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Computational techniques for assessing the reliability and sustainability of electrical power systems: A review

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ABSTRACT

Power systems employ measures of reliability indices to indicate the effectiveness a power system to perform its basic function of supplying electrical energy to its consumers. The amount of energy required in a generating system to ensure an adequate supply of electricity is determined using analytical and simulation techniques. This study focuses on reviewing the generation reliability assessment methods of power systems using Monte Carlo simulation (MCS) and variance reduction techniques (VRTs). MCS is a very flexible method for reliability assessment of the power systems, by the sequential process it can imitate the random nature of the system components and can be broadly classified into two, sequential and non-sequential simulations. A brief introduction to MCS is provided. Unlike analytical methods, MCS can be used to quantitatively estimate the system reliability in even the most complex system generating capacity situations. The major drawback of the MCS is that it requires more computational time to reach for converging with estimated the values of reliability indices. This paper presents an effective methods for accelerating MCS in power system reliability assessment. VRT used is to manipulate the way each sample of an MCS is defined in order to both preserve the randomness of the method and decrease the variance of the estimation. In addition, the study presents detailed descriptions of generation reliability assessment methods, in order to provide computationally efficient and precise methodologies based on the pattern simulation technique. These methodologies offer significantly improved computational ability during evaluations of power generation reliability.

1. Introduction

The basic function of a power system is to supply electrical power efficiently to consumers as economically as possible, with a reasonable assurance of quality and continuity. The modern society required the to be continuously the supply of electrical energy on consumers demand [1]. A wide range of techniques are available for assessing engineering systems and evaluating their reliability indices, and these should be carefully interpreted and understood.

Generating capacity reliability indices assist in producing sufficient energy to satisfy demand using a given amount of energy consumption in the system. Generating capacity can be defined in terms of adequacy of as the installed generating capacity required satisfying a particular load demand. The amount of generating capacity required to ensure sufficiency of electricity supply is determined by evaluating the reliability indices of the power system. There are two main approaches; the use of analytical methods and the performance of simulations using the Monte Carlo simulation (MCS) [2,103,143].

Both approaches have advantages and disadvantages [4–7]. Analytical methods generally use basic knowledge and mathematical models, recounting and combining the probabilities and frequencies of system conditions to check reliability indices. MCS describes a problem as a sequence of actual experiments that determines the operating characteristics of a system and its components. Reliability indices are then evaluated by observing the experiments. In general, reliability evaluation depends on the analytical assessment methods [8] but introduces MCS as an alternative solution to illustrate the random behavior of a system and its components.

The advantage of MCS over analytical techniques is its improved capability to simulate the actual operation of a power system; hence, it provides a more accurate evaluation of reliability indices [1,9]. MCS is an extremely robust computer-based technique for estimating system reliability and, in most cases, applying MCS requires considerable computational time to obtain accurate and reliable results. Moreover, it

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requires input information in the form of distributions as well as the more conventional prospect values used in many analytical methods [10].

This work reviews reliability assessment methods for power systems generating capacity based on the use of MCS, supplemented by the application of applied VRTs since the number of samples required by MCS methods can be reduced using VRTs [101,142,144]. VRTs rely on presumed information concerning the analytical model of a system under simulation and are effective for reducing variance. The combination of VRTs and the Monte Carlo algorithm minimizes computational effort, and in many cases, the VRTs employed to provide the same general applicability as the standard MCS (sampling) method, but offer superior computational efficiency.

The main objective of this paper is to present efficient estimation and accurate models based on a pattern simulation technique to minimize computational efforts significantly while evaluating generation system reliability. Reliability evaluation is an important aspect of any generation system, many techniques have been developed to assess power system reliability. Hence, in this study, focus on a comprehensive review of the probabilistic techniques applied to reliability evaluation of the generation systems. The two main probabilistic techniques that the analytical approach and the MCS approach. Father, this study displays by using the various methods are available in the literature, that used to improve the MCS approach namely variance reduction techniques. In addition, the study presents descriptions of the new robust computational intelligence techniques that are widely used in power system generation applications. These techniques are often utilized to solve the complex problems in power system, which are difficult to solve with conventional methods.

