Voltage Collapse Prediction for Egyptian Interconnected Electrical Grid EIEG

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Abstract: Voltage collapse is an undesired phenomenon that occurs due to voltage instability and is generally associated with weak or stressed system (heavily loaded lines), long lines, radial networks, faults and/or reactive power shortages. Its occurrence is not frequent in developed countries despite their large and complex networks but its frequency is high in Egypt. Voltage collapses are highly catastrophic anytime they occur. On the Egyptian Interconnected Electrical Grid EIEG, the system collapse phenomenon is frequently experienced and often leads to either partial or total system collapse blackout, which greatly impairs the nation's socio-economic development and industrialization. This high rate is due to the fact that the EIEG is weak, highly stressed, long and radial in nature hence lacking flexibility. The analysis is performed for EIEG power system. Modern advances in technology are changing the way utility industry increase the transmission of power throughout the country. Distributed energy resources are constantly improving their reliability and power capabilities. The model analysis technique is performed for system using the constant load model. The simulation results are Q-V curves on weak voltages by Power World Simulator PWS Software and Matlab Program.

Keywords: Voltage collapse, Egyptian Interconnected Electrical Grid EIEG, Distributed Energy Resources, Reliability and Power Capabilities.

1. Introduction

Power system stability has been recognized as an important problem for secure system operation since the 1920s [1-5]. Many major blackouts caused by power system instability have illustrated the importance of this phenomenon [6-10]. Voltage collapse may be total or partial blackout. Many major blackouts throughout the world have been directly associated to this phenomenon, e.g. in France, Italy, Japan, Great Britain, USA, etc. The analysis of this problem shows that the major causes is the system's inability to meet the reactive power demands [11-16].The world has witnessed several voltage collapse incidences in the last decades, prominent incidents that attracted much attention happened at Belgium (August 1982), Sweden (December 1983), Tokyo (July1987), Tennessee (August. 1987), Hydro Quebec (March 1989) and the recent major blackout incidence that happened in 2003 in North America and some parts of Europe [17-20]. A comprehensive list comprising the time frame is summarized in Table (1) [10].

Voltage instability has been observed in several forms, which was reached to complete blackouts of power systems in several countries [21]. Power systems institutes such as IEEE, CIGRE, IEE and EPRI have turned great attention to the subject [22]. An IEEE subcommittee was formed in 1986 for its studies[10-12]. In future the subject will have a direct access to other interests such as power system security, reliability, planning, control methods and power system harmonics suppression. The excessive use of power electronic devices will augment the chances of occurrence of the phenomena. Electronic static VAR compensators, flexible AC transmission systems and HVDC systems will be widely used to counteract the effect of such devices and to improve the voltage stability situation of large systems [23-25]. Power quality is

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a recent subject appeared with complication of power systems [26]. It concerns several subjects, which are treated in detail in this research [27-29].

Table 1. Analysis real collapses involves

No.	Occurrence of Disturbance	Year
1	New York State Pool disturbance	1970
2	Jacksonville Florida system disturbance	1977
3	Zealand Denmark system disturbance	1979
4	Central Oregon system disturbance	1981
5	Belgium system disturbance, Florida system disturbance, and Northern Belgium system disturbance	1982
6	Northern California system disturbance, Japanese system disturbance, and Swedish system disturbance	1983
7	Northeast United States system disturbance	1984
8	England system disturbance, and Miles City HVDC links	1986
9	Western French system disturbance, Tokyo system disturbance, Indiana system disturbance, and Mississippi system disturbance	1987
10	South Carolina system disturbance	1989
11	Western France system disturbance, and Baltimore and Washington DC system disturbance	1990
12	Sri Lanka power system disturbance	1995
13	Western System Co-ordination Council system disturbance, and North Indian Grid system disturbance	1996
14	North American power system disturbance	2003
15	National Grid system of Pakistan disturbances	2006

