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Improvement of Voltage Stability Margin and Bus Voltage Control by Reactive Power Injection

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Abstract: This paper presents voltage stability margin of five bus system and control the stability margin in stressed conditions. This study proposes a control method to reactive power injection while maintaining a minimum amount of voltage stability margin and bus voltage limits. The present power system is a complex network consisting of several sub networks such as generation, transmission and distribution sub-networks. Use of new technology and the growth in interconnections are continuously increasing the complexity of the system. These highly complex modern power systems are operating in severely stressed conditions. Therefore, ensuring the voltage stability margin of these systems has become one of the major concerns for the power system. This paper deals with P-V curve to calculate voltage stability margin. By reactive power injection voltage stability margin is controlled and bus voltage limits comes within permissible limit.

Keywords: P-V curve, Reactive power injection, Voltage stability margin.

I. INTRODUCTION

Present day power systems are being operated closer to their stability limits due to economic and environmental constraints. Maintaining a stable and secure operation of a power system is therefore very important and challenging issue. Voltage stability is a major concern in power system operation since it has been the cause for many power blackouts [1] around the world. There has been a continually increasing interest and investigation into voltage stability. Voltage instability has been given much attention by power system researchers and planners in recent years. Major contributory factors to voltage instability are power system configuration, generation pattern and load pattern [2-3]. The system load is slowly increased along a certain direction to the point of voltage collapse. The variation of load voltage magnitude V with loading P is plotted as the P-V curve. The MW distance from the base operating point to the critical collapse point, namely load active power (P) margin is a good measure of proximity to voltage stability [4]. Voltage stability problems have been encountered by many power utilities that are forced to operate their generation and transmission network under increasingly stressed condition. The power system network can be modified to ease voltage instability by adding shunt capacitors at the weakest bus of the system [5-6]. At any point of time, a power system operating condition should be stable, meeting various operational criteria, and it should also be secure in the event of any credible contingency. Voltage instability phenomena are the ones in which the receiving end voltage decreases well below its normal value. Voltage collapse is the process by which the voltage falls to a low, unacceptable value as a result of an avalanche of events accompanying voltage instability [7].

II. PROBLEM FORMULATION

(a) Load P margin

Load P margin can be directly obtained from the P-V curve. The current operating value of real power delivered to the load (base operating point) is P_o and the maximum possible power transfer is $P_{max.}$ The load P margin is defined as the difference between two quantities:

$$P_{margin} = P_{max} - P_o \quad \ldots\ldots\ldots\ldots.. (1)$$

The load P margin depends on how the loads and generation are increased. Generally the loads on all nodes in a power system do not increase at the same rate. In order to accommodate the increased load, the power output of the generators also needs to be increased. This uneven increase in the loading and generation can be modelled by

$$\begin{aligned} P_g &= P_{go} + \lambda P_{gd} \\ P_l &= P_{l0} + \lambda P_{ld} \\ Q_l &= Q_{l0} + \lambda Q_{ld} \quad \ldots\ldots\ldots\ldots.. (2) \end{aligned}$$

Where P_g is a vector of active power generated by the generators, P_l is a vector of active power delivered to the loads, and Q_l is a vector of reactive power delivered to the loads. Subscript 0 represents base case. The vector $P_{gd,}$ P_{ld} and Q_{ld} define the direction of power change. λ is a parameter that defines the magnitude of loading along the direction of load/ generation increase.

(b) Calculation of Load P Margin

The network equations in terms of admittance matrix at bus i can be given in polar coordinates as

$$P_i = V_i^2 G_{ii} + V_i \sum_{i\neq j} Vj(Gij\cos\theta ij + Bij\sin\theta ij)$$
$$Q_i = -V_i^2 B_{ii} + V_i \sum_{i\neq j} Vi(Gij\cos\theta ij - Bij\sin\theta ij) \qquad \ldots\ldots\ldots\ldots\ldots (3)$$

Where $Y_{ij} = G_{ij} + jB_{ij}$ is the ij^th element of the admittance matrix Y, $V_i = V_i e^{j\theta i}$ is the voltage phasor at bus i, $\theta_{ij} = \theta_i - \theta_j$ is the voltage angle difference between the buses i and j, and $S_i = P_i + jQ_i$ is the complex power injected to i.

