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Locational transmission capacity reserve determination using system well-being analysis

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ABSTRACT

This paper presents a methodology to determine the locational transmission capacity reserve required to provide additional transmission transfer capability to access remote generation. The methodology is based on translating the accepted deterministic criteria into probabilistic measures using the system well-being analysis framework. The objective of utilizing system well-being analysis is to help to identify and characterize the actual system reliability concerns regarding the exclusive use of deterministic criteria, and to help to determine what the appropriate deterministic reliability criteria should be so that power utilities can adjust and expand the deterministic criteria to cope with uncertainty considerations that exist in practical power systems. An application of system well-being analysis to determine the locational transmission capacity reserve on an actual island system in Canada is illustrated in this paper.

1. Introduction

Deterministic criteria have been employed by most power utilities for bulk electric system planning and operation for many years due to their favorable features such as uncomplicated concept, simple implementation and assessment, and solid judgment. In order to incorporate system reliability in transmission system planning, most power utilities use deterministic techniques such as the N-1 security criterion which implies that the system should be able to withstand the outage of any major single component, i.e. the worst single contingency, without violating the operating criteria. The traditional deterministic approach typically considers pre-specified constraints on operating conditions such as generation patterns, MW flows and bus voltages, to determine if the loss of a single circuit or generator will result in a violation of the operating criteria. The drawback with this practice is that all the resulting limits are inflexible outcomes in which there is no mechanism for adjusting the limit inflexibility as a function of the probability or consequence of the contingency occurring [1]. In other words, deterministic measures strictly indicate that either the system meets or does not meet the given criteria, and do not provide any guiding information on the likelihood and/or how far off (or how close) the system is to meeting (or to violating) the criteria.

Deterministic reliability criteria are used to limit the stress level of a system without creating unacceptable risk. Reliability criteria determine the balance between reliability and the allowable system utilization in system planning and operation. Power system restructuring compounded with rising penetration of intermittent energy sources, creates an increased transmission utilization resulting in an increase in the system stress level. The design, operation and application of deterministic criteria to properly balance the utilization and reliability of power systems will become increasingly challenging in the changing system environment. A transmission transfer limit determined solely by the N-1 criterion may no longer be the appropriate choice [2] under new power system paradigms.

Although the N-1 security criterion has conveniently and reasonably served power utilities quite well in the past, it does not however guarantee that the system security will remain sufficient for present systems and for future systems involving greater uncertainties. Deterministic approaches, therefore, may not be consistent and thus may not provide an accurate reliability assessment for actual system conditions. The essential weakness of the N-1 criterion is basically due to the fact that it does not incorporate the stochastic nature of power system behavior and therefore does not provide an actual system reliability assessment [3]. The deterministic N-1 criterion is, however, definitely easier for

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engineers, managers and regulators to appreciate than quantitative indices obtained using probabilistic approaches. This conflict can be eased by incorporating the deterministic N-1 criterion, which is an inflexible criterion, in a probabilistic framework to provide a resulting flexible criterion. This concept is designated as system well-being analysis [4,5], which provides a mechanism to augment the traditional deterministic criteria using probabilistic analysis procedures. The intent in utilizing system well-being analysis in the study described in this paper is not to simply replace deterministic criteria with probabilistic reliability considerations. The purpose includes identifying and characterizing the actual system reliability concerns in addition to determining what appropriate deterministic reliability criteria should be utilized so that power utilities can adjust and expand these criteria to meet the new stochastic realities.

