

Evaluation of static synchronous compensator in order to loading margin study in power system

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Abstract

This paper presents a study of FACTS devices mainly static synchronous compensator (STATCOM) on loading margin study and power stability. Their steady state modeling and effects on power system performance have been studied. Effects of STATCOM on system loadability have been discussed and presented here. Continuation power flow is used to evaluate the effects of this device on system loadability. Eigenvector analysis applied at the maximum loading point is used to rank the most critical voltage buses. After that, it would be possible to optimize location of STATCOM in order to achieve maximum enhancement of system loadability. The models and methodology for placing STATCOM are tested in a 14 bus system. Test system reveals that the incorporation of STATCOM significantly improves Loading Margin and the line power transfer capability of the system and therefore, the stability of the system is increased.

Keywords: Continuation power flow; maximum loading; STATCOM; voltage stability.

Introduction

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition (IEEE-CIGRE, 2004). If voltage stability exists, the voltage and power of the system will be controllable at all times. In general, the inability of the system to supply the required demand leads to voltage instability (voltage collapse). The nature of voltage instability phenomena can be either fast (short-term with voltage collapse in the order of fractions of a second to a few sec) or slow (long-term, with voltage collapse in min to hours) (IEEE-CIGRE, 2004). Short-term voltage stability problems are usually associated with the rapid response of voltage controllers (e.g., generators' automatic voltage regulator (AVR)) and power electronic converters, such as those encountered in flexible AC transmission system or FACTS controllers and high voltage DC (HVDC) links. In the case of voltage regulators, voltage instability is usually related to inappropriate tuning of the system controllers. Voltage stability in converters, on the other hand, is associated with commutation issues in the electronic switches that make up the converters, particularly when these converters are connected to "weak" AC systems, i.e., systems with poor reactive power support. The voltage stability problems usually occur in systems under high loading. A disturbance which ends to voltage collapsing may have different reasons, but the main one is weakness and debility of power system meeting power reactive demand (Kundur, 1993). In fact the voltage stability phenomenon may be due to slow change of the load in the system or large contingency occurring such as

loss of generators, transmission lines and transformers. These disturbances are led to voltage progressive drop in a vital section of system, which cause instability (Taylor, 1993).

The only way to save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse. Introducing the sources of reactive power, i.e., shunt capacitors and/or flexible AC transmission system (FACTS) controllers at the appropriate location is the most effective way for utilities to improve voltage stability of the system (Kamarposhti *et al.*, 2008). A static synchronous compensator (STATCOM) is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices.

Point of collapse method and continuation method are used for voltage collapse studies (Kazemi *et al.*, 2006). Of these two techniques, continuation power flow method is used for voltage analysis. The conventional power flow computation began with Gauss-Seidal method. Then the alternative Newton-Raphson iterative method was used which is reliable, computationally faster and more economical in storage requirement (Stevenson, 1982). Most researchers found that the Jacobian of the Newton-Raphson power flow calculation became singular at the steady state voltage stability limit (Ajarapu & Christy, 1992). The stability limit or critical point is defined as the point where the power flow Jacobian is a singular.

Therefore when the power flow approaches the critical point, it will diverge and give a large error.

The saddle node bifurcation (SNB) is one of the approaches that can be used to solve this singularity problem. The Jacobian can reach the SNB in many ways, such as increase the impedance in a key tie line, increase the generation level at a generator with weak transmission while decreasing generation at all other generators, increase the load at a single bus or increase the load at all buses. But this method requires modification for solving singularity problem. For example when the critical point differs from the SNB point, the critical point may not provide a security measure and the curve may not provide a forecast of the system trajectory.

Continuation power flow was introduced to solve this singularity problem. The continuation power flow can be described as a power flow solution that can maintain the stability of the power system under normal and disturbances conditions. Therefore the main purpose of Continuation Power Flow is to find the continuity of power flow solution for a given load change. In this paper, the continuation power flow locates a critical voltage point in P-V curve. The FACTS device, STATCOM, is proposed to compensate the transfer capability of transmission line. The advantages of STATCOM are voltage stability, and increase reactive power and voltage adjustment.