III. REACTIVE POWER INJECTION

Reactive power is a concept used by engineers to describe the background energy movement in an Alternating Current (AC) system arising from the production of electric and magnetic fields. These fields store energy which changes through each AC cycle. Devices which store energy by virtue of a magnetic field produced by a flow of current are said to absorb reactive power (viz. transformers, Reactors) and those which store energy by virtue of electric fields are said to generate reactive power (viz. Capacitors). Power flows must be carefully controlled for a power system to operate within acceptable voltage limits. Reactive power flows can give rise to substantial voltage changes across the system, which means that it is necessary to maintain reactive power balances between sources of generation and points of demand. Reactive power supports the voltages that must be controlled for system reliability. In AC power networks, while active power corresponds to useful work, reactive power supports voltage magnitudes that are controlled for system reliability, voltage stability, and operational acceptability.

In order to keep the receiving end voltage at a specified value $|V_R|$, a fixed amount of VARs (Q_R) must be drawn from the line. To accomplish this under conditions of a varying VAR demand Q_D, the VAR balance equation at the receiving end is now

$$Q_R + Q_C = Q_D \qquad \ldots\ldots.. (4)$$

Fluctuations in Q_D are absorbed by the VAR generator Q_C such that the VARs drawn from the line remain fixed at Q_R. The receiving end voltage would thus remain fixed at $|V_R|$. VAR compensation can, in fact, be made automatic by using the signal from the VAR meter installed at the receiving end of the line.

If $|V_R|$ is in line kV, and X_C is the per phase capacitive reactance of the capacitor bank. The expression for VARs fed into the line can be derived as under.

$$I_C = j \frac{|VR|}{\sqrt{3}\, XC} \text{ kA}$$

$$jQ_C \text{ (three- phase)} = 3 \frac{|VR|}{\sqrt{3}} (-I_C)$$

$$= j3 \times \frac{|VR|}{\sqrt{3}} \times \frac{|VR|}{\sqrt{3}\, Xc} \text{ MVA}$$

$$\therefore Q_C \text{ (three - phase)} = \frac{|VR|2}{Xc} \text{ MVAR} \qquad \ldots\ldots\ldots\ldots\ldots. (5)$$

If inductors are employed instead, VARs fed into the line are

$$Q_L \text{ (three - phase)} = -\frac{|VR|2}{XL} \text{ MVAR} \qquad \ldots\ldots\ldots\ldots\ldots. (6)$$

Under heavy load conditions, when positive VARs are needed, capacitor banks are employed; while under light load conditions, when negative VARs are needed, inductor banks are switched on.

The following observations can be made for static VAR generators:

1. Capacitor and inductor banks can be switched on in steps. However, stepless (smooth) VAR control can now be achieved using SCR circuitry.
2. Since Q_C is proportional to the square of terminal voltage, for a given capacitor bank, their effectiveness tends to decrease as the voltage sags under full load conditions.
3. Capacitors act as short circuit when switched 'on'.

In the recent past economic competition has lead to an interest in maintaining an optimum, secure and reliable power system operation. One such security issue is the voltage stability of the system. Several voltage instability incidents have been reported, all over the globe [8].

IV. SIMULATION AND RESULTS

The proposed shunt capacitor for steady state voltage stability margin estimation is applied to the five bus system shown in figure 1. The system consists of 5 loads, 2 generators and 6 transmission lines. A power flow execution has been done to find the solution along the P-V curve for a specified bus voltage limit. To compute the load P margin for stressed conditions and load increase for all the loads. In stressed condition load P margin is 86.1MW, but in healthy condition load P margin is as 110.6MW. When load demand is increased the voltage stability margin reduced. The bus voltage limits have been loosed and transmission line losses increased, therefore reactive power injection is needed.