The remainder of this paper is arranged as follows: Section (2) contains an analysis of a power system demonstrating that the main functional zones provide the most convenient basis for its division. Section (3), explains the basic principles of the analytical methods and the Monte Carlo simulation. Section (4), illustrates the Variance Reduction Techniques and discusses the importance of sampling in Monte Carlo simulation. Section (5) clarifies several methodologies for reducing computational effort by combining the Monte Carlo simulation and the Variance Reduction Techniques. Finally, Section (6) presents the conclusions of the work.

2. Generation reliability assessment

Quantitative reliability assessments should not only evaluate a system's actual physical components in terms of performance and random behavior, but also the overall requirements, procedures, and engineering issues inherent in the system's operation [11]. A power system is an extremely complex, advanced and integrated structure [12]; even the most advanced computer programs lack the capacity for comprehensive, holistic interpretation for these systems. Consequently, power systems are frequently divided into appropriate subsystems that can be separately analysed.

The most convenient means for dividing a power system are its main functional zones; namely its generating capacity systems, composite systems, and distributed power systems. Hierarchical levels (HL) have been developed [13] to determine an identical means of grouping and identifying the aforementioned functional zones, as illustrated in Fig. 1. The figure shows that the primary level (HLI) refers to the generation facilities and their capability to satisfy pooled system demand; the second level (HLII) refers to the composite generating and transmission system and its capability to deliver energy to other major points; and the last level (HLIII) refers to the entire system as well as the distribution system and its capability to satisfy the energy demands of individual customers.

The main function of a power system is to supply consumers with electrical power as economically as possible at an acceptable level of quality [14,15]. The term reliability index, when applied to generation

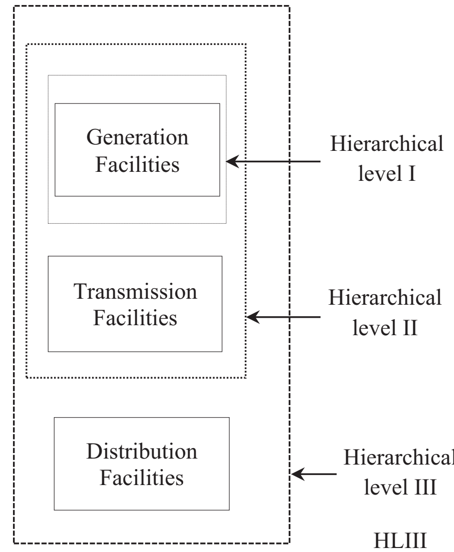

Fig. 1. Hierarchical reliability assessment levels [1].

systems, refers to performance measures of the generating system capacity that can influence the continuity of electrical power supply to the customer. Two basic concepts are used in system capacity assessments: adequacy and security. Generating capacity requirements can also be separated into two basic categories: static capacity, which correlates with the long-term estimate of overall system demand; and operating capacity, which is a short-term correlation with the actual capacity required to meet a specified load.

Adequacy assessment considers the entirety of the facilities within a system and their sufficiency to satisfy consumer load demands. Adequacy is therefore associated with a static level of demand which is exclusive of transient system disturbances [2]. The evaluation of generating adequacy reliability can, therefore, be addressed by using either probabilistic or deterministic method. Over the last few decades, a large number of publications have proposed different probability techniques for generation reliability evaluation [16–23]. Adequacy correlates with the system's ability to satisfy load demand in the case of planned or unplanned capacity outages.

Inadequacy can result from insufficient available generation capacity or inability of the transmission or distribution networks to transfer energy to the customer load points. Often, therefore, calculation of the adequacy indices used in assessing generation power systems at one of the three hierarchical levels depends fundamentally on the expected values of a random variable which representing the average value of the reliability indices within a probability distribution. There are many indexes to assess the adequacy of a power system as can be seen in Fig. 2.

3. Adequacy assessment methods

Determining the amount of generating capacity required to satisfy load demand is an important concept in electrical power system operation and planning. The modern approach to evaluating reliability indices for generation system capacity is based on two alternative assessment methods for predicting the reserve capacity required to meet the load demand with a predetermined level of reliability. These assessment methods comprise analytical and simulation techniques and both approaches are used in electric power utilities at the present time.

Simulation techniques are used to imitate unpredictable performance in power systems, either in a random or sequential way [1,9]. Analytical assessment methods are easily and simply applied using mathematical analysis to derive precise analytical solutions to the value