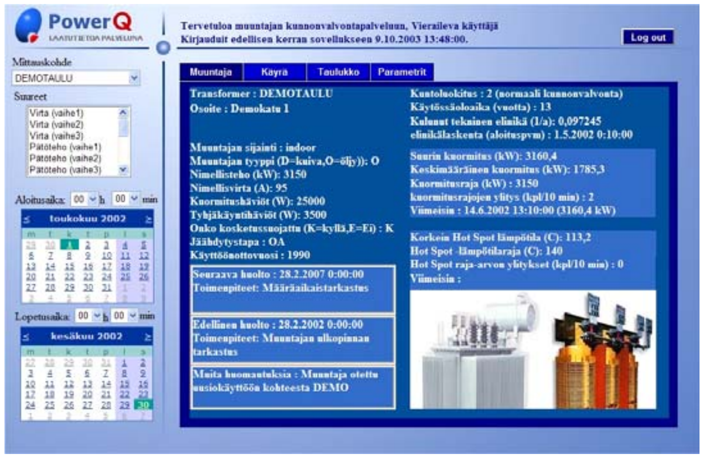

Fig. 2 Condition monitoring information from transformer condition monitoring application

Because the application is for multiple-use and the data must be secured from not privileged use, authorization is required. The user is entitled to monitor through the application all the measuring points that are authorized for him. The authorization operation is done during the log in sequence. After logging in the main page with transformer condition monitoring information of the selected measuring point is presented.

The web application consists of the several functionalities. From the main page the user can see plenty of necessary condition monitoring and maintenance information of the selected transformer. E.g. maintenance personnel can use the application even during the field operation to achieve necessary information, if they have the possibility to access Internet. The condition monitoring and maintenance information consists of:

- General information of the transformer,
- Maintenance actions done and coming,
- Measured average and maximum loading,
- Calculated average and maximum hot spot temperature values,
- The times when the loading and hot spot temperature limits have been exceeded
- Real and calculated cumulative age of the transformer.

The user can also check measured quantities with the application both in table and chart mode. Quantities are selected from the list and the time period from the calendar components from the right hand side as shown in Fig. 2. After selection, the quantities selected are shown in the web page from the selected time period. The changes the user makes during the data viewing are updated rationally into the WWW pages, e.g. both chart and table presentation are updated if the selected time period is changed. The calculation parameters used can also be checked from the application when false calculation results are suspected.

5. UTILIZING CONDITION MONITORING CONCEPT WITH POWER QUALITY MEASUREMENTS

Different standards have been published for power quality evaluation and in the standards different limits e.g. for interruption times, voltage and frequency levels are given. The standards are used for power quality evaluation and to define, if the power quality is in standardized limits in different points of the network. Measurements from the network will probably increase in the future, because end users are more and more interested about the power quality in their common coupling point. The power quality information serves also local network company by showing the possible places for rational network investments. Measurement devices will also become cheaper in the near future, which also lowers the threshold to invest in measurement devices.

The measurement data collected from the network can be used as a basis for power quality applications but also for other purposes, for example condition monitoring of the network components. Thus power quality measurements are not the only reason to measure power quality information from the network. The similar methods as depicted in the previous chapter for transformers can be utilised also for example for cables. The thermal behaviour of the transformer and cables is quite well known and ageing and temperature values can be calculated for both of the components in some accuracy with existing calculation algorithms.

With the described condition monitoring concept better knowledge of the network components is available in a cost effective way, because extra measurements are not needed. If power quality analysis and condition monitoring methods are utilised at the same time, the calculation methods for network component monitoring and quality evaluations can be implemented as a part of the data storing events e.g. with stored procedures or the data can be analysed with independent applications as depicted in previous chapter. In a case when the metering device is installed e.g. to measure transformer, both power quality and condition monitoring applications can utilise same metering information and data stores. This means that if e.g. the power quality measurements are necessary in a substation level, it is quite inexpensive to add also simple condition-monitoring methods into the same concept and this way add the value of the measurement system. The system with different applications utilising unified data measured from the network is depicted in Fig. 3.

