Estimating the Voltage Stability of electrical Power Systems using Field Programmable Get Array (F.P.G.A) Technique

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ABSTRACT

The modal analysis method is used to investigate the stability of the power system. Q-V curves are used to confirm the obtained results and to predict the stability margin or distance to voltage collapse based on the reactive power load demand. The load is connected to several selected buses in the Western System Coordinating Council (WSCC) 3-Machines 9-Bus power system . The weakest buses, which contribute the most to the critical mode, are identified using the participation factor. The Field Programmable Get Array (F.P.G.A) Technique is used to solve this problem on –line design programmable using the Very High Speed Language (V.H.D.L) technique. Two Spartan 3 Cit are used, the first is to resave power information from computer and the second is to transmit power information to the network.

KEY WORDS

Voltage Stability, Voltage collapse, Q-V Curves, Field Programmable Get Array (F.P.G.A), Modal Analysis.

1. INTRODUCTIO

The Voltage collapse problem is one of the major problems facing the electric power utilities in many countries. It is also a main concern in power systems operation and planning. It can be characterized by a continuous decrease of the system voltage. In the initial stage the decrease of the system voltage starts gradually and then decreases rapidly. The following can be considered the main contributing factors to the problem [1].

1. Stressed power system; i.e. high active power loading in the system.
2. Inadequate reactive power resources.
3. Load characteristics at low voltage magnitudes and their difference from those traditionally used in stability studies.

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4. Transformers tap changer responding to decreasing voltage magnitudes at the load buses.
5. Unexpected and or unwanted relay operation may occur during conditions with decreased voltage magnitudes.

This problem is a dynamic phenomenon and transient stability simulation may be used. However, such simulations do not readily provide sensitivity information or the degree of stability. They are also time consuming in terms of computers and engineering effort required for analysis of results. The problem regularly requires inspection of a wide range of system conditions and a large number of contingencies. For such application, the steady state analysis approach is much more suitable and can provide much insight into the voltage and reactive power loads problem [2] and [3].

So, there is a requirement to have an analytical method, which can predict the voltage collapse problem in a power system. As a result, considerable attention has been given to this problem by many power system researchers. A number of techniques have been proposed in the literature for the analysis of this problem [4].

The problem of reactive power and voltage control is well known and is considered by many researchers. It is known that to maintain an acceptable system voltage profile, a sufficient reactive support at appropriate locations must be found. Nevertheless, maintaining a good voltage profile does not automatically guarantee voltage stability. On the other hand, low voltage although frequently associated with voltage instability is not necessarily its cause [5] and [6].

Fig. (1) shows the Q-V curve which is a general method used by many utilities to assess the voltage stability. it can be used to determine proximity to voltage collapse since it directly assesses shortage of reactive power. The curves mainly show the sensitivity and variation of bus voltage with respect to reactive power injection. Using the Q-V curves, the stability margin or distance to voltage collapse at a specific bus can be evaluated. V-Q or voltage- reactive power curves are generated by series of power flow simulation, they plot the voltage at a lest bus or critical bus versus reactive power at the same bus. The bus is considered to be a PV bus, where the reactive output power is plotted versus scheduled voltage. Most of the time these curves are termed Q-V curves rather than V-Q curves. Scheduling reactive load rather than voltage produces Q-V curves. These curves are a more general method of assessing voltage stability. They are used by utilities as a workhorse for voltage stability analysis to determine the proximity to voltage collapse and to establish system design criteria based on Q and V margins determined from the curves. Operators may use the curves to check whether the voltage stability of the system can be maintained or not and take suitable control actions. The sensitivity and variation of bus voltages with respect to the reactive power injection can be observed clearly. The main drawback with Q-V curves is that it is generally not known previously at which buses the curves should be generated.

