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A time-varying transformer outage model for on-line operational risk assessment

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ABSTRACT

The failure probabilities of system components may vary with changes in the operating conditions. Performing a probabilistic risk assessment in real-time is challenging, since component failure probabilities are difficult to predict. Accordingly, this paper introduces a delayed semi-Markov process that incorporates real-time data from advanced sensors, as a means of efficiently calculating time-varying or condition-based failure probabilities. To demonstrate the feasibility of the procedure, a time-varying transformer outage model with numerical examples is presented. In the proposed technique, an analytic random model is developed to accommodate the impact of real-time dissolved gas analysis data, as well as other conditions pertaining to the failure probabilities of system components.

1. Introduction

In order to operate a power system with a smaller security margin that meets essential economic specifications in the power market, more refined methods are required for dealing with uncertain variables in power system security assessments. A probabilistic risk assessment (PRA) program is a useful tool for system operators to carry out risk assessments [1]. There has been some research on security assessments, using risk indices that can quantify the likelihood and severity of the contingencies [2–8].

Probability-based reliability assessments for generation and transmission are already well developed for system planning purposes [9–14]. However, there are fundamental differences between system planning and system operations, and one of the most important of these lies in the modeling of component outage. The objective of on-line operational risk assessments is to use currently available information to predict operational risk, and take appropriate operational measures to deal with upcoming system states over a short-term time frame (minutes or hours). In contrast, reliability assessments for system planning are concerned with making decisions on system enhancements over a long-term time frame (years) [15].

The component outage data used in traditional reliability evaluations are usually average values based on long-term statistical records [9,10]. However, this type of long-term average outage data is not suitable for real-time operational risk assessments, since the operating conditions of system components (such as external environment and internal deterioration) change occasionally under real-time conditions, and this affects the failure probabilities of the system components. Hence, a time-varying outage model of the components should be both useful and appropriate. As a particular example, this paper presents a time-varying transformer outage model, and its feasibility is demonstrated.

Utilities perform preventive maintenance (PM) on their assets in order to maximize their long-term profits, while delivering high-quality service to their customers with acceptable and manageable risks. The operating parameters of transformers are periodically recorded during maintenance, and the resulting data can be used to predict transformer failure probabilities, and applied in reliability-centered maintenance (RCM) [16–19].

It has been more than forty years since on-line transformer-monitoring and fault-diagnosis applications were first introduced in electric power systems [20–23]. These applications are capable of continuously monitoring and analyzing transformer operating conditions. They can detect changes in the operating conditions based on a historical database, and identify potential problems before they become catastrophic. The relevant techniques include dissolved gas analysis (DGA), analyses of partial discharge (PD), hottest spot temperature (HST), and winding deformation [24–27]. Among these, DGA has gained worldwide acceptance as a means of detecting incipient faults, and is widely used. Both IEC [28] and IEEE [29] have issued reference guides for the interpretation of DGA data.

On-line monitoring data with precise time stamps can be used to predict component failure probabilities. In this paper, DGA data are used to formulate a transformer outage model, and the model is then applied to operational risk assessments. Other useful data

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