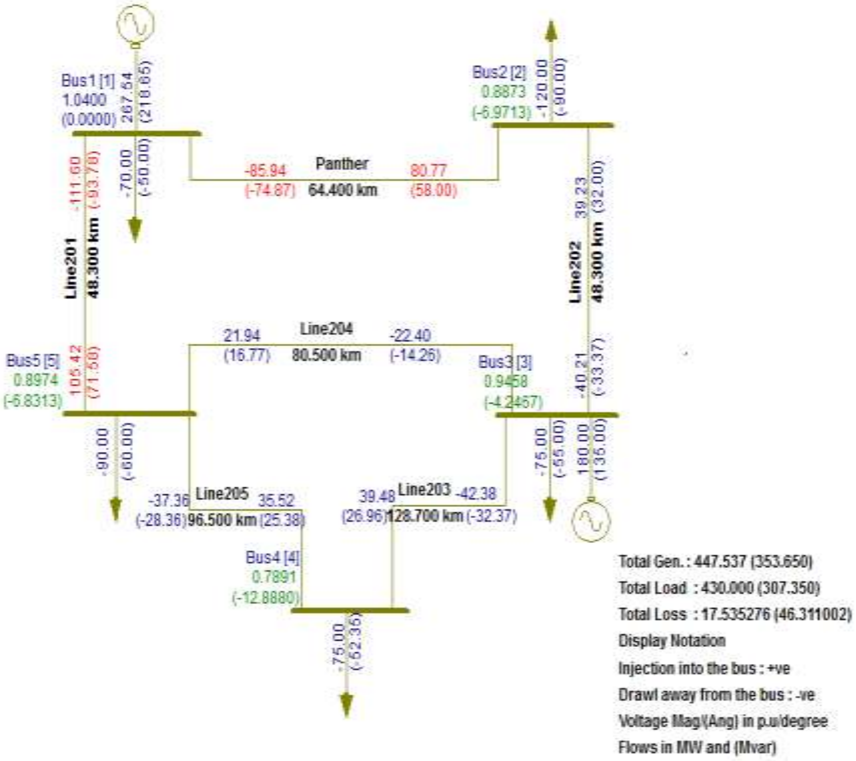

Fig.1 Five Bus Model of a Power System

From figure1 the maximum stressed bus voltage is 0.7891 pu of bus four and other buses 2, 5 and 3 have loose the permissible limits of voltage. The losses increase up to the maximum values of 17.53 MW. Rating of the shunt capacitors depend upon the voltage of bus. The shunt capacitor placed near the loads all KVAr ratings of the banks are 15MVAr at 12KV, 50MVAr at 36KV recently [9]. Here we are used two shunt capacitors of 100MVAr for reactive power balancing. Voltage of different buses has been given in table. The table 1 shows data for stressed conditions.

TABLE 1

Bus No.	Real Power in MW	Reactive Power in MVAr	Cosφ	Voltage (pu)
Bus1	70	50	0.814	1.04
Bus2	120	90	0.80	0.8873
Bus3	75	55	0.8064	0.9458
Bus4	75	52	0.82	0.7891
Bus5	90	60	0.832	0.8974

Here, P-V curve has been shown for 2, 4 and 5 buses in healthy condition. Where as in healthy condition system has maximum loading of 368.62MW. In this loading the system works with normally and maintaining voltage stability margin of 110.6MW.

