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# Multi-parameter trajectory sensitivity approach for location of series-connected controllers to enhance power system transient stability

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ABSTRACT

Determining suitable locations of series-connected controllers is a practical problem when it is necessary to install them in modern power systems. The aim of this paper is to find the best location of series controllers in order to reduce the proximity to instability of a current operating point of a power system, from a transient stability viewpoint. In order to achieve this goal, a general approach has been developed based on an index of proximity to instability and trajectory sensitivity analysis. An efficient way to carry out multi-parameter sensitivities is formulated analytically and solved simultaneously with the set of differential-algebraic equations representing power system's dynamics within a single-frame of reference. Simulations are performed on 9-bus and 39-bus benchmark power systems for illustration purposes. Results show that the proposed approach provides the most effective location of series-connected controllers to improve the power system's transient behavior.



## 1. Introduction

Advances in Flexible AC Transmission Systems (FACTS) controllers have led to their application in improving electric power systems' controllability [1,2]. It has been recognized that the location of these controllers has a large impact on their performance with regard to the control objective to be fulfilled. The best allocation for one objective may be less suitable for another objective. This has motivated the development of several kinds of approaches for finding proper locations of FACTS controllers in order to improve the power system's static or dynamic performance. Methodologies based on singular value decomposition [3], bus participation factor [4], augmented Lagrange multipliers [5], heuristic methods [6,7], mixed integer linear programming [8] and a sensitivity-based approach [9,10] have been proposed to allocate controllers to satisfy suitable steady-state control objectives. On the other hand, proper locations to improve damping of low-frequency electromechanical oscillations have been determined based on modal analysis [11–13] and residue method [14,15].

Transient stability analysis is also an essential study in the operation and planning of an electric power system [16]. If this study determines that a rotor angle transient instability takes place due to large electromechanical oscillations among generation units and lack of synchronizing torque on the system, control actions have to be taken to prevent partial or complete service interruption. Among different preventive control measures, it is possible to apply series compensation in a proper place to regain an acceptable state of equilibrium after the disturbance by improving the system's stability condition [16]. The stability condition can be computed by a time domain simulation which is applicable for arbitrarily complicated models, and it is feasible for large-scale power system analysis. However, this simulation only provides information about a single scenario, and repeated simulations have to be done to assess the degree of system stability for any change in system operating conditions.

The system's stability condition can be examined from the viewpoint of system energy rather than in time domain through the Transient Energy Function Method (TEF) [17,18]. In this method, the numerical integration of the system dynamic equations is limited to the fault-on period to determine the energy associated with the system at the end of the disturbance. A major advantage of the TEF method is that can provide a quantitative measure of how stable or unstable a particular case may be in terms of the transient energy margin. This in-turn allows sensitivity analysis to give information about the effect of system's parameter variation on system's stability. In this context, based on the TEF method, a critical energy sensitivity analysis of the post-fault period is proposed in [19] to determine the effective location of FACTS devices, where the entire network is reduced to the internal node of the machines. Analytical expressions for energy margin sensitivity are proposed in [20] to assess the effect of change of line impedance on the energy margin for a specified contingency scenario, considering the machine internal node formulation. This methodology is extended in [21] to determine the effectiveness of shunt and series FACTS

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