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Reliability model for frequency converter in electrified railway

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ABSTRACT

Reliability analysis of frequency converters based on failures and outages reports constitute an important basis for asset performance and management. Two- and four-state reliability models that recognize the operating characteristics of base load units and peaking units are presented and compared in this study. In this study, a four-state model is modified to a three-state model by combining the 'needed' and 'not-needed' forced-out states. Moreover, the transitions in the three-state model for power frequency converter have been designed according to real operational data. An outage-reporting database modelled considering IEEE STD 762 is presented and compared with the existing failure-reporting database of the case considered here. Furthermore, a method to extract information missing in the failure-reporting database by electrical readings is proposed to meet the requirements of the outage-reporting database. The study found that the results of indexes based on the IEEE four-state model are not reasonable for the frequency converter given their differences with the gas-turbine results under operational conditions. The forced outage rates and availability factors of twelve actual traction frequency converters of Swedish railways network are presented to validate the modified model.

1. Introduction

The behaviour of an electric power system is stochastic in nature, and therefore, it is logical to assess such systems using probabilistic techniques [9]. Probabilistic power-system reliability evaluation is becoming increasingly important in new electric utility environments. For ensuring the reliability of power systems, several probabilistic technique measures have been proposed to describe the performance of a generating unit [15]. These performance measures are valuable for identifying weak areas that need reinforcement, monitoring responses to system design changes and establishing indices that serve as guides for acceptable values in future reliability assessments [9,25].

The [15] standardizes terminology and indices to measure reliability, availability and productivity for electric power units. Forced outage rate (FOR) is the one of most common probabilistic indices used for generating units. FOR is a measure of the probability that a generating unit will not be available due to forced outages and is considered as a conventional unavailability index according to the two-state model. The two-state model is suitable for base load units, but it is unsuitable for intermittent operating unit representation because it delivers unreasonably high unavailability index for peaking units [11]. Peaking units normally operate for relatively short periods contrary to base load units that work all the time. Hence to recognize this behaviour, an IEEE task group extended the basic two-state model to a four-state representation for peaking units [16].

The challenge now is to determine the extent to which the four-state reliability model is compatible with operation conditions and transition among states for different peaking units. [10] observed that this model is not reasonable for gas turbines of the Canadian Electricity Association (CEA) in light of the observation of a large number of transitions from the reserve shutdown state to the forced-out but not-needed state. Therefore, they modified the IEEE four-state model by changing the transition states. [5] proposed a model to evaluate the reliability of unified power flow controllers (UPFC). They used three-state and multi-state Markov models to calculate the probability, frequency and duration of states of a UPFC in a composite system reliability evaluation. [19] proposed a three-state reliability model based on the IEEE four-state model for peaking units to consider not only the probability of failure during operation but also the probability of failure due to synchronization in a timely manner. [21] proposed a new version of the four-state model according to the load conditions and load uncertainty for evaluating operational reliability.

The models proposed in literature are based on the differences with the IEEE four-state model in operating conditions. For instance, starting failure can be consider as such differences. The

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probability of starting failure is the inability to serve load during all or part of a demand period. The probability of starting failures is one of the most important reasons for configuring transitions in the IEEE four-state model. This attempt to reach synchronization does not exist in some power units such as frequency converters, but it presents a sizeable challenge in some other power units. The model considers the main difference between power frequency converters and gas turbine units. Therefore, the main purpose of this study is to modify a unit-state model according to the differences in operational conditions and changing the transitions according to the real operational data of a power frequency converter.

In addition, the design of the unit-state reliability model is highly depends on the existing outage database. The main properties of reported outage data from the viewpoint of interpretation of power unit performance are unit state, timing residence and power capacity terms [15]. There are some difficulties and challenges in applying reported failure data to the multi-state model. Among these issues, the major ones are related to the lack of complete data in the main categories of the outage-data reporting system. Therefore, the second issue considered in the study is the development of a methodology to extract missing information from failure data reported using electrical readings to meet the requirements of the outage-data reporting system.