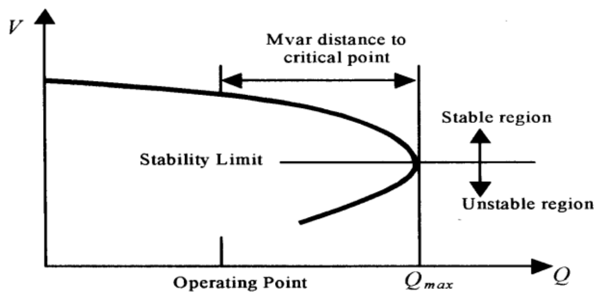

Figure 1 Typical V-Q curve

Field programmable get array using Spartan 3cit connected from computer by Cable RS232 to resaved the information output, the number of weakest bus and size of shunt capacitor must be correction this bus.tow Spartan 3 cit used the firs is resaved the values of size and location of shunt capacitor at series binary number and second transmit this values to sub distribution board to input the standard capacitor at weakest bus ON-LINE , shown in Fig. (2,3,4).

Fig. 2 The form of Spartan 3 cit

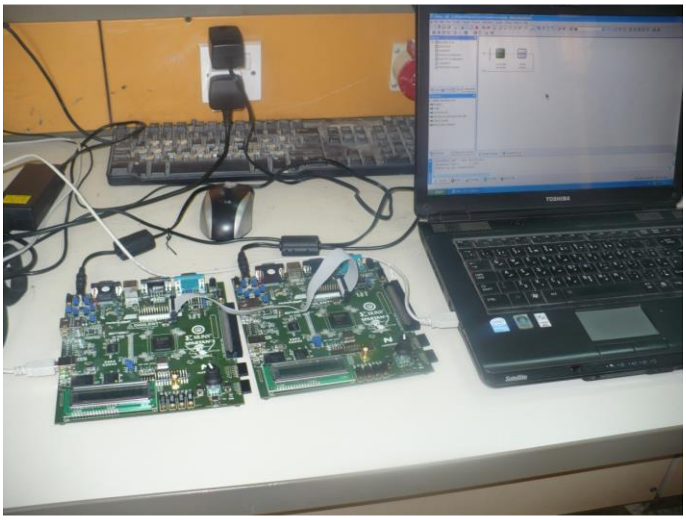

Fig 3 Two spartan 3 cit conect to computer by cabl rs232 practicly

Fig 4 Two spartan3 cit at operation

3. MODAL ANALYSIS

The modal analysis mainly depends on the power-flow Jacobian matrix. An algorithm for the modal method analysis used in this study.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_{11} & J_{12}\\ J_{21} & J_{22}\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta V\end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

By letting $\Delta P = 0$ in Equ. (1):

$$\Delta P = 0 - J_{11}\,\Delta\theta + J_{12}\,\Delta V\,, \Delta\theta = -J_{11}^{-1}\,J_{12}\Delta V \ldots\ldots \quad (2)$$

$$\Delta Q = J_{21}\,\Delta\theta + J_{22}\,\Delta V \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Substituting Equ. (2) in Equ. (3):

$$\Delta Q = J_R \Delta V \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$J_R = [J_{22} - J_{21} J_{11}^{-1} J_{12}]$$

JR is the reduced Jacobian matrix of the system.
Equ. (4) can be written as

$$\Delta V = J_R^{-1} \Delta Q \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The matrix J_R represents the linearized relationship between the incremental changes in bus voltage (ΔV) and bus reactive power injection (ΔQ). It's well known that, the system voltage is affected by both real and reactive power variations. hi order to focus the stud of the reactive demand and supply problem of the system as well as minimize computational effort by reducing dimensions of the Jacobian matrix I the real power (ΔP = 0) and angle part from the system in Equ. (4) are eliminated. The eigenvalues and eigenvectors of the reduced order Jacobian matrix *JR* are used for the voltage

stability characteristics analysis. Voltage instability can be detected by identifying modes of the eigenvalues matrix *JR*. The magnitude of the eigenvalues provides a relative measure of proximity to instability. The eigenvectors on the other hand present information related to the mechanism of loss of voltage stability.
Eigenvalue analysis of *JR* results in the following:

$$J_R = \Phi \Lambda \Gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

Where
Φ = right eigenvector matrix of *JR*
Λ = left eigenvector matrix of *JR*
□r□□= diagonal eigenvalue matrix of *JR*
Equation (1.6) ca be written as:

$$J_R^{-1} = \Phi \Lambda^{-1} \Gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (7)$$