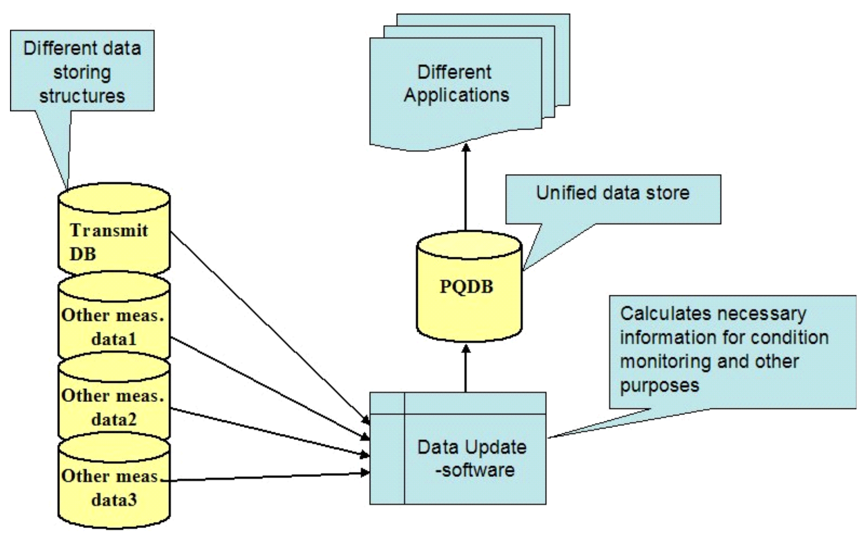

Fig. 3 Possibilities to utilize information for different applications

6. INFORMATION SHARING IN DEREGULATED ELECTRICITY MARKETS

Nowadays network utilities have been focusing on their core businesses. This means that network companies concentrate on their most important business areas (i.e. managing the network assets) and other functionalities are outsourced. For example many utilities have given their maintenance operations and network construction work for other companies. This has created new challenges for data transfer between different business partners, because network utilities have to deliver all the necessary information for their subcontractors and if the management system is centralized, quite much handicraft is needed for data separation. The work can be eased with new type of Internet applications. One solution is to outsource also the application development work using companies that provide application service provisioning (ASP) services. ASP concept can be used for example to present power quality information and condition monitoring data for different subcontractors quite easily.

An IT company using ASP concept usually operates, owns and takes care of maintaining application development and servers that run for specific applications. The ASP company employs the people needed to maintain the application and makes possible for customer to access the application trough Internet with a web browser. The approach gives some advantages if compared to traditional software development. ASP services are quite fast to setup and the applications do not need any software development from the end user. The ASP company is also maintaining the system, which is an obvious benefit if compared to traditional applications. This eliminates the need to employ more workers for maintaining operations. In addition, the end users do not have to worry about the license problems and supporting applications, which are usually needed for IT operations.

Both the power quality and condition monitoring activities can be implemented as an ASP service. The ASP concept does not demand that data stores and applications are located in the same place. If the data is stored in two different locations, the other data store also acts as a backup system of the measured data. Data is accessed in all cases through the Internet and both the measured and calculated values can be presented for the user with a graphical user interface. Also different reports can be browsed and downloaded with the web browser if implemented in the application. The information showed can be limited with different user profiles, and this gives certain benefits for security purposes. With this kind of applications network utilities can present all the information necessary but not more for their subcontractors, customers and of course for their own personnel.

7. CONCLUSIONS

Methods described in [1-3] can be used to evaluate hot spot temperature and ageing factor in some accuracy if the three-phase current, ambient temperature and adequate calculation parameter information from the studied transformer are available. With the different calculation functions maintenance actions and the replacement time of distribution transformers can be determined more accurately than with traditional methods. For a transformer supplying loads with severe harmonics, the effects of current harmonics should be taken into account in the calculation e.g. by using the equations presented in [4]. In this case the information of the amplitudes of predominant current harmonics must be available in order to evaluate the excess losses caused by harmonics. The methods can be integrated for condition monitoring purposes in various ways. TUT has done lots of research work in this field and various applications for transformer condition monitoring purposes have been developed.

In this paper web-based application for transformer condition monitoring purposes has been presented. The application utilises described standards [1, 2, 4] and it has been implemented in system, which uses a smart kWh meter. With the concept presented it is possible to collect and show all the necessary data of the transformer for monitoring purposes. Similar applications can also be developed for other network components, the ageing mechanisms of which are known and can be calculated.

The developed application has many benefits if compared to traditional types of applications. In the implemented concept, monitoring methods can also be integrated to existing measurement systems, which measure e.g. power quality quantities. In this way the measured information, if it is sufficient, can be utilized further for other purposes that could give added value for the whole measurement system and increase the effectiveness of utilising measurement data.

Web-based applications can be used to share information between different players in the electricity network business. Nowadays, when network utilities concentrate on their core businesses, it is necessary to deliver information also for their subcontractors and partners. For this purpose WWW applications give efficient tools. With different applications, which identify the users logging in, the information needed can be delivered independent of time and place for several business participants. This way it is also possible to avoid the extra work, which should be done if unnecessary information should be separated from the information delivered for partners. If the network company does not want to develop this kind of applications by itself, it is possible nowadays to purchase rights to use e.g. the described applications from ASP software companies. If the information sharing is done with an ASP concept, the network companies can concentrate on their most important work without having to worry about IT infrastructure.

8. REFERENCES

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