TRANSFORMER CONDITION ASSESSMENT INTEGRATED WITH RELIABILITY ANALYSIS

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ABSTRACT

This paper describes a network analysis concept for transformers, where condition assessment information from a transformer monitoring system is utilized with a reliability analysis to support network maintenance and planning. In the concept, condition monitoring information is used as an input for the reliability analysis, which improves accuracy of the analysis. The economical studies carried out based on the concept are elucidated with a simplistic business case for in-house installed distribution transformers. The case evaluates costs and benefits of a condition monitoring system based on kWh-meter measurements.

INTRODUCTION

Distribution system operators (later DSO's) utilize computer-based tools widely for network planning, operation and control. The basic systems used today have already several valuable functionalities for network asset management. Furthermore, DSO's are currently developing or have already developed their ICT system infrastructure to provide better services for customers and to meet the demands of the society. One example of the development work is meter management systems, which not only supports hourly invoicing but at the same time can be used to provide detailed information for customers of their electricity usage. This is one example among others revealing that more and more information is collected from the network.

Modern ICT systems contain plenty of valuable data, which can be but it is not comprehensively used to support and improve network asset utilization. This kind of information exists for example in kWh-meter data management systems, power quality measurement systems and also even in SCADA and distribution management systems. When looking existing data purely from asset management perspective, it can be seen that there is information which can be used to develop new automatic ICT-based asset management functionalities. One example of this is to use map material and customer measurement data to support network reliability and life-cycle analysis and based on that, built more decision making capability directly to the system.

Life-cycle cost and risk optimization of assets can be divided in three different time aspects. Short-term optimization can be considered as part of network operation and control optimization, mid-term optimization can be considered as part of the maintenance activity optimization and long-term optimization can be considered as part of total investment life-cycle optimization in network planning phase. Existing network information can support different asset optimization tasks in several ways. In short-term perspective, data from kWh-meters can for example be used to indicate failure location in low voltage network and minimize interruption time [1]. In mid-term, measured temperature and loading data combined with geographical information can be used to optimize maintenance activities from risk perspective. The approach is elucidated more in details for a transformer in this paper. In long-term perspective, for example information of the installation environment (forest, field, road or city, suburban, rural, etc.) can be used to optimize timing of the investment and choose optimal network structure [2].

CONCEPT TO USE TRANSFORMER CONDITION INFORMATION AS PART OF RELIABILITY ANALYSIS

The main principle of the developed concept is to utilize available data from the network and combine it with maintenance information to indicate optimal timing for a transformer maintenance or replacement. The concept utilizes information from the customer electricity usage, the network topology, component structures and also condition assessment information from transformers. Customer, network and component related information is used to indicate consequences of a network component failure and define average failure rate of a component. Those facts are defined with the reliability based network analysis/asset management (later RNA/AM) methodology. Condition assessment of a transformer is based on the thermal loss-of life evaluation, which defines a life expectancy of a transformer in a certain moment of time. Based on condition assessment and component structure information, probability of the failure can be defined for each component in a certain time period. When combining improved failure rate information with the RNA/AM analysis, the criticality of a transformer can be characterized in proper way. The information can be used to optimize maintenance and reinvestment activities in the network. Background of the both parts of the concept is shortly described in following chapters.

Transformer condition assessment

The condition assessment methodology is based on a calculated hot-spot temperature behavior and aging of a transformer. The principles for modeling are adapted from the IEC and IEEE loading guides and/or artificial neural network models developed in TUT. The used methodologies have been evaluated in [3, 4]. The studies have shown that the methodologies can be used for condition assessment in normal loading conditions. With proper input information, the methodology is applicable both for primary and distribution transformer evaluation. The methodology has been implemented as a part of existing applications as described in [3, 5]. The developed condition assessment methodology have been demonstrated by utilizing available structural, loading and temperature measurement information from various data sources such as meter data management system (MDMS), power quality measurement system, network information system (NIS) and SCADA. The latest example of the work is the pilot implementation, which utilizes information from modern kWh -meters.

In the solution, the loading data is collected with a kWh-meter and stored in MDMS, NIS is used to define transformer nameplate information and road administration temperature measurement system is used to provide ambient temperature. In the approach, kWh-meter has also been used to collect and store top-oil temperature measurements done with external probe. More information about the solution can be found [6]. One benefit of the system is that it utilizes existing data systems and it is possible to build up in some accuracy without any extra measurements.