Where ΦΓ = I
Substituting Equ. (7) in Equ. (5):

$$\Delta V = \Phi \Lambda^{-1} \Gamma \Delta Q \qquad (8)$$

Where
λ_i is the i[th] eigenvalue, Φ_i is the of i[th] column right eigenvector and
Γ_i is the i[th] row left eigenvector of matrix JR. Each eigenvalue
λ_i and corresponding right and left eigenvectors Φ_i and Γ_i, define the ith mode of the system. The ith modal reactive power variation is defined as:

$$\Delta Q_{mi} = K_i \Phi_i \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (9)$$

Where, K_i is a scale factor to normalize vector ΔQ_i so that,

$$K_i^2 \sum_j \Phi_{ji}^2 = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (10)$$

Equ. (10) can be summarized as follows:
1. If $\lambda_i = 0$, the i[th] modal voltage will collapse because any change in that modal reactive power will cause infinite modal voltage variation.
2. If $\lambda_i > 0$, the i[th] modal voltage and i[th] reactive power variation are along the same direction, indicating that the system is voltage stable.
3. If $\lambda i < 0$, the ith modal voltage and the ith reactive power variation are along the opposite directions, indicating that the system is voltage unstable.In general it can be said that, a system is voltage stable if the eigenvalues of JR are all positive. This is different from dynamic systems where eigenvalues with negative real parts are stable.
Field programmable get array using Spartan 3cit connected from computer by Cable RS232 to resaved the information output, the number of weakest bus and size of shunt capacitor must be correction this bus. This information input by binary number to cit ,very high speed language (V.H.D.L) can be change number to (0,1)

and resaved this value them the second cit transmit this value from sub distribution board to chose the size and location of weak bus.

4. CASE STUDY IMPLEMENTATIONS AND RESULTS

The modal analysis method is applied to the Western System Coordinating Council (WSCC) 3-Machines 9-Bus system, in Fig. (3).

The voltage profile of the buses is presented from the load flow simulation Fig. (4). Then, the minimum eigenvalue of the reduced Jacobian matrix is calculated. After that, the weakest load buses, which are subject to voltage collapse, are identified by computing the participating factors, Fig. (5). The voltage profile of all buses of the related power system is obtained from the load flow. It can be seen that all the bus voltages are within the acceptable level (±5%); some standards consider (±10%). The lowest voltage compared to the other buses can be noticed in bus number.

