Voltage Stability Enhancement with STATCOM

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Abstract - In this paper the voltage stability analysis of power system has been analyzed. In Recent time, increased attention has been devoted to the voltage instability phenomenon in power systems. Many techniques have been planned in the literature for evaluating and predicting voltage stability using steady state analysis methods. In this paper modal analysis method is used for voltage stability analysis. In modal analysis technique makes use of the power system Jacobian matrix to determine the Eigen values necessary for the evaluation of the voltage stability of the power system. It identifies if the Eigen values are positive, shows system is stable while a negative Eigen value indicates that the system is unstable. The analysis is performed for IEEE 5 bus system and the most critical mode is identified for each system. After that find weak bus of the system bus, which contributes the most to the critical mode, are identified using the participation factor.

Keywords: Voltage Stability, STATCOM, Modal Analysis, Reduced Jacobian Matrix, Eigen value, Bus Participation factor.

I. INTRODUCTION

For the power system analysis and design power flow analysis is used and for planning, optimization, operation and control power flow study is most important at all stages of power system. They are important for planning, economic scheduling, operation and exchange of power between utilities [1]. Over the time human race has become very much dependent upon electrical energy, to fulfil their daily needs. There are few problems that we face. They are individual power outages and power disruption. To maintain the urban lifestyle there is enormous demand of power so transmission systems are being pushed to operate closer to their stability limit and also reaching close to their thermal limits. The constraints faced in maintain the demand and supply of power equal or matched are:

1. To full fill the need of power within the thermal limit.

2. Sometimes when the power demand is greater than the supply then there is stability.

Problem and this causes blackouts incurring vast losses. The characteristic of the power delivered is affected by the above two reasons. Now the requirement arises to check the above constraints and they can be done by enhancing the power system control. These limitations can be controlled by FACTS devices. Flexible ac transmission system is full form of FACTS. To determine the match between the demand and supplies of power, control over the power flow and enhancement in system stability is important which can be achieved by the FACTS devices. . FACTS devices have now became the requires of the hour. It is now becoming our need to use FACTS devices to enhance the efficiency of the power system [2].

To decrease the power transmission loss reactive power compensation is used. Reactive power compensation is also used to maintain power transmission capability and to maintain the supply voltage [2].

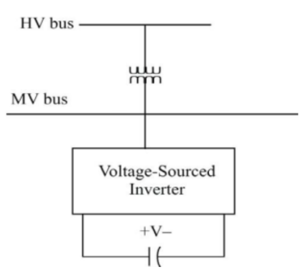
The increasing number of power system blackouts in many countries in current years; is a most important source of concern. Power engineers are interested in preventing blackouts and ensuring that a constant and reliable electricity supply is available to all customers. Early voltage instability, which may result from continues load growth or system contingencies, is essentially a local phenomenon. However, sequences of events accompanying voltage instability may have terrible effects, including a resultant low-voltage profile in a significant area of the power network, known as the voltage collapse phenomenon. Harsh instances of voltage collapse, including the August 2003 blackout in North - Eastern U.S.A and Canada, have highlighted the significance of constantly maintaining an acceptable level of voltage stability. The design and analysis of exact methods to evaluate the voltage stability of a power system and predict incipient voltage instability, are therefore of special interest in the field of power system planning and protection [1-4].

The voltage stability of a power system refers to its capability to properly maintain steady, acceptable voltage levels at all buses in the network at all times, even after being subjected to a disturbance or contingency. A power system may enter a state of voltage instability when the system is subjected to a steady increase in load demand or a change in operating conditions, or a disturbance. This causes a better demand in reactive power. Voltage instability is characterized by steadily decreasing voltage levels at one or more nodes in the power system. Both static and dynamic approaches are used to examine the problem of voltage stability. The static analysis method is more attractive than the dynamic method and well suited to voltage stability analysis of power systems over a wide range of system conditions [1-4].Many static methods for voltage stability analysis are presented in the literature, most utilizing a variation of the same common principle. Some common static methods are summarized and contrasted in this document. The modal analysis method of the load flow Jacobian presented by GAO, Morisson and Kundur in 1992, is of particular interest. This method, in addition to providing an exact estimate of the system proximity to instability using the system Eigen values, identifies the elements of the power system contributing the most towards incipient voltage instability (critical load buses, branches and generators).

To maximize the steady state transmittable power and to control the voltage profile shunt compensation is used. STATCOM (Static Compensator) is a shunt compensator and comes under FACTS device category that is being applied to long transmission lines maintain the supply voltage [5]. Reactive power compensation improves the voltage profile of the system, increase the power transfer in the lines and reduce losses. Synchronous compensator is one such device that is used for reactive power compensation. It provides reactive power compensation thereby improving the voltage profile of the system [2].Statcom is most important used for voltage stability.

