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General asset management model in the context of an electric utility: Application to power transformers

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ABSTRACT

GAMMEU[1] constitutes an integrated approach that covers the different elements related to the asset management of power transformers in the environment of a utility. GAMMEU harmonizes and inter-relates all the relevant subsystems of the asset management that normally are studied as individual entities and not as a system. Concretely, GAMMEU consists of a platform for data integration, an intelligent system for detection and diagnosis of failures, a failure rate estimation model, a module of reliability analysis and an optimisation model for maintenance scheduling. In this work, a brief description of the elements of GAMMEU is presented and the implementation of the intelligent system for detection and diagnosis as well as the failure rate estimation model is exemplified using data of measurements performed in real power transformers. A robust anomaly detection module using prediction models based on artificial intelligence techniques was developed for top oil temperature monitoring and the use of decision trees as classifiers for the assessment of FRA[2] measurements is also illustrated. For failure rate estimation, the use of a model based on hidden Markov chains is presented using data of dissolved gas analysis tests. The experience obtained from the implementation of part of the modules of GAMMEU using real data has demonstrated its feasibility.

1. Introduction

As a consequence of liberalization, investments in new transmission equipment have significantly declined over the past 15 years. Many transformers are working well beyond their intended life and are operating under increasing stress. As load is increasing, new generation, and economically motivated transmission flows push equipment beyond nameplate limits. As a result, business in the electrical sector has dramatically changed and for this reason, it is imperative to look for new opportunities and strategies for allowing electric utilities to survive these changes.

In order to counterattack the undesirable consequences of the previously mentioned factors, utilities have looked for new methods and strategies that allow not only to achieve determined levels of reliability but also to do it in the most cost-effective manner. Among the different controllable elements that directly affect the network reliability, maintenance is the one of major relevance. Between maintenance and reliability there is a clear relationship. If the equipment is not maintained, the probability of failure occurrence will increase, while in the case that the equipment is well maintained, it will be lower, but of course, at higher maintenance costs. In this sense, equilibrium between reliability and maintenance expenditure is required.

As indicated in [1], the present state-of-the-art in maintenance strategies offers new opportunities which are structured in at least three basic approaches for making decisions related to maintenance. These opportunities are: (1) condition-based maintenance (CBM); 2) reliability centred maintenance (RCM); and (3) optimisation techniques (asset management/Risk Management).

Ref. [2] presents an interesting work that shows the experience in Germany regarding the application of the RCM-strategy. By determining both condition and importance criteria, the strategy allows for determining which equipment has to be maintained first. It is worth mentioning the existence of a commercially available tool that works using this strategy [3]. Most of the authors who have written about this subject give positive opinions with regard to the implementation of the RCM strategy through condition and importance indices. Nevertheless, there are also some sceptical works, as the one indicated in [4], where it is stated that the implementation of RCM programs in this way represents a significant step in the direction of “getting the most out” of the equipment installed. However, the approach is still heuristic, and its applica-

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[1] GAMMEU: general asset management model for an electric utility.
[2] Frequency response analysis.

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tion requires experience and judgement at every turn. Besides, it is stated that the RCM can take a long time before enough data are collected for making such judgements. For this reason, in [4], several mathematical models have been proposed to aid maintenance scheduling.

Another tool is the system ADRES described in [5]. This system was developed as a decision making support tool for maintenance activities. As can be observed in this article, the decision support information is given in the form of a scoring system. On the other hand, information regarding reliability is an input data that should be provided instead of being calculated by the system. One major disadvantage detected in this work is that the system does not link the condition monitoring with the decision support tool.

Another example is the maintenance management system SOFIA described in Ref. [6]. This tool uses condition models to estimate equipment condition in the future taking into account planned maintenance measures as well as the predicted environmental conditions. A case study for a long term maintenance program for one substation is presented including the life cycle cost analysis, which clearly indicates the benefits achieved by the new system. This system is basically a software implementation for maintenance scheduling based on CBM. The system predicts the condition and the costs of the maintenance activities and in this way, the maintenance works are planned. The main disadvantage of this tool is that the importance or the risks associated to the equipment are not taken into consideration. Nevertheless, as stated in this paper, great benefit has been achieved thanks to the use of this tool.

