



Formulation, computation and improvement of steady state security margins in power systems. Part I: Theoretical framework

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ARTICLE INFO

Article history:

Received 22 March 2010

Received in revised form 5 July 2010

Accepted 13 August 2010

Keywords:

Steady state analysis

Security margins

Power flow feasibility

Contingency analysis

Voltage collapse

Total transfer capability

ABSTRACT

A steady state security margin for a particular operational point can be defined as the distance from this initial point to the secure operational limits of the system. Four of the most used steady state security margins are the power flow feasibility margin, the contingency feasibility margin, the load margin to voltage collapse, and the total transfer capability between system areas. A comprehensive literature survey has shown that these security margins have been studied separately. This fact has suggested to the authors the possibility of researching a common analysis framework valid for all of them. This is the first part of a two-part paper. In part I, a novel mathematical formulation valid to address the study of any steady state security margin is proposed. The developed general approach is presented in three steps: (a) formulation, (b) computation, and (c) improvement of security margins. In part II, the performance of the proposed approach when used to compute and improve the aforementioned steady security margins is illustrated through its application to the Spanish power system. Results denote that this approach can be a useful tool to solve a variety of practical situations in modern real power systems.

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1. Introduction

A steady state security margin for a particular operational point can be defined as the distance from this initial point to the secure operational limits of the system. In the field of electric power systems, the security margins are closely related with the different states where the system could be operated: normal, alert, emergency and extreme [1]. Therefore, steady state security margins are measures of how far or close from these operating states the system is.

Various steady state security margins are commonly used in power system planning and operation. This paper is focused on four of the most widely used steady state security margins: the power flow feasibility margin, the contingency feasibility margin, the load margin to voltage collapse, and the total transfer capability between system areas. The power flow feasibility margin indicates how far a power system that is infeasible in the base case is from being feasible, whereas the contingency feasibility margin measures how far a power system that is infeasible under contingency is from feasibility. In this regard, infeasible means that no solution can be found for the power flow equations. Moreover, the load margin to voltage collapse represents the distance of the static power flow equations from the initial point of operation to its saddle-node bifurcation.

Finally, the total transfer capability is defined as the amount of electric power that can be transferred over the interconnected transmission network between system areas under some established system security conditions.

These four security margins are qualitatively represented by different physical magnitudes. In this paper, a comprehensive literature survey of these four margins is presented. A wide variety of techniques have been developed not only for the computation of security margins but also for their improvement by using different control resources such as voltage control devices, active power generation redispatch, or emergency load shedding. Nevertheless, the literature survey has shown that these security margins have been studied separately. Consequently, the authors deemed it interesting to research the possibility of developing a common analysis framework valid for all of them. Thus, this paper proposes a general framework to unify all the aforementioned steady state security margins under the same mathematical formulation. This approach allows designing a general method to compute and improve steady state security margins.

The proposed approach is presented in three steps: (a) formulation, (b) computation, and (c) improvement of security margins. The proposed steady state security margin computation methodology is based on the combination of continuation and non-linear optimization techniques. It has been designed using a sequential linear programming scheme, and is valid for any control resources of the system such as voltage control devices, active power generation redispatch, or emergency load shedding.

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