II. STATCOM

Statcom is also known as the "static synchronous controller". It is shunt connected static var controller whose capacitive or inductive output current can be controlled independent of the ac system voltage"[5]. The Statcom is a facts controller based on VSC (voltage sourced converter). A VSC generate a synchronous voltage of fundamental frequency, controllable magnitude and phase angle. If a VSC is shunt-connected to a system via a coupling transformer, the resulting Statcom can inject or absorb reactive power to or from the bus to which it is connected and thus regulate the bus voltage magnitude [1].



STATCOM is used to provide reactive power to the ac system, beside that, it will provide the dc power required for both inverters. The reactive power can be compensated either by improving the receiving voltage or by reducing the line reactance [7].

III. MODAL ANALYSIS

Modal analysis is a rigorous technique to handle steady-state voltage stability for large-scale power systems. In this method, participation factors are computed to identify critical buses, branches and generators in the system [Variational Approach in Modal Analysis]. According to modal analysis the smallest Eigen values of reduced power flow Jacobian provide a relative measure of proximity to voltage instability in some sense. [5]. The modal analysis generally depends on the power-flow Jacobian matrix. A flowchart for the modal method analysis used in this study is shown in figure 4.2. A system is voltage stable at a given operating condition if for every bus in the system, bus voltage magnitude increases as reactive power injection at the same bus is increased. A system is said to be voltage unstable, if the voltage magnitude decreases at one bus in the system, as the reactive power injection at the same bus is increased. In other words, a system is voltage stable if Q-V sensitivity is positive for every bus and unstable if Q-V sensitivity is negative for at least one bus [6].

IV. REDUCED JACOBIAN MATRIX

The linearized steady state system power voltage equations are given by

Where,

ΔP = Incremental Change in Bus Real Power.

ΔQ = Incremental Change in Bus Reactive Power P.

$\Delta\theta$ = Incremental Change in Bus Voltage Angle θ .

ΔV = Incremental Change in Bus Voltage Magnitude V.

If the conventional power flow model is used for voltage stability analysis the Jacobian matrix in (4.1) is the same as the Jacobian matrix used when the power flow equations are solved using the Newton-Raphson technique. System voltage stability is affected by both P and Q. However at each operating point P is kept constant and voltage stability is evaluated by considering the incremental relationship between Q and V. This is analogous to the Q-V curve approach. Although incremental changes in P are neglected in the formulation, the effects of changes in system load or power transfer levels are taken into account by studying the incremental relationship between Q and V at different operating conditions and magnitude is desired then the assumption $\Delta P=0$ can be assumed, this yields

$$\Delta Q=[]\Delta V \quad (1.1)$$

Rearrangement of equation (1.1) gives

$$\Delta V=J_R^{-1}\Delta Q \quad (1.2)$$

Where

$$J_R=[J_{qv}-Jq\,\theta J_p\,\theta^{-1}J_{pv}] \quad (1.3)$$

J_R is the reduced Jacobian matrix of the system relating the reactive power injections and the bus voltage magnitude. It can be represented as $JR=\xi\Lambda\eta$ where η = Left Eigen vector matrix of J_R, ξ = Right eigenvector matrix of J_R, Λ = Diagonal Eigen value matrix of J_R and

$$J_R^{-1}=\xi\Lambda^{-1}\eta \quad (1.4)$$

From equation (1.4) and (1.2) we get

$$\Delta V=\xi\Lambda^{-1}\eta\Delta Q \quad (1.5)$$

Or $\Delta V= \Delta Q$

η_i = i^{th} row left Eigen vector of matrix of J_R

ξ_i = i^{th} column right Eigen vector of matrix of J_R

Each Eigen value λi and corresponding right and left Eigen vectors define the i^{th} mode of Q-V response. Since $\xi^{-1}=\eta$

Equation (6.6) becomes $\eta\ \Delta V=\Lambda^{-1}\eta\Delta Q$ or

$$V=\Lambda^{-1}q \quad (6.7)$$

Where

$v= \eta\Delta V$, is the vector of modal voltage variations.

$q= \eta\Delta Q$, is the vector of modal reactive power variations.

The difference between equations (6.3) and (6.7) is that Λ^{-1} is a diagonal matrix whereas J_R^{-1} is non diagonal. Equation (6.3) represents uncoupled first order equations [].thus for the i^{th} mode

$$v_i=q_i/\lambda_i \quad (1.6)$$

A system is stable if the Eigen values of the Jacobian are all positive. Those who are used to small signal stability analysis using Eigen value techniques may find the prerequisite for the Eigen values of the Jacobian to be positive for voltage stability a little confusing because in the study of small signal stability, an Eigen value with positive real part indicates that the system is unstable. The correlation between system voltage stability and Eigen values of the Jacobian J_R, is best implicit by relating the Eigen values of J, with the V-Q sensitivities(Which must be positive for stability) at each bus. For practical purposes, J_R, can be in use as a symmetric matrix and therefore, the Eigen values of J_R are close to being simply real. If all the Eigen values are positive, J_R, is positive the system is voltage stable. As the system is stressed out, the Eigen values of J_R become smaller until. At the critical point of system voltage stability, as a minimum one value of the Eigen values of J_R, becomes zero. If some of the Eigen values of J_R are negative the system is unstable [7].