Model of FACTS devices

The typical quasi-steady-state description of a power system, corresponding to a transient stability model, is given by the differential-algebraic equations (Kazemi & Badrzadeh, 2004):

$$\dot{x} = f(x, y, \lambda, p) \quad (1)$$

$$0 = g(x, y, \lambda, p)$$

Where x corresponds to the system state variables and y represents the algebraic variables. The variable λ stands for a parameter or a set of parameters that slowly change in time, so that the system moves from one equilibrium point to another until reaching the collapse point and p stands for a parameter that is directly controllable, such as shunt and series compensations. (The value of λ at equilibrium point λ_0 corresponds to the maximum loading level or loadability margin in p.u.)

STATCOM

A STATCOM works by rebuilding the incoming voltage waveform by switching back and forth from inductive to capacitive load. If it is inductive, it will supply reactive AC power. If it is capacitive, it will absorb reactive AC power. This is how it acts as a source/sink. STATCOM is the voltage-source inverter (VSI), which converts a DC input voltage into AC output voltage in order to compensate the active and reactive power needed by the system (Canizares, 2000). STATCOM is a shunt-connected device, which controls the voltage at the connected bus to the reference value by adjusting voltage and angle of internal voltage source. STATCOM exhibits constant current characteristics when the voltage is low/high

under/over the limit (Kamarposhti & Alinezhad, 2009).

The AC circuit is considered in steady-state, whereas the DC circuit is described by the following differential equation, in terms of the voltage V_{dc} on the capacitor (Kamarposhti *et al.*, 2008).

$$V_{dc} = \frac{P}{CV_{dc}} - \frac{V_{dc}}{R_c C} - \frac{R(P^2 + Q^2)}{CV^2 V_{dc}} \quad (2)$$

The power injection at the AC bus has the form:

$$P = V^2 G - kV_{dc} - V_G \cos(\theta - \alpha) - KV_{dc}VB \sin(\theta - \alpha) \quad (3)$$

$$Q = -V^2 B + kV_{dc}VB \cos(\theta - \alpha) - kV_{dc}VG \sin(\theta - \alpha) \quad (4)$$

Where, $k = \sqrt{3/8m}$.

Continuation power flow

Continuation methods overcome certain difficulties of successive power flow solution methods, as they are not based on a particular system model, and allow the user to trace the complete voltage profile by automatically changing the value of λ ; without having to worry about singularities of system equations. The strategy used in these methods is shown in Fig. 1 (Kazemi *et al.*, 2006). Where a known equilibrium point (z_1, λ_1) is used to

compute the direction vector Δz_1 and a change $\Delta \lambda_1$ of the system parameter. This first step is known as the predictor, since it generates an initial guess $(z_1 + \Delta z_1, \lambda_1 + \Delta \lambda_1)$; which is then used in the corrector step to compute a new equilibrium point (z_2, λ_2) on the system profile. Since the Jacobian

$D_z F|^*$ is singular at the collapse point, a parameterization is sometimes needed in the predictor and/or corrector steps, depending on the techniques used, to guarantee a well behaved numerical solution of the related equations. A detailed description of these techniques is referred to Refs (Huneault & Galiana, 1990; Ajarapu & Christy, 1992).

Continuation methods were combined with the Load Flow technique, giving birth to the Continuation Power Flow methods. The aim of these methods is to allow computing the maximum loadability point, eliminating the singularity of the Jacobian matrix by including the system loadability factor as a new system variable (López-Luis *et al.*, 2007). The use of continuation power flow analysis can solve this problem by reformulating the power flow equations so that they remain well-conditioned at all possible loading conditions. This solution allows the system to be stable at stable and unstable equilibrium points.

Results and discussion

IEEE 14 bus test system

A 14-bus test system as shown in Fig. 2 has been used to study a methodology for the placement and design of the FACTS controllers. PSAT is power system analysis software, which has many features including power flow and continuation power flow (Milano, 2009) Using continuation power flow feature of PSAT, voltage