Reliability based network analysis

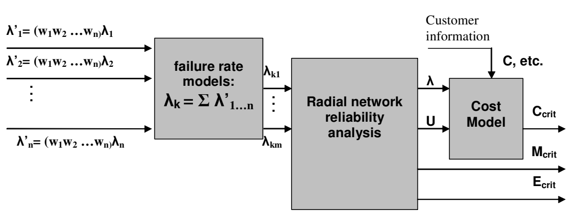

Figure 1: RNA/AM module structure

The basic idea of the RNA/AM methodology is depicted in Figure 1. The failure rate module is calculating an average failure rate for each component based on information from extraordinary stress factors and the structure of the component. The second module, radial network reliability analysis, calculates consequences of a failure. The cost model module calculates costs both customer and utility perspective caused by a failed component. More detailed information about the analysis is available in [7].

The first pilot application of the RNA/AM methodology has been carried out as part of the research project in TUT. After the project, the pilot application has been used in several other research projects [2, 8, 9]. Commercial RNA/AM tool is also developed based on research project.

Vattenfall Nordic Distribution Networks Finland (later Vattenfall) participated actively for the research project and later on also for development of a commercial application. The RNA/AM methodology is integrated today as a part of existing NIS –system as described in [10]. Vattenfall has utilized the RNA/AM tool successfully to give guidance for investment decisions both project and strategic level. The tool has been used to support the strategic decisions to build the network with weatherproof technology, selecting reinvestment sites from the network, finding optimal investments from the reliability point of view and also to update the planning instructions of the network. [11] summarizes the utilization experiences with the practical examples. The tool has also been used in a network index development work carried out in Vattenfall. [12] describes in more detail an analysis case done by Vattenfall Power Consultant, where the RNA/AM analysis is used to calculate the novel reliability index SACDI. Based on the practical experiments, the tool has proven to offer valuable information to support long-term asset management.

Modeling principles of the concept

When seeking reinvestment sites from the network, the RNA/AM analysis results are in practice combined manually together with other information, such as age and condition information. This is necessary because these factors are not comprehensively recognized in reliability analysis. In a case of a transformer, condition assessment based on thermal loss-of life evaluation can be used as an input for the reliability based network analysis to consider age and condition related factors more precisely.

Currently the RNA/AM tool takes into account the environmental factors and some structural data affecting an average transformer failure rate probability, such as lightning and overvoltage protection. These factors are mainly affecting the probability of a failure due to extraordinary stresses and indicate average durability against stresses of a transformer. The analysis does not take into account the aging factors or accomplished maintenance actions for the components, which are affecting to the life expectancy and on the other hand also failure probability of a component.

The general approach to take into account normal aging of a component together with extraordinary stresses in failure rate evaluation is depicted in Figure 2. As depicted in the figure, the failure rate analysis is dependent on structural and surrounding environmental data, but also on monitoring, inspection and maintenance data. Structural data is used to define average stress durability/failure rate of a certain transformer population and surrounding environment data is used to define the external stresses affecting to a transformer. Maintenance, inspection and monitoring data can be used to define where in the life curve a component is located. In a case of a transformer condition assessment, methodology described earlier can be used to define the normal aging and life expectancy of a transformer and therefore also durability against extraordinary stresses in a certain moment of time. With the concept, it is possible to include an aging factor for the failure rate analysis and therefore evaluate more precisely the criticality of a component in a certain moment of time as part of the RNA/AM analysis.

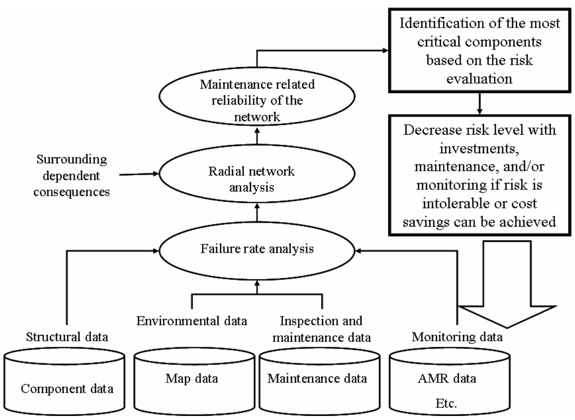

Figure 2: Analysis concept based on RNA/AM and transformer condition assessment methodology

