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Chronological simulation for transmission reliability margin evaluation with time varying loads

A.B. Rodrigues [1], M.G. Da Silva *,[1]

Federal University of Maranhão, Department of Electrical Engineering, 65080-040 São Luís Maranhão, Brazil

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ABSTRACT

This paper has as objective to assess the chronological variations in the Available Transfer Capability (ATC) caused by uncertainties associated with hourly load fluctuations and equipment availabilities. The system states resulting from these uncertainties are generated using the Monte Carlo Method with Sequential Simulation (MCMSS). The ATC for each generated state is evaluated through a linear optimal power flow based on the Interior-Point Method. These ATC values have been used to generate the probability distribution of the hourly ATC. This probability distribution enabled to estimate the Transmission Reliability Margin (TRM) for a specified risk level. The results, with a modified version of the IEEE Reliability test System, demonstrate that the time dependent uncertainties have a significant impact on the TRM.

1. Introduction

The restructuring of the electric sector has been stimulated by the economic benefits to society resulting from the deregulation of other industries such as telecomunications and airlines. Currently, electrical utilities around the world are undergoing a radical transformation from an essentially regulated and monopolistic industry to a new model characterized by competition in generation with guaranteed access to open transmission [1].

The supply competition and the open transmission services have caused an increase in the number of transactions among market agents such as generation/distribution companies, pool companies and brokers [2,3]. The transactions carried out among these agents are defined by market forces without considering engineering problems of controlling, operating and planning of an electrical power system. Consequently, there may exist transactions that violate system operation constraints, that is, unfeasible transactions. Nevertheless, the transmission expansion has not been stimulated. This situation has been caused by right-of-way constraints and investment limits for the power sector budget due to economic difficulties. These constraints have compelled transmission providers to operate the interconnections near to their limits. Due to this operating condition new indices have been developed with the objective of providing a quantitative assessment of the power transfer reliability, among them the ATC.

The ATC is a measure of the transfer capability remaining in the physical transmission network for future commercial activity over and above already committed uses [4]. Consequently, the ATC is subject to uncertainties in system parameters such as: generation dispatch patterns, load fluctuations and equipment (lines and generators) availabilities. These uncertainties may cause significant variations in the ATC. Due to this, the North American Electric Reliability Council (NERC) has recognized the importance of including the system uncertainties in the ATC evaluation [4].

Usually, the impact of system uncertainties on the ATC has been assessed using probabilistic methods [5–13]. These methods have been preferred due to their capacity to model, not only the severity of a state or event and its impact on system behavior and operation, but also the likehood or probability of its occurrence. The combination of severity and probability provides indices that really express the system risk [14–17].

The probabilistic assessment of power transfers consists basically of two main steps: the selection of a system state and the power transfer evaluation for the selected state. The power transfer evaluation for a system state was carried out using both nonlinear [5–10] and linear [11–13] models of the electrical network. On the other hand, the most used technique for the state selection is the Monte Carlo Method (MCM) with non-sequential simulation [7–13]. The MCM with non-sequential simulation can accurately model uncertainties associated with equipment availabilities and load forecast errors. These uncertainties can be modeled without

* Corresponding author.
E-mail addresses: nebulok_99@yahoo.com (A.B. Rodrigues), guia@dee.ufma.br (M.G. Da Silva).

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considering the system chronological state transition process. However, the ATC is a function of chronology dependent phenomena such as: hourly load variations, equipment maintenance and limited-energy hydro resources. Furthermore, NERC has recognized the importance of assessing the ATC in a time dependent structure [4].

The impact of time dependent parameters in the ATC may be modeled with the application of the MCMSS [18–23]. The main aim of this paper is to carry out a probabilistic analysis of chronological variations in the ATC using the MCMSS. The ATC associated with each sampled system state will be evaluated by a linear Optimal Power Flow (OPF) algorithm. This algorithm is based on the Interior-Point Method for linear programming. These ATC values have been used to obtain the probability distribution of the hourly ATC. This probability distribution enables to estimate the TRM for a specified risk level. The TRM is defined as the amount of the transmission transfer capability necessary to assure that the interconnected transmission network is secure under a reasonable range of uncertainties in the system conditions [4]. The proposed methodology, to analyse chronological variations in the TRM, has been tested in a modified version of the IEEE Reliability Test System [24], henceforth called MRTS. This assessment was carried out for a weekly study period. The results with the MRTS demonstrate that the uncertainties associated with hourly load transitions and equipment availability cause significant variations in the TRM.

The rest of the paper is organized as follows: Sections 2 and 3 describes the methodology used to analyse the chronological variations in ATC and TRM, respectively. The results are given in Section 5. General conclusions are given in Section 6.