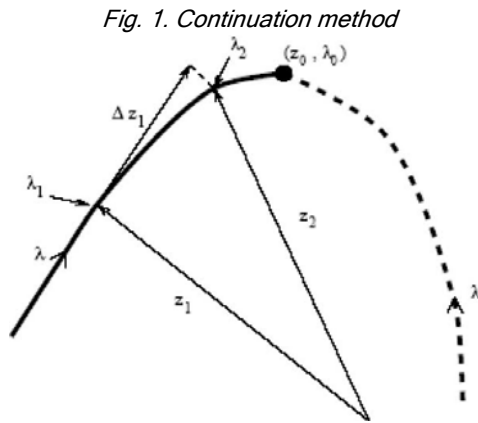


Fig. 2. Single line diagram of IEEE 14 bus test

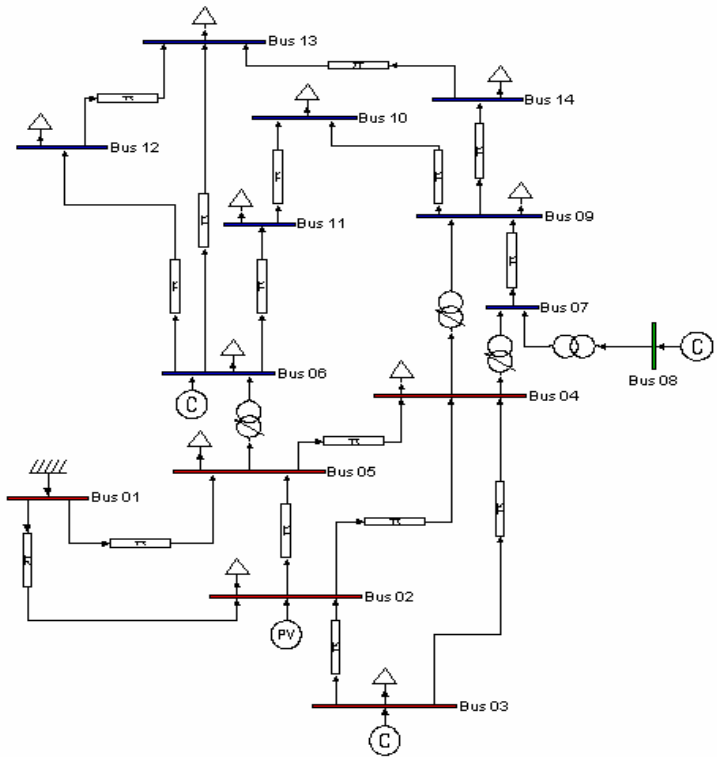


Fig. 3. Voltage profile of system without STATCOM

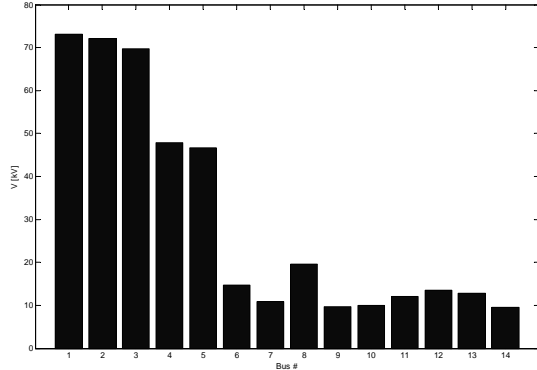


Fig. 4. PV curve for 14-bus system without STATCOM

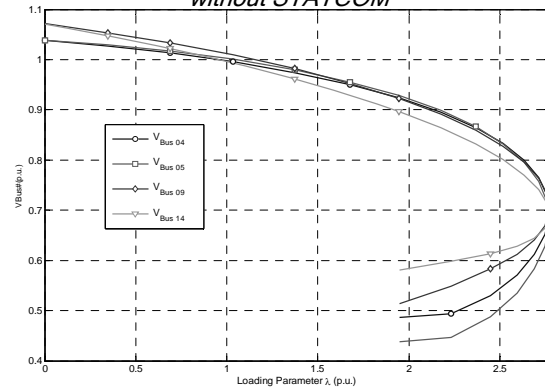


Fig. 5. Voltage profile of system with STATCOM

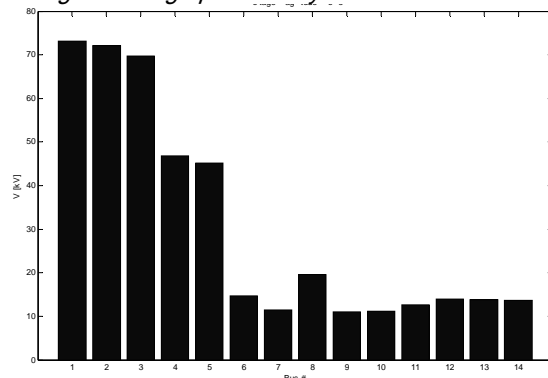
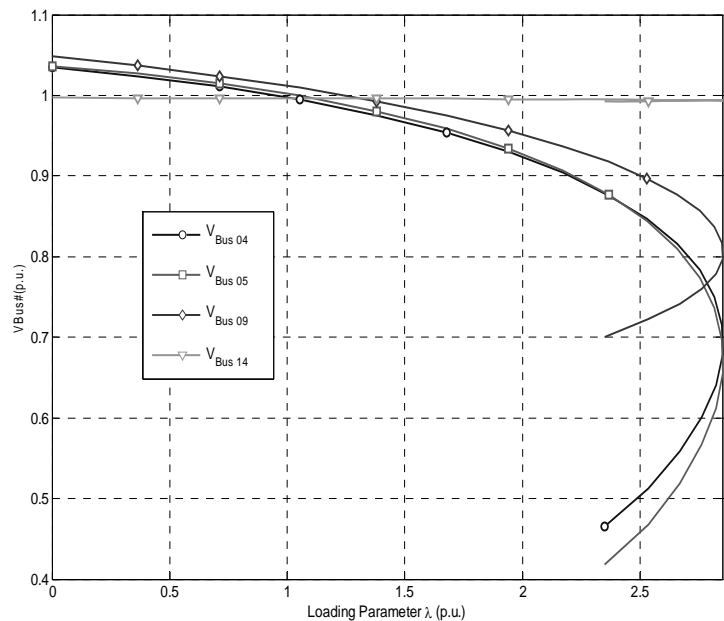


Fig. 6. PV curve for 14-bus system with STATCOM



stability of the test system is investigated. The behavior of the system has been studied with and without STATCOM under different loading conditions. In this study the limits of active and reactive power in PV buses are considered and typical PQ model is used for the loads. Since continuation methods are typically used in power flow equations, they have become known as continuation power flows. Therefore, typically one starts from an initial stable operating point and increases the constant power loads by a factor λ , until the singular point of the linearization of the power flow equations is reached.

The loads can be defined as:

$$\begin{aligned} P_L &= P_{L0}(1 + \lambda) \\ Q_L &= Q_{L0}(1 + \lambda) \end{aligned} \quad (5)$$

Where, P_{L0} and Q_{L0} are the active and reactive base loads, whereas P_L , and Q_L , are the active and reactive loads at bus L for the current operating point as defined by λ .

Fig. 3 shows Voltage profile of 14-bus test system without STATCOM. Fig. 6. depicts the PV curve of four buses identified as "critical" namely, bus No. 14. The system presents a collapse or maximum loading point, where the system Jacobian matrix becomes singular at $\lambda_{\max} = 2.77$ p.u.. Based on largest entries in the right and left eigenvectors associated to the zero eigenvalue at the collapse point, bus 14 is indicated as the "critical voltage bus" needing Q support. The critical buses are identified as buses 4, 5, 9 and 14 their