The approach can be used to improve the accuracy of the analysis, which is obvious. Furthermore, the developed principle can also be used for example to define, where in the network condition measurements for transformers should be done. The evaluation can be seen as a stepwise process. First step in the process is to evaluate existing situation, which is based on the current network and component information. When using the concept described in this paper, the analysis is carried out with the RNA/AM analysis. The results of the analysis are then used to identify and locate the components having the highest criticality. When the most critical components are found, the next step is to carry out a cost/benefit analysis for implementation of the condition monitoring system for a selected component group. This is done by evaluating how the monitoring system will affect to failure probability, failure costs, etc. and by comparing the facts with the implementation costs. As a result of the analysis, the added value of the system is provided for each transformer and also for the whole system. The results can be used to make decisions about the usability of the evaluated system and selecting suitable locations for the measurements.

CASE: INDOOR TRANSFORMER CONDITION MONITORING IN A CITY AREA

To elucidate the described decision-making process, a simplistic case study to evaluate costs and benefits for distribution transformer condition monitoring system for 400 in-house installed transformers is carried out. The system consists of 400 additional kWh-meters, which are installed to monitor transformer loading and temperature behavior. Risk of a failure is considered before system implementation already to be sufficient level and therefore the business case is directly linked to economical calculations. Transformers are also presumed to operate in the similar environment (similar customers structure and loading, similar operational response times in failures, etc.), which simplifies the evaluation. Relevant case information is given below:

- Failure rate due to aging purely is 0,0025 before new system is in place. When new monitoring system is implemented failure rate is decreased with 50%.
- A kWh -meter investment cost is 300 €/meter.
- A kWh -meter reading and data storage costs are 100 €/a. Because existing measurement system is used, there are no other additional costs.
- IT system development costs with required follow up functionality is 30 000 € and annual system operating costs is 2000 €/a.
- Inspection cost is 200€/unit, which can be decreased by 133,3 €/unit with the new monitoring system.
- Failure costs caused to the customers from regulation model perspective decreases 7 930 €/a with the new system annually (possibility to avoid unplanned interruption).
- Fault repair costs decreases with the new system annually 7 500 €/a with the population of 400 meters.

Table 1: Business case evaluation for condition monitoring system

Year	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Costs							
Investment, meters	120 000 €	-	-	-	-	-	-
Annual meter costs	0	40 000 €	40 000 €	40 000 €	40 000 €	40 000 €	40 000 €
Application project	30 000 €	-	-	-	-	-	-
Application, annual	-	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €
Total annual costs	150 000 €	42 000 €	42 000 €	42 000 €	42 000 €	42 000 €	42 000 €
Savings							
Inspections	-	53 333 €	53 333 €	53 333 €	53 333 €	53 333 €	53 333 €
Fault costs, regulation	-	7 930 €	7 930 €	7 930 €	7 930 €	7 930 €	7 930 €
Fault repair costs	-	7 500 €	7 500 €	7 500 €	7 500 €	7 500 €	7 500 €
Total annual savings	0 €	68 763 €	68 763 €	68 763 €	68 763 €	68 763 €	68 763 €
Annual total result	-150 000 €	26 763 €	26 763 €	26 763 €	26 763 €	26 763 €	26 763 €
Accumulated total result	-150 000 €	-123 237 €	-96 473 €	-69 710 €	-42 947 €	-16 183 €	10 580 €

The business case results are presented in Table 1. As can be seen from the table, the investment costs are covered with these parameters in seven-year period and break-even year would be in Year 6 based on direct cash flow calculations and when the interest and inflation rates are neglected.

CONCLUSIONS

In this paper a network analysis concept for transformers is described, where condition assessment information from a transformer monitoring system is combined with reliability analysis data. Both reliability analysis and condition monitoring methodologies have been studied comprehensively separately earlier and this paper summarizes the possibilities to combine methodologies as one concept. As a conclusion, the studies indicate that the developed condition assessment approach for transformers can be used for distribution transformer condition monitoring and also as input information for the reliability based network analysis. With the concept, it is possible to include aging factor for failure rate analysis and reliability based life-cycle cost evaluation of a transformer and thus improve the accuracy of the reliability based network analysis. The concept can also be used to evaluate, how beneficial it is introduce new systems for example for condition monitoring. This has also been elucidated with a simple cost/benefit evaluation.

The presented principles can be developed based on information already available from the existing network systems and/or by utilizing existing measurement systems. Therefore implementation does not require extensive data collection from the network. Because of this, the approach is quite simple to implement, if the data quality is adequate and system infrastructure supports the flexible data exchange between different systems.

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