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# Voltage stability assessment of a power system incorporating FACTS controllers using unique network equivalent

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**Abstract** Voltage instability is considered as a main threat to stability, security, and reliability in the modern power systems. Prediction of voltage stability limit of multi-bus system through its two-bus equivalent model is a hot topic of the research in the field of power system operation and control. This paper presents a novel method to assess voltage stability status using a unique two-bus π-network equivalent derived with OPF solution of the actual system at different operating conditions. As the FACTS controllers are now an ineluctable part of power system, this paper considers an SVC and a TCSC in OPF formulation to assess voltage stable states of any interconnected power system in terms of its reduced two-bus integrated π-equivalent system. Simulation results for a practical power system establish that the proposed methodology is highly promising to assess voltage stability in a better way as compared to existing series equivalent model.


## 1. Introduction

Present-day power systems are highly complex and widespread and operating much closer to their breakdown limits due to economical, environmental, political, and technical factors. This scenario makes the power systems more vulnerable to stability and security problems. Voltage stability has been recognized as one of these concerns and is referred to the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and/or after being subjected to a disturbance [1,2]. A system is said to have entered a state of voltage instability when a disturbance, increase in load demand, or a change in system condition causes a progressive and uncontrollable drop in voltage which can occur because of the inability of the network to meet the increasing demand for reactive power [3,4]. Voltage instability is the cause of system collapse, in which the system voltage decays to a level from which it is unable to recover. Several large-scale power system blackouts in the recent past all over the globe have been the consequences of instabilities characterized by voltage collapse phenomena. Hence, a proper analysis of voltage stability is essential for successful operation and planning of the power system.

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Furthermore, a better voltage stable system contributes to reliability and reduction of system losses [5].

Over the last few decades, voltage stability is a very crucial and hot point for both utilities and researchers. Several techniques have been proposed in the literature for predicting the voltage instability and collapse of the power system. Voltage stability being problem of power system under steady state operation, load flow study has long been used to find voltage stability and security indicators [6,7]. Continuation power flow technique enables the researchers to identify critical point of voltage stability along with maximum system loadability. Load flow Jacobian and bifurcation analysis have been proved to be the effective tools to identify voltage collapse point [8,9]. Many researchers also used the conventional $P$–$V$ or $Q$–$V$ curves, generated from the repetitive load flow solutions with successively increased load, for the assessment of voltage stability of the critical bus in a power system [1]. A $P$–$Q$ plane of stability is also used as a tool to assess the voltage stability limit of a power system [10].

Efforts also have been done to develop the concept of deriving single line two-bus equivalent network of any multi-bus power system to get a quick overview on the system voltage stability in a global mode [11]. Here, the actual system is reduced into an equivalent two-bus system and then the global voltage stability indices for indicating the state of the actual system are easily computed by using the parameters of the equivalent model. This concept is very attractive due to its simplicity and less computational effort and the occurrence of voltage collapse on the basis of the single line equivalent can be studied easily and it is not necessary to consider every line or bus of the system separately. In [12,13], the authors have proposed a method to reduce the given power system into its single line equivalent model on the basis of the equations of load flow solution and total power loss of the actual system for the assessment of voltage stability in the global scenario. Significant research has also been devoted for developing different voltage stability indicators to study the occurrence of a voltage collapse, using the concept of reduced two-bus equivalent [14–18]. This single line equivalent system is simply a power line having series equivalent impedance which is obtained by lumping series impedances and shunt admittances of transmission lines *altogether* available from the results of load flow study performed on the actual system. Accurate assessment of voltage stability is possible if the power system is faithfully represented by an equivalent two-bus system. As the series impedances and shunt admittances are lumped, the series model indicates voltage collapse at higher voltage level and specifies no appreciable change with increase in system load. Also, in case of compensated power systems, the equivalent series impedance of series model results in capacitive line impedance which apparently indicates over series capacitive compensation of the actual system. But it does not represent the actual scenario. So, it is hard to draw any sharp inference regarding voltage stability from the series equivalent model.

On the other hand, the advances in flexible ac transmission system (FACTS) controllers have led their applications in improving the overall performance of power networks [19]. Several studies analyzing the application of FACTS controllers for voltage and angle stability have been reported in [20]. Among the well known FACTS controllers, SVC, TCSC, and STATCOM are the most widely used controllers for effective improvement of voltage stability and so the overall stability of the power system. To analyze the effect of these controllers, steady state models have been developed over the decades. Load flow analysis using such models would provide data necessary to calculate the voltage stability indicators in order to evaluate the response of the system at any particular operating point.

On the basis of the previously mentioned literature, this paper proposes a unique π-network two-bus equivalent model for a multi-bus power system for more accurate assessment of voltage stability in global scenario. The proposed model is obtained by an innovative methodology considering the effect of shunt branch admittances and series impedances of transmission lines *separately* available from the optimal power flow solution of the multi-bus power system. In addition, this paper considers the incorporation of steady state models of SVC and TCSC controllers into the optimal power flow program to investigate their impact on power system performance in terms of voltage stability assessed in the equivalent two-bus domain by digital computer simulation. Newton's method of OPF is adopted here to calculate the system state variables for different operating conditions of the multi-bus power network considering economic criteria [21,22]. The simulation also includes the identification of the weakest load bus and determination of the global voltage stable states of the system following the derived unique π-network two-bus equivalent system. Simulation results obtained with proposed approach are compared with the results of well-established series equivalent system. Improvement in voltage stability margins using the FACTS controllers is also compared for the test system considered. The proposed concept has been tested in a wide range of power networks of varying sizes. In this paper, a real life power system (203-bus Indian Eastern Grid) has been considered as the test system to illustrate the utility of the proposed method.

## 2. Modeling of FACTS controllers

The FACTS technology has provided the power system greater control of power, secure loading of transmission lines, greater ability to transfer power, prevention of cascading outages and damping of power system oscillations [19]. Among the important FACTS controllers, SVC and TCSC are most suitable for the voltage control. This paper considers the steady state models of SVC and TCSC controllers in OPF formulation which are discussed in the following section.

### 2.1. Static var compensator

Static var compensators have been extensively used in power system applications to provide the controlled reactive power and voltage stability improvement. The SVC firing angle model has been used here for optimal power flow analysis [22,23]. It is made up of the parallel combination of a thyristor controlled reactor (TCR) and a fixed capacitor. The SVC is connected to the transmission network via a step-down transformer as shown in Fig. 1.

The SVC is considered as a continuous, shunt variable susceptance, which is adjusted in order to achieve a specified voltage magnitude while satisfying constraint conditions. Suitable control of the equivalent reactance is brought about by varying the current through the TCR by controlling the gate firing instant of thyristors and thus the equivalent susceptance $B_{t\_svc}$