voltage profiles obtained through continuation method are shown in Figs. 3 and 4. Among these buses, bus 14 has the weakest voltage profile. Voltage magnitude in maximum loading point in bus 14 that is known as the weakest bus is 9.5 KV. Based on collapse analysis bus 14 is targeted as the first location for an STATCOM. The new maximum loading point in this condition is $\lambda_{\max} = 2.85$ p.u. Shunt compensation device injects the reactive power at the connected bus. The weakest bus (bus 14) of the system is located at the load area and it requires reactive power the most. Introducing reactive power at bus 14 or in its vicinity can improve voltage stability margin. Voltage profiles at the collapse point of system with various Shunt compensation device is shown in Fig. 5. When STATCOM is connected at bus 14 we can observe from Fig. 6 that bus-14 has a flatter voltage profile. In IEEE 14-bus test system, shunt compensation device provides a higher loading margin and a better voltage.

Conclusion

FACTS device, STATCOM, employed for voltage stability enhancement is presented. The continuation power flow with the simulation of system is studied and investigated using IEEE 14 bus test system. The previous researches show that continuation power flow can be concluded as one of good tools to run power flow. There are many methods or strategy that has been used in order to employ continuation power flow. The

continuation method can avoid ill-conditioning problems and avoid the usual convergence problems seen in AC power flow methods near the turning point. The test system requires reactive power the most at the weakest bus, which is located in the distribution level. Introducing reactive power at this bus using STATCOM can improve loading margin. The results presented in this paper clearly show how STATCOM can be used to increase system loadability and voltage profile in practical power systems.

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