The remainder of this paper is organized as follows. Section 2 describes reliability modelling for power units. Section 3 presents the modified model for power converters. Section 4 introduces a traction frequency converter as a case study. The data extraction program for reading the electrical measurement database is given section 5. Section 6 discusses the results of the case study, and Section 7 presents the conclusions of the present study.

2. Reliability modelling for power unit

Probabilistic reliability analysis has been successfully applied to power-system planning and operation problems such as electrical generation [1,6,12,14,21-25]. The application of probability techniques mainly depend on the availability of data which requires comprehensive data collection of assets such as generating units [11]. In addition, the output of a model is strongly depends on the quality of the data and size of the collected sample. Low quality data or using small sample will increase the uncertainty of the decision making. Furthermore, to have an effective input for reliability analysis to the design, operation and maintenance process, it is necessary to ensure that the right person has access to the right data, in the right format (standardized format) at the right time [7,18]. [2,3] proposed a holistic solution to measure and manage the degree of uncertainty in the reliability indices of repairable systems. They used a novel approach namely fuzzy transformation method to capture the data uncertainty in fuzzy reliability computations to achieve the best possible accuracy using minimum data.

This section describes outage-data reporting for power units, as well as the Markov-process-based unit-state reliability models.

2.1. Outage-Data reporting system for power units

The IEEE STD 762 introduces the main properties of the required outage data of power units in addition to the indexes for measuring reliability, availability, and productivity. Outage-data reporting schemes must be developed and evolved to produce reliable data in suitable forms with details appropriate for the unit-state reliability model. According to IEEE STD 762, outage data should include information such as unit state and time spent in each state [20,15].

2.1.1. Unit states

A unit state is a particular unit condition or status of a unit that is important for collecting data for unit performance. The number of unit states depends on the reliability model used, which describes the actual state of each unit at all times. These states are mutually exclusive and exhaustive. Consequently, these states divide calendar time into non-overlapping segments. Fig. 1 shows the states of activated units: available and unavailable states are divided into additional, mutually exclusive states, for example, 'in-service state' and 'reserve-shutdown state' as available states, and 'planned-outage state' and 'unplanned-outage state' as unavailable states.

Many state descriptions can be used to define the current state of a power unit in order to apply IEEE 762 and calculate the required reliability and availability indexes. The definitions of a few states are as follows:

A- *Available:* A converter is capable of converting service, regardless of whether it is actually in service and regardless of the capacity level that can be provided.

1. *In-service*: The unit is 'electrically connected to the system' and is available for providing output power.
2. *Reserve-shutdown*: The unit is available, but not in service because the system-load demands do not require the unit to operate.

B- *Unavailable*: The converter does not provide power because of a planned outage (maintenance) or forced outage.

1. *Planned-outage*: The state in which a converter is not providing output power due to planned maintenance on a subsystem or component during a time period and can be consider as preventive maintenance. In addition, unplanned outage is referring to the corrective maintenance activities on the frequency converter.
2. *Forced-outage*: A converter is unavailable due to catastrophic component failure resulting in inadequate or complete lack of output power. An outage that results from emergency conditions directly associated with the requirement that a compo-

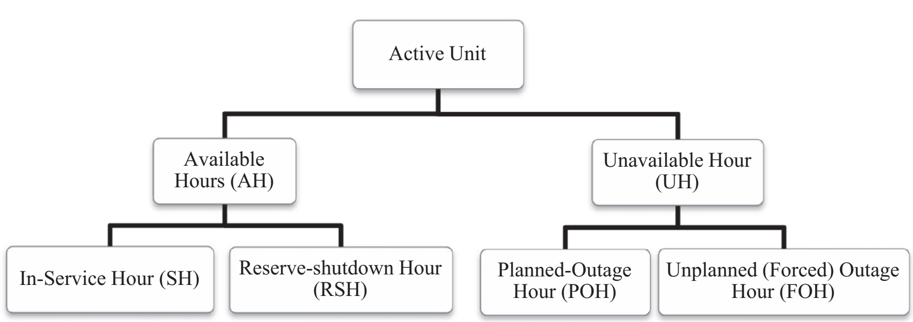

Fig. 1. Unit states and time designations.