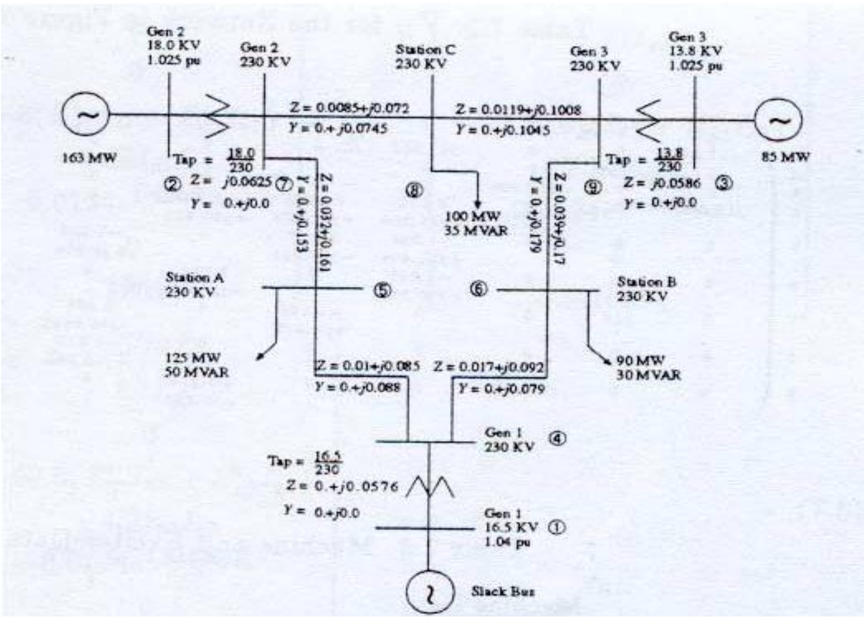

Fig. 5 The Western System Coordinating Council (WSCC) 3-Machines 9-Bus system

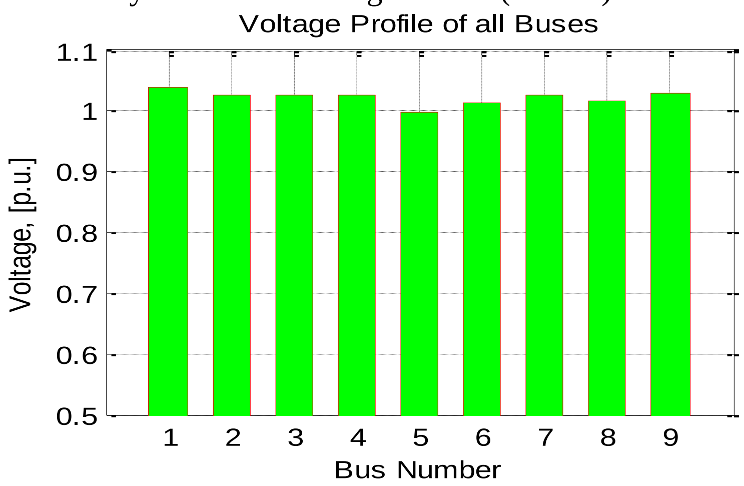

Fig. 6 Voltage profile of all buses of the Western System Coordinating Council(WSCC) 3-Machines 9-Bus System