The magnitude of the Eigen values provides a relative measure of the proximity of the system to instability. The critical modes associated with of the full Jacobian and the reduced are employed to analysis the behaviour of the FACTS devices.

V. PARTICIPATION FACTORS

The participation factor of the j^{th} variable in the i^{th} mode is defined as the product of the j^{th}´s components of the right and left eigenvectors corresponding to the i^{th} mode.

Bus Participation factors are dimensionless magnitudes. In other words, they are independent on the units of the state variables. In addition, both the sum of the participation factors of all variables in a mode and the sum of the participation of all modes in a variable are equal to one [7].

The minimum Eigen values, which become close to instability, need to be observed more closely. The appropriate definition and determination as to which node or load bus participates in the selected modes become very important. This necessitates a tool, called the participation factor, for identifying the weakest nodes or load buses that are making significant contribution to the selected modes. If ξ_i and η_i represent the right- and left- hand eigenvectors, respectively, for the Eigen value Λi of the matrix J_R, then the participation factor measuring the participation of the k^{th} bus in i^{th} mode is defined as

$$P_{ki} = \xi_{ki}\eta_{ki}$$

Note that for all the small Eigen values, bus participation factors determine the area close to voltage instability. The node or bus k with highest P_{ki} is the most contributing factor in determining the V-Q sensitivity at i^{th} mode. Therefore, the bus participation factor determines the area close to voltage instability provided by the smallest Eigen value of J_R. A MATLAB m-file is developed to compute the participating factor at i_{th} mode.

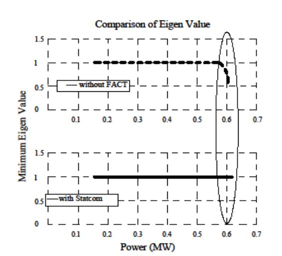
VI. RESULTS

IMPACT OF STATCOM ON VOLTAGE STABILTY Statcom is connected to the most participating bus 4. The bus power sensitivities present in the Jacobian for the converged iteration are evaluated. The minimum Eigen value of the Jacobian matrix with or without STATCOM is calculated and shown in table ().

TABLE 1.1

CASE		MINIMUM EIGEN VALUE OF REDUCED JACOBIAN
1.	Without STATCOM	0.1574
2.	With STATCOM	1.00

It can be observed that the voltage stability is significantly enhanced with the addition of STATCOM at the critical loading.



Comparison Of Eigen Value

The Point of Placement of Controller (STATCOM)

The networks with voltage dependent loads there is a modification in the load flow iterative algorithms. Load flow solution is obtained with their modified equations and by increasing the load in steps. Reduced Jacobian matrix for the last converged iteration for different types of loads is obtained and the minimum Eigen value is calculated. Here relevant Eigen values of the reduced Jacobian matrix for the IEEE 5 bus system.

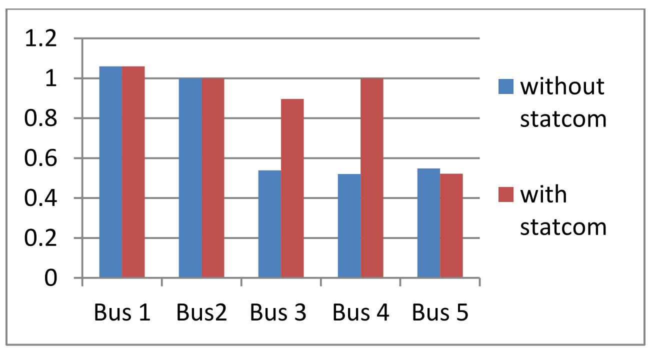
Table 1.2: Eigen value for IEEE 5 bus network

No. of modes	Eigen value at critical loading
1	19.9211
2	-0.1574
3	2.2450
4	1.1054
5	1.000

Participation factor for the critical modes (corresponding to minimum Eigen values in each case) is found out by following the procedure in section []. Corresponding to the 2nd mode the most participating is 4th bus. Hence the FACTS Controller (STATCOM) is placed on the 4th bus. The voltage of all the buses at the critical loading is shown in table [1.3].

Table 1.3: Bus voltages for the critical loading

Bus No.	Voltage at buses at critical loading (without STATCOM)	Voltage at buses at critical loading(with STATCOM)
1	1.0600	1.0600
2	1	1
3	0.5389	0.8964
4	0.5202	1
5	0.5483	0.5221



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