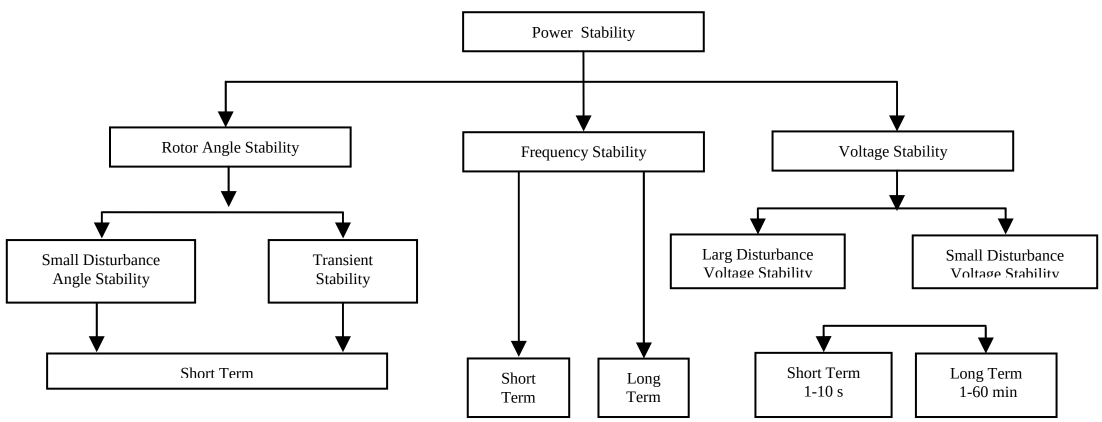

Figure 1. Classification of power system stability [5].

Based on the size of the disturbance, voltage stability can be further classified into the following two subcategories as shown in Figure (1):

- The study period of interest is in the order of several seconds.
- Long-term voltage stability involves slower acting equipment such as tap-changing transformers, thermostatically

In general, the research aim agreed about the weakest buses that contribute to voltage collapse for the following points [8]:

- The EIEG power system has been simulated and tested in this research to illustrate the proposed analysis methods.

- The method computes the smallest eigen value and the associated eigenvectors of the reduced Jacobian matrix using the steady state system model.
- Then, the participating factor can be used to identify the weakest node or bus in the system associated to the minimum eigen value.
- Using the Q-V curves, the stability margin or the distance to voltage collapse is identified based on voltage and reactive power variation.

2. Voltage Collapse Problem

A. Identification of the Weak Load Buses

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 [27]. If Φ_i and Γ_i represent the right and left hand eigenvectors, respectively, for the eigen value λ_i of the matrix J_R, then the participation factor measuring the participation of the kth bus in ith mode is defined as:

$$\boldsymbol{P_{ki}} = \Phi_{\boldsymbol{ki}}\Gamma_{\boldsymbol{ki}} \tag{1}$$

Note that for all the small eigen values, bus participation factors determine the area close to voltage instability. Equation (1) implies that P_{ki} shows the participation of the ith eigen value to the V-Q sensitivity at bus k. The node or bus k with highest P_{ki} is the most contributing factor in determining the V-Q sensitivity at ith 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 ith mode [21].

B. Q-V Curve

V-Q or voltage reactive power curves are generated by series of power flow simulation. They plot the voltage at a test 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 [22].

As a traditional solution in system planning and operation, the voltage level is used as an index of system voltage instability. If it exceeds the limit, reactive support is installed to improve voltage profiles. With such action, voltage level can be maintained within acceptable limits under a wide range of MW loadings. In reality, voltage level may never decline below that limit as the system approaches its steady state stability limits. Consequently, voltage levels should not be used as a voltage collapse warning index [23].

In this research, the voltage collapse problem is studied. Figure (2) shows a typical Q-V curve, and the following can be anticipated results:

- The magnitude of the smallest eigen value gives us a measure of how close the system is to the voltage collapse.
- The participating factor can be used