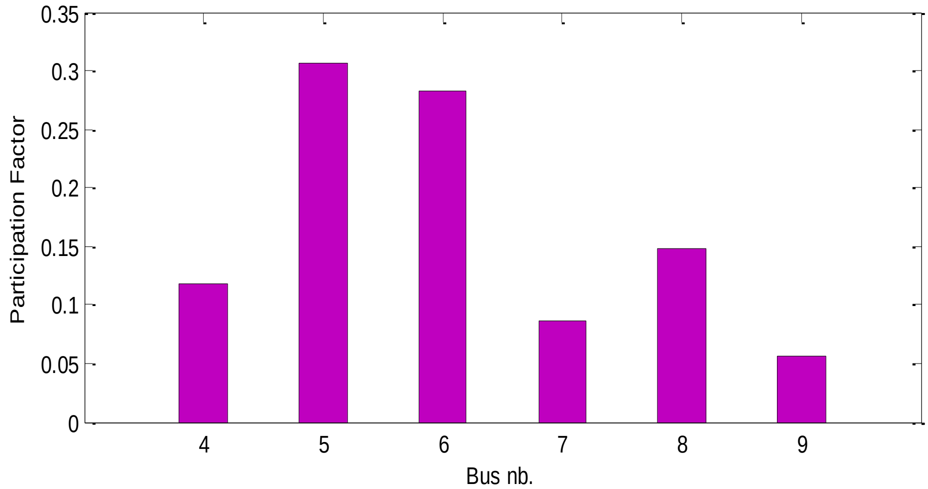

Fig. 7 Participation factor for 9 bus system

Table 1 Eigenvalue of 9-bus system WSCC

	1	2	3	4	5	6
Eigenvalue	51.0938	5.9589	46.6306	12.9438	14.9108	36.3053

The Q-V curves are used to determine the Mvar distance to the voltage instability point or the voltage stability margins. The margins were loading points before the voltage collapse. Consequently, these curves can be used to predict the maximum-security margins that can be reached. In other words, by using Q-Curves, it is possible for the operators and the planners to know, what is the maximum reactive power that can be achieved or added to the weakest bus before reaching minimum voltage limit or voltage instability. In addition, the calculated Mvar margins could relate to the size of shunt capacitor or static VAR compensation in the load area. The Q-V curves were computed for the weakest buses of the critical mode in the related power system as expected by the modal analysis method. The Q-V curves shown in figure 1confirm the results obtained previously by the modal analysis method. It can be seen clearly that bus 5 is the most critical bus compared with the other buses, where any more increase in the reactive power demand at that bus will cause a voltage collapse. Table(1)shows the eignvalue of buses (4,5,6,7,8,9) to find weakest bus. Fig 1shws the apparent power of the system .Fig (2)shows the participation factor to find the weakest bus ,bus 5 ,6 and 8 is unstable ,the system go to collapse. Fig (8,9,10,11,12,13) shows the operation system before and after improvement .

Table 2 ***Voltage and reactive power margins for the related power system from Q-V curves bus – 5***

Operating Point		Maximum with standard		Stability Margin		stability Margin after compensation	
V_{PU}	Q_{PU}	V_{PU}	Q_{PU}	ΔV	ΔQ	ΔV	ΔQ
1	0.45	0.6	0.32	0.4	2.75	0.002	2.3

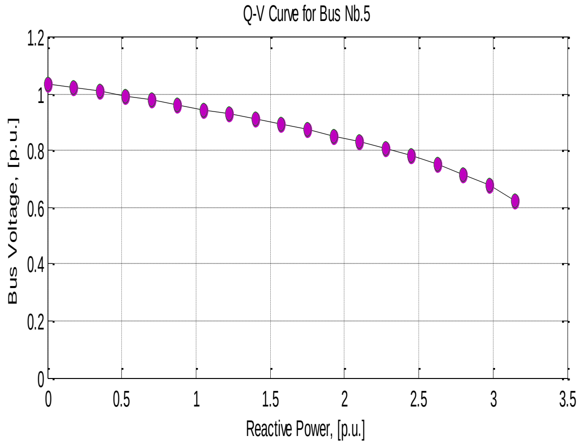

Fig. 8 Q-V curve for bus 5 before compensation

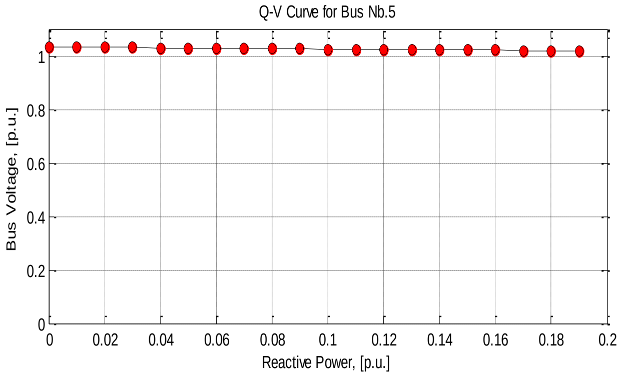

Fig. 9 The Q-V curve for bus 5 after compensation

Table 3 Voltage and reactive power margins for the related power system from Q-V curve bus-6.

Operating Point		Maximum with standard		Stability Margin		Stability Margin after compensation	
V_{PU}	Q_{PU}	V_{PU}	Q_{PU}	ΔV	ΔQ	ΔV	ΔQ
1	0.4	0.625	2.9	0.6	2.5	0.002	2.1

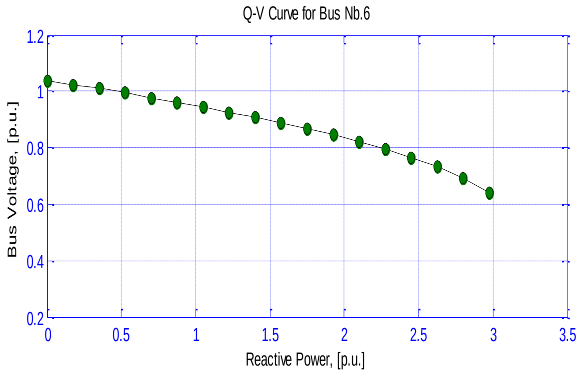

Fig. 10 The Q-V curve for bus 6 before compensation.