This paper proposes a methodology to determine the required locational transmission capacity reserve using system well-being analysis. The locational transmission capacity reserve is defined as the additional transmission capacity required to access and deliver the required power from more remote generation to supply a local area load. This can be considered as an interconnected system (or multi-area) reliability assessment in which the local generation reserve margin and/or transmission capacity reserve through the inter-tie lines can be assessed. The probabilistic multi-area reliability assessment based on traditional adequacy consideration was applied to determine the local generation reserve margin [6]. In contrast to the long-term transmission system planning and design arena, most power utilities essentially rely on deterministic security criteria to justify the transmission system capacity requirement as well as additional transmission capacity in the form of capacity reserve. In some utility jurisdictions, and particularly for generation deficit areas (load dominant area) that rely heavily on inter-tie lines to access remote generation from neighboring areas, a stringent deterministic security rule such as the N-1-G criterion in which a loss of single transmission component together with a loss of critical local generating unit is applied [7,8]. The use of the N-1-G security criterion in transmission planning, on one hand, could improve the system reliability. On the other hand, the resulting reliability level associated with this criterion may not be consistent and may involve significant cost if the size of the critical local generating unit in the studied area is quite large leading to a substantial amount of transmission capacity being reserved under the specified security criterion. The method proposed in this paper attempts to reasonably determine the additional transmission capacity as the reserve required to access remote generation through the interconnected systems. The methodology is based on translating deterministic criteria into probabilistic measures using system well-being analysis. Once the probabilistic index driven by the deterministic criteria has been established, this index can be used as a benchmark value to determine the locational transmission capacity reserve requirement. This paper is organized as follows. Section 2 explains the system well-being analysis concept. Section 3 presents the study system and conditions used in the study. The study methodology is then described in Section 4. Section 5 shows the study results for the base case scenario and the sensitivity study scenarios. Section 6 presents the conclusions.

2. System well-being analysis

Most power utilities use deterministic techniques such as the N-1 security criterion to assess the reliability of bulk electric systems. There are two types of security analysis: transient (dynamic) and steady-state (static) analyses. Transient stability assessment consists of determining if the system oscillations following an outage or a fault will cause loss of synchronism between generators. The objective of static security analysis is to determine whether, following the occurrence of a contingency, there exists a new steady-state secure operating point where the perturbed power system will settle after the dynamic oscillations have damped out. Incorporation of steady-state security considerations in the adequacy evaluation is designated as security constrained adequacy analysis that is focused on the overall operation of the bulk power system as presented in this study. Although the study presented in the paper focuses on static security and adequacy considerations while ignoring transient stability phenomena, the transient stability consideration can also be incorporated into the system well-being analysis framework if required since this only requires adding transient stability analysis outcomes in division among the healthy, marginal and at-risk states.

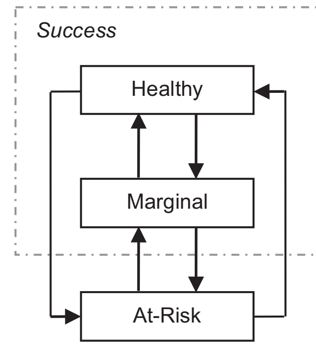

Fig. 1. System well-being framework.

A bulk electric system is traditionally divided into several operating states in terms of the degree to which adequacy and security constraints are satisfied [9–12]. The system well-being concept is a probabilistic framework incorporating the simplified operating states associated with the accepted deterministic N-1 criterion. The well-being structure shown in Fig. 1 was proposed in [4], and is a simplified version of the traditional operating state framework described in [9–12]. System well-being analysis applications using analytical techniques are presented in [13,14]. The system well-being analysis concept has been extended using non-sequential [15] and sequential [16] Monte Carlo simulation techniques. System well-being can be categorized into the three states of healthy, marginal, and at-risk, as shown in Fig. 1. In the healthy state, all equipment and operating constraints are within limits, and there is sufficient margin to serve the total load demand, even with the loss of any element, i.e., generator or transmission line. In the marginal state, the system is still operating within limits, but there is no longer sufficient margin to satisfy the acceptable deterministic criterion. In the at-risk state, equipment or system constraints are violated, and load is curtailed. In other words, the at-risk state is the loss of load state in a traditional adequacy assessment.

Well-being analysis provides a combined structure that incorporates deterministic considerations within a probabilistic framework by determining the likelihood of encountering marginal system states in addition to encountering system at-risk states. In other words, it provides system engineers and risk managers with a quantitative interpretation of the degree of system security (healthy state) and insecurity (marginal state) in a bulk electric power system in addition to the traditional risk measures. If some contingencies (system states) that used to reside in the healthy state move or transition to the marginal state, the system becomes stressed and the probability of the marginal state increases. As a result, system conditions become more difficult for the system operator to manage when the system is under N-1 situations. In other words, the higher the healthy state probability is planned or designed, the more robust the system will be from both planning