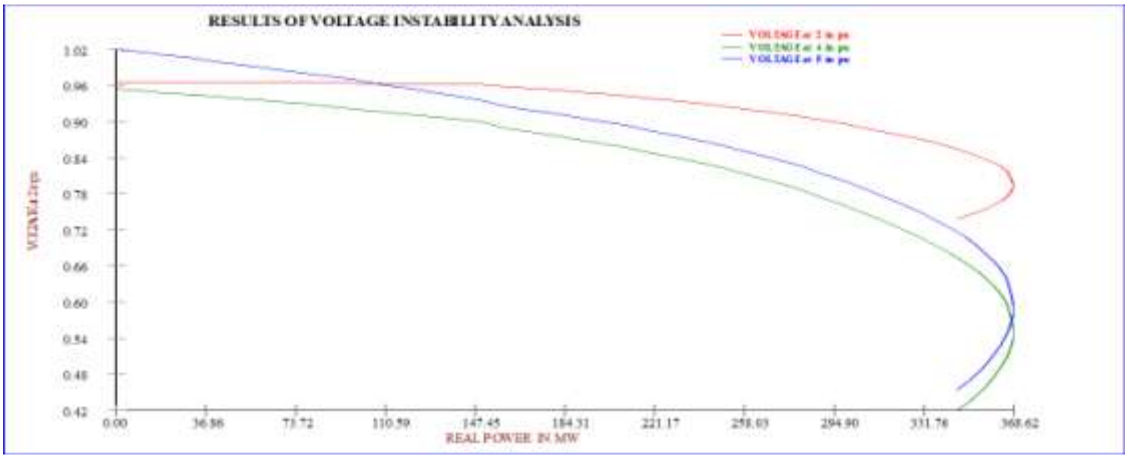

Fig. 2 P-V curves for a 3 load buses (In Healthy condition)

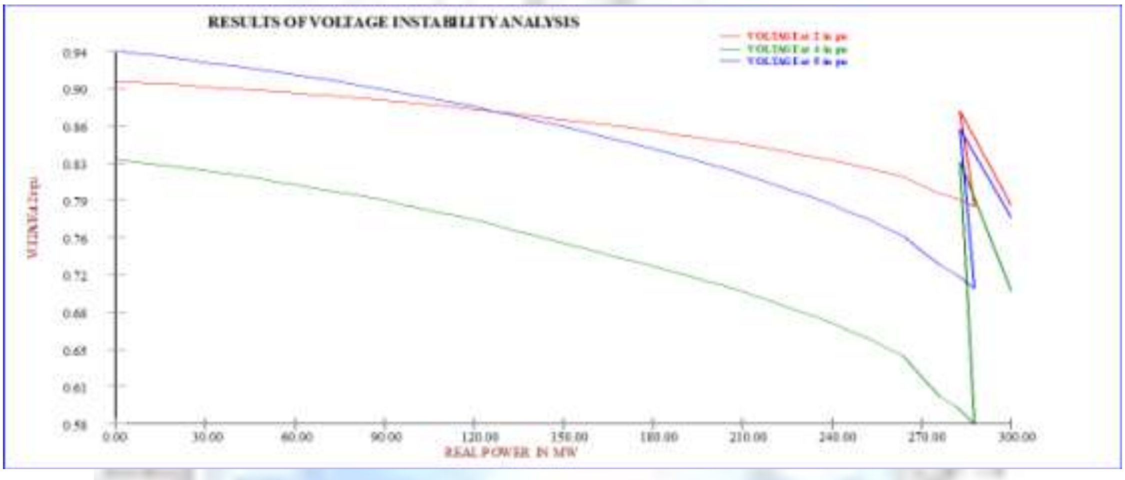

Fig. 3 P-V curves for a 3 load buses (In Stressed conditions)

When load is increased the stressing is also increased in system, it is shown in figure 3. Maximum loading has been reduced and bus voltage is very low. Improvement of P margin by shunt capacitors and maintaining bus voltage limits and voltage stability margin of the system. The shunt capacitor placed bus 2 and bus 5 of 100MVAr. The bus voltage increased upto the permissible limits and losses of transmission lines reduced.