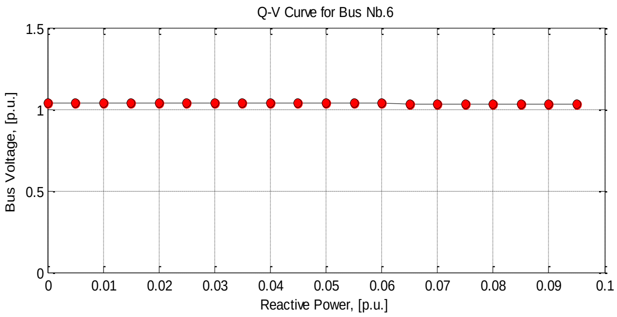

Fig. 11 Q-V curve for bus 6 after compensation

Table 4 Voltage and reactive power margins for related power system from Q-V curves bus-8

Operating Point		Maximum with standard		Stability Margin		Stability Margin after compensation	
V_{PU}	Q_{PU}	V_{PU}	Q_{PU}	ΔV	ΔQ	ΔV	ΔQ
1	0.5	0.72	3.25	0.28	2.75	0.002	2.28

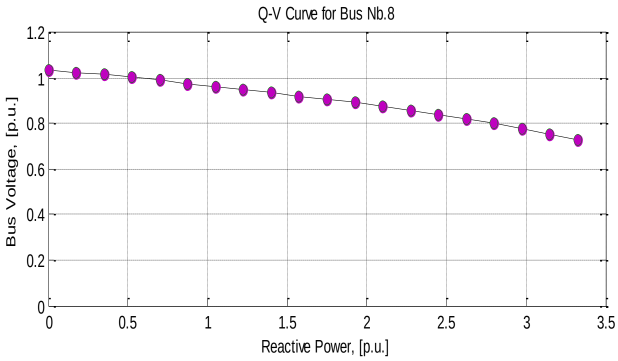

Fig. 12 The Q-V curve for bus 8 before compensation

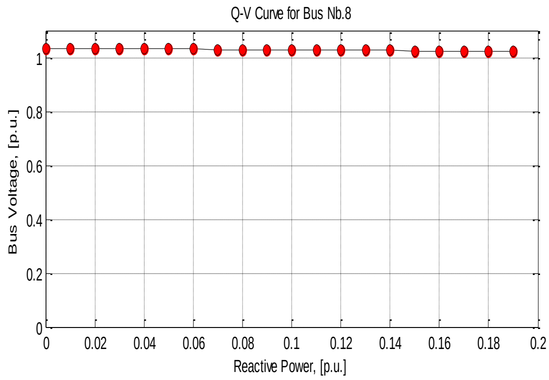

Fig. 13 The Q-V curve for bus 8 after compensation

5. CONCLUSIONS

The Modal analysis technique is applied to investigate the stability of the power systems. The method computes the smallest eigenvalue and the associated eigenvectors of the reduced Jacobian matrix using the steady state system model. The magnitude of the smallest eigenvalue gives us a measure of how close the system is to the voltage collapse. Then, the participating factor can be used to identify the weakest node or bus in the system associated to the minimum eigenvalue. The Q-V curves are used successfully to confirm the result obtained by Model analysis technique, where the same buses are found to be the weakest and contributing to voltage collapse. Using the Q-V curves, the stability margin or the distance to voltage collapse is identified based on voltage and reactive power variation. Furthermore, the result can be used to evaluate the reactive power compensation.

The results obtained by the constant load model and the voltage dependent load models agreed about the weakest buses that contribute to voltage instability or voltage collapse. However, using voltage dependent load models changes the stability margin and the distance to voltage collapse is improved. In addition, using the voltage dependent load models maintains much better voltage level. Field Programmable Get Array (F.P.G.A.) can be used as an on-line solution for the voltage collapse problem used spartan3 cit by input shunt capacitor at weak bus before voltage collapse incident.

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