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# Probabilistic generating capacity adequacy evaluation: Research roadmap

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ABSTRACT

Evaluation of the adequacy of generating capacity is one of the main planning challenges within the field of power system. With respect to the evaluation of power system reliability, a variety of criteria and techniques have been developed and utilized by numerous utilities over a number of decades. Of these, deterministic and probabilistic techniques are the ones widely used for the evaluation of generating capacity adequacy. Nowadays, modern power systems have emphasized the need for probabilistic techniques to address the challenges that power system undergone and ensure generation adequacy where the applicability of deterministic techniques is no longer valid.

The goal of this roadmap research paper is to provide a comprehensive and adequate overview of commonly used probabilistic techniques for generating system adequacy assessment: analytical, non-sequential, and sequential Monte Carlo simulation. The literature review presented in this paper, which includes theories, methodologies, analyses, and discussions, aims to provide useful information to planners or developers who endeavor to assess the reliability of existing power generation systems and plan for future generating capacity additions. Moreover, a valuable background review assembled from different sources is expected to serve students and researchers who are interested in studying in this area.



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## 1. Introduction

With regard to power systems, reliability is the measure of their overall ability to meet the electrical energy needs of customers [1]. According to the North American Electric Reliability Corporation (NERC), power system reliability can be defined as: "the ability to meet the electricity needs of end-use customers, even when unexpected equipment failures or other conditions reduce the amount of available power supply" [2]. Power system reliability is typically viewed as having two aspects: system adequacy and system security [3–5]. System adequacy can be defined as the existence of sufficient facilities within a power system to meet the load requirements without the violation of steady-state limits. System adequacy refers to static conditions rather than dynamic and transient system disturbances, and is normally associated with the reliability assessment of system planning in a long-term timeframe, from a year to several years. System security, however, signifies the ability of the system to withstand various sudden disturbances, such as voltage instability situations or unanticipated sudden loss of system elements. System security is therefore associated with dynamic or operational measures in a short-term timeframe of between a few minutes and an hour.

These two fundamental concepts (system adequacy and security) are ubiquitous throughout the literatures in North America and they are in accordance with existing reliability definitions of the North American Electric Reliability Corporation (NERC) and the Institute of Electrical and Electronics Engineers (IEEE). These two categories are viewed in most literatures in Europe as long-term security of electricity supply and short-term security of electricity supply [6]. According to Eurelectric [7], long-term security of supply refers to "the ability of providing electricity to end-users with a specified level of continuity and quality in a sustainable manner". The short-term security of supply, on the other hand, relates to "the actual delivery of electricity, and means the operational reliability of the system as a whole and its assets, including the ability to overcome short-term failures of individual components".

Modern power systems are very large, complex, highly integrated networks, and thus it is difficult, if not impossible, to evaluate the reliability of an entire power system [3]. In this respect, within the field of power system reliability, a power system is traditionally divided into three functional zones (generation, transmission, and distribution) to provide a succinct means of identifying the part of the power system being analyzed. The three functional zones can be organized into three hierarchical levels, as shown in Fig. 1 [5].

At hierarchical level I (HL-I), reliability evaluation usually pertains to generating capacity adequacy, with the only concern being an examination of the ability of the system to meet the aggregated system load. At this level, the transmission and distribution facilities are disregarded [8,9]. Adequacy evaluation at hierarchical level II (HL-II) includes both the generation and transmission facilities and usually pertains to the evaluation of the reliability of the composite system or bulk power system. At this level, adequacy evaluation becomes an assessment of the integrated ability of the generation and transmission systems to deliver energy to the load points [10,11]. The last level indicates an overall assessment that includes consideration of all three functional segments and is identified as hierarchical level III (HL-III). Adequacy evaluation at HL-III, which includes all three functional zones simultaneously, is quite difficult to conduct in a practical system due to the computational complexity and large-scale modeling involved. Thus, reliability analysis at this level is usually performed separately in the distribution functional zone, using the results of HL-II as an input [12,13].

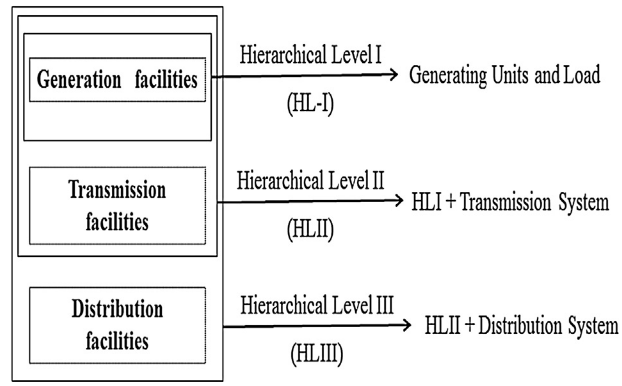


**Fig. 1.** Hierarchical reliability assessment levels [5].

The research work presented in this paper is devoted to the aspect of adequacy assessment of power generating systems, and deals only with the HL-I adequacy analysis, leaving other the levels for future investigation.

The main goal of this paper is to provide a comprehensive and adequate overview of the literature pertaining to generating system adequacy assessment in particular; targeting planners, developers, researchers and students interested in studying in this area. Accordingly, to achieve the ultimate objectives of this research, this paper is divided into five main parts. The first part reviews the general aspects associated with power system reliability, covering its scientific definitions as well as main types and categories. The second part reviews the basic concepts and related aspects of generating system adequacy assessment, and includes the adequacy problem statement, detailed description of the involved elements. The third part describes the required methodologies and calculations to evaluate the adequacy capacity for conventional generation using the most common probabilistic techniques (analytical, non-sequential and sequential Monte Carlo simulation (MCS)). The fourth part presents the application of these methods to two test systems, designated the Roy Billiton test system (RBTS) and the IEEE reliability test system (IEEE-RTS), and evaluates their adequacy by examining the data related to their supply and demand systems. The obtained results using three probabilistic techniques are validated and verified with the available work in literature that assembled from different resources and this is followed by exhaustive discussion on the performance and efficiency of the three evaluation techniques considering different aspects. The final part discusses the generation adequacy problem when wind generation is integrated. It also reviews what some of the reported works have been proposed to involve wind generation into adequacy assessment.

## 2. Adequacy assessment HL-I

The basic representation for a system being analyzed in HL-I can be considered as a single bus with both the generation and load models connected to it. Therefore, the transmission systems and