The work presented in [7] is a very complete and interesting contribution that inspired the conception of the GAMMEU model. The main particularities of this work is the development of a platform for data integration and the application of different methods for estimating failure rates from condition data, which as will be seen next, constitutes one of the key features of the GAMMEU model. The main disadvantage of this work is that the failure rate estimation of the power transformers is only based on DGA (dissolved gasses analysis) and there is a lack of anomaly detection systems as well as expert systems required for guiding engineers during diagnostic tasks.

In contrast to the previously mentioned work, the intelligent system for predictive maintenance SIMAP presented in [8] describes a robust approach for scheduling the maintenance activities of the gearbox of a wind turbine according to the information obtained from an anomaly detection module, a health condition assessment module and a diagnostic expert system, all of them developed under artificial intelligence techniques. The disadvantages of this method are on one hand the lack of a methodology for transforming the condition data into failure rate, and on the other hand, the requirement of knowledge about the history of faults for the development of a health condition assessment module.

Taking as base the identified necessities and the revision of the tools already developed, the challenge of developing a new approach for satisfying the detected necessities was identified. As a result, GAMMEU was conceptualised and it characterises itself for having the following elements:

A platform for data integration. This is of great importance given that the condition assessment task demands information not only about the condition, but also about the operation, maintenance and nameplate data. Additionally, by means of such a platform, the information exchange among elements of the models is facilitated. This idea was partially obtained from [7].

System for the detection of anomalies and their diagnostic. The application of artificial intelligence techniques is proposed for allowing the detection of anomalies and assessment of diagnostic measurements. The work of Ref. [8] was a source of inspiration for the conception of this system.

Failure rates estimation from information about the condition. The most important reliability index, i.e., the failure rate, will be estimated by a failure rate estimation model. This idea was inspired by the works quoted in [7,9–11]. Here it is important to mention that there are different methods for estimating failure rates by modelling the maintenance process [12,13]. These models establish a link between maintenance and reliability, which is a necessity that utilities have been expressing for a long time. The possibility of modelling maintenance becomes important when the objective consists of evaluating different maintenance policies (corrective maintenance or time-based maintenance). However, when maintenance is based on condition, the necessity of comparing different maintenance policies, in terms of reliability, changes to the necessity of transforming the condition information into failure rates.

Reliability analysis. As reliability becomes more important to both utilities and customers, reliability studies will become just as important as, or even more important than power flow studies. For this reason, the importance of introducing a module for reliability analysis as part of GAMMEU has been determined.

Optimisation module for maintenance scheduling. This module offers the flexibility of optimising and scheduling maintenance decisions under different objective functions and under defined technical and economical restrictions and availability of resources.

Next the content of each of the elements of GAMMEU is described. First a general description of GAMMEU is presented in a form of a block diagram in Section 2. The concept of the platform for data integration and its technological aspects are presented in Section 3. Then in Section 4, each of the elements of the intelligent system of detection and diagnosis (anomaly detection module, diagnostic module and condition assessment module) are presented. The development and implementation of the anomaly detection module is illustrated for top oil temperature monitoring using records of an on-line monitoring system installed in a 30 MVA transformer. While for the illustration of the diagnostic module, the methodology for the implementation of an intelligent system of assessment of frequency response analysis (FRA) is presented and its application on real transformers is exemplified through real case studies. The methodology for the implementation of the condition assessment module is also described in Section 4 and exemplified using real data of diagnostic measurements. Section 5 deals with the estimation of the failure rate of transformers based on the results of the condition assessment module presented in Section 4. As example, records of DGA measurements of a 40 MVA transformer that failed 34 months after its installation were used for illustrating the implementation of the failure rate estimation model. In Section 6, the failure rate estimated in Section 5 is proposed to be used for computing the mean time to failure (MMTF) data required for conducting reliability analysis. The reliability indices obtained from Section 6 are proposed to be used in Section 7 for the development of an optimisation model for maintenance scheduling. After the conceptualisation of GAMMEU and its elements, for a feasible real implementation, in Section 8 GAMMEU is adapted to the environment of a utility, where the typical information technology tools used by the utilities (ERPS, MMS, etc.) are represented and linked to the elements of GAMMEU.

2. General description of GAMMEU

GAMMEU is based on the features mentioned in Section 1. As can be observed in Fig. 1, the model consists of the following elements:

- Information technology platform for data integration
- Intelligent system for detection and diagnosis
- Failure rate estimation model
- Reliability analysis
- Optimisation model for maintenance scheduling.