2. Outline of methodology

In a competitive environment, the generation companies, distribution utilities and brokers market energy through bilateral or multilateral transactions. However, not all energy is marketed through bilateral and multiateral transactions [3,25]. For example, generators and loads may carry out price and quantity bids in a Pool [25].

The bilateral/multilateral transactions and the loads/generators belonging to the Pool use the transmission system in a shared way. Therefore, there must be a coordination strategy between Pool dispatch and bilateral/multilateral transactions. In this paper, the ATC is evaluated considering the simultaneous existence of both Pool and bilateral transacations in the same market structure. The strategy used to coordinate the Pool dispatch and bilateral transactions is the Pool Protection Mode (PPM) [25]. In the PPM, the generators and loads belonging to the Pool have priority over bilateral transactions. That is, bilateral transactions are introduced in the electric network after the load/generation dispatch in the Pool. This priorization procedure guarantees that the power transfers between selling and buying nodes of bilateral transactions do not cause a deterioration of the reliability indices associated with the Pool loads. Nevertheless, other strategies for coordination between Pool and bilateral transactions are possible. For example, bilateral transactions have priority over the load of the Pool when these have declared in advance [25].

By analysing the PPM, it can be noted that an amount of the transmission transfer capability is reserved for the Pool entities. This amount is known as Capacity Benefit Margin [4]. In this way, the PPM models the Capacity Benefit Margin as firm transfers [8]. In other words, curtailments in the Pool loads are not used to improve the ATC.

In the PPM, the system operator must evaluate the ATC, associated with the bilateral transactions, after the Pool dispatch has been carried out. The ATC associated with a bilateral transaction is the maximum amount of power that a transmission system can transport in addition to the already committed transmission services, when power is injected at one location (selling node) and the same amount of power is extracted at the same time at another location (buying node) without violation of transmission constraints [26,27]. The ATC values evaluated by the system operator are posted in an OASIS (Open Access Same-Time Information System) aiming to help power marketers, sellers and buyers to schedule their energy interchanges.

In this paper, the bilateral contract ATC is evaluated considering uncertainties associated with chronological load variations and equipment availabilities. These uncertainties have been modeled using the MCMSS. The MCMSS is the natural tool for estimating probabilistic indices in systems with time correlated or time dependent operation [18–23]. The MCMSS consists basically of generating one sample of system scenarios to estimate probabilistic indices from this sample. A system scenario is composed of a collection of system states in chronological order. That is, a system state can be considered as "a conceivable static photo of the system", while a system scenario can be considered as "a video containing a conceivable story of the system, covering the study period (e.g. a week or a year)" [20]. Usually, the system operating scenarios are generated using a State Duration Sampling Technique [15]. In this approach, the state transition sequences of the components are firstly generated by sampling the duration of the up and down states. These durations are sampled using the probability distributions that model the operation and repair times. Secondly, the state transition sequence of the components are combined to generate a system scenario. In this paper, the duration of up and down states associated with generators and circuits have been sampled using the Inverse Transform Method [15]. In this method, the state durations are sampled as follows:

(1) Generate a uniform distribution random number U between [0,1];
(2) Calculate the duration of the current state by $X = F^{-1}(U)$, where $F^{-1}(U)$ is the inverse of the cumulative probability distribution $F(X)$ that models the duration X of the current state. If the durations of the up and down states are exponentially distributed, then $X = -\overline{T}\ln(U)$. If the present state is the up-state, $\overline{T}$ is equal to the Mean Time to Failure (MTTF). On the other hand, if the current state is the down state, $\overline{T}$ is equal to the Mean Time to Repair (MTTR).

After the system scenario has been generated, the ATC assessment of each system state of the scenario is carried out in chronological order. This assessment consists of two main steps. First, the Pool dispatch is carried out with the objective of minimizing the generation costs and maximizing the customers worth subject to the following constraints: power balance equation, power injection limits and circuits loading [1]. Secondly, the ATC is evaluated by maximizing the power injections in the selling and buying nodes of the bilateral transactions, in accordance with the Willingness to Pay to Avoid Curtailments (WPAC) of each transaction [2]. The ATC evaluation must satisfy the same constraints of the Pool dispatch. Furthermore, the objective function of the ATC evaluation minimizes the costs of the available generation resources that may be used to improve the ATC.

The Pool dispatch and the ATC evaluation are solved using the version of the Predictor-Corrector Primal-Dual Interior-Point Method proposed in [28]. The method proposed in Ref. [28] has been chosen because:

(1) variables with upper and lower bounds are easily modeled;
(2) unified modeling of inequality and equality constraints is considered;