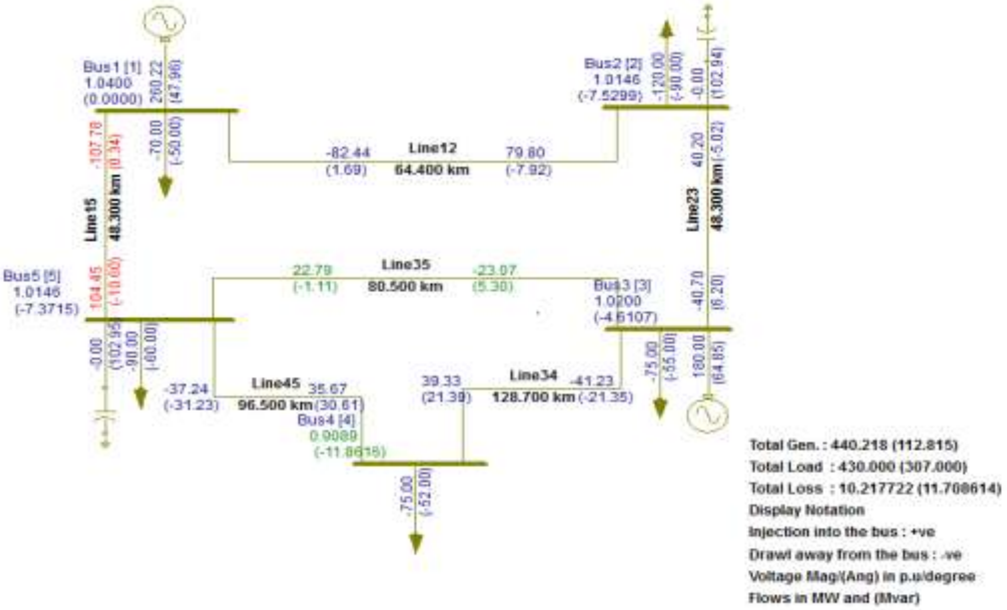

Fig. 4 Five Bus Model of a Power System (with shunt capacitors)

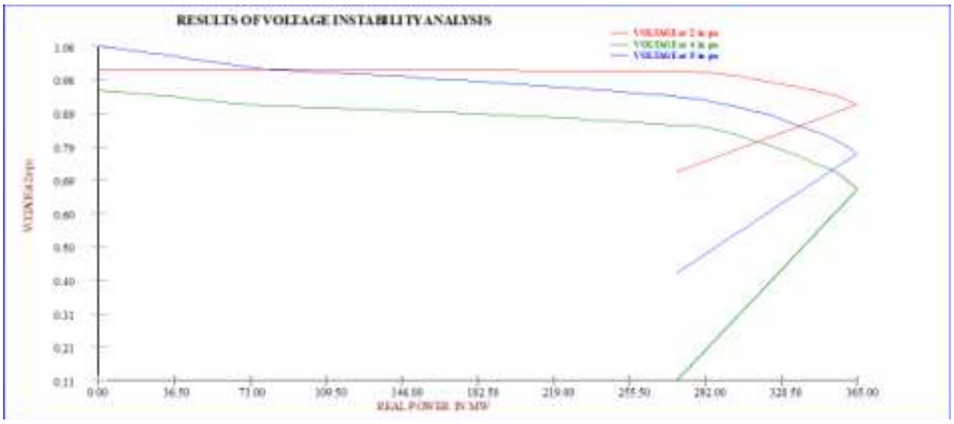

Fig. 5 P-V curves for a 3 load buses (after improving voltage stability margin)

Above figure 5 shows the increasing voltage stability margin and bus voltage limits of the system. In this figure load P margin increased upto 109.5MW. Therefore stressing on the P-V curve has been reduced. Table 2 shows the improved bus voltage with same loaded power system. The P-V curve shows the stressing is reduced and maximum loading is also increased.

TABLE 2

Bus No.	Real Power in MW	Reactive Power in MVAr	Cosφ	Voltage (pu)
Bus1	70	50	0.814	1.04
Bus2	120	90	0.80	1.0146
Bus3	75	55	0.8064	1.0200
Bus4	75	52	0.82	0.9089
Bus5	90	60	0.832	1.0146

A secure operating limit is the most stressed among a given set of operating points such that the system can withstand specified limit of bus voltage and stability margin. The voltage stability margin increase from minimum loading 287 MW to maximum loading 365 MW. System voltage magnitudes are expected to be in the 0.92 – 1.05 p.u. range where as the amount of voltage stability margin (VSM) is expected to be increased by 30% [10].

V. CONCLUSION

In this paper voltage stability margin and bus voltage has been improved by shunt capacitors. Injection of reactive power controls the transmission lines losses and reduced the percentage loading of the lines. Voltage stability margin has been predicted by the P-V curve because the voltage magnitude and active power best predictors of the voltage stability margin. Voltage collapse has the nose point, after this nose point voltage is fall down and security limit of the system fails. The shunt capacitor has two advantages one is the reactive power balance and other is the power factor improvement.

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