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Formulation, computation and improvement of steady state security margins in power systems. Part II: Results

F.M. Echavarren *, E. Lobato, L. Rouco, T. Gómez

School of Engineering of Universidad Pontificia Comillas, C/Alberto Aguilera, 23, 28015 Madrid, Spain

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ABSTRACT

A steady state security margin for a particular operating point can be defined as the distance from this initial point to the secure operating 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. This is the second part of a two part paper. Part I has proposed a novel framework of a general model able to formulate, compute and improve any steady state security margin. In Part II the performance of the general model is validated by solving a variety of practical situations in modern real power systems. Actual examples of the Spanish power system will be used for this purpose. The same computation and improvement algorithms outlined in Part I have been applied for the four security margins considered in the study, outlining the convenience of defining a general framework valid for the four of them. The general model is used here in Part II to compute and improve: (a) the power flow feasibility margin (assessing the influence of the reactive power generation limits in the Spanish power system), (b) the contingency feasibility margin (assessing the influence of transmission and generation capacity in maintaining a correct voltage profile), (c) the load margin to voltage collapse (assessing the location and quantity of loads that must be shed in order to be far away from voltage collapse) and (d) the total transfer capability (assessing the export import pattern of electric power between different areas of the Spanish system).

1. Introduction

A steady state security margin for a particular operating point can be defined as the distance from this initial point to the secure operating 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. Therefore, steady state security margins are measurements of how far or close is the system from these operating states. The study of any steady state security margin implies three tasks: definition, computation and improvement. This paper focuses on four of the most useful steady state security margins: power flow feasibility margin, contingency feasibility margin, load margin to voltages collapse and total transfer capability (*TTC*).

This is the second part of a two-part paper. Part I has reviewed these four index within the literature: there exist many techniques not only for their computation but also for their improvement using the control resources of the system, such as voltage control resources, active power generation redispatch or emergency load shedding. The literature survey demonstrated that these security margins have been covered separately and suggests the possibility of researching a common framework valid for all of them. In this way, a general framework has been formulated in Part I, able to define, compute and improve any steady state security margin.

This general formulation is based on a non-linear optimization problem. The objective function consists of maximizing the security margin, subject to equality constraints (system state equations) and inequality constraints (system variables limits).

Using this general formulation, two general methodologies, one for solving the general security margin computation problem and another for the security margin improvement, have also been developed in Part I of the paper. The steady state security margins computation methodology is based on the combination of continuation and optimization techniques. The solution obtained is not only the security margin, but also the state variables and the Lagrange multipliers of the computation problem constraints. The steady state security margin improvement methodology has been designed using a sequential linear programming scheme, where first order sensitivities of the security margin with respect to the system control variables are computed and introduced in the optimization programming model. The improvement methodology is a general formulation and thus valid for any control resource of the system.

* Corresponding author. Tel.: +34 91 542 28 00x4283; fax: +34 91 540 62 89.
E-mail address: francisco.echavarren@iit.upcomillas.es (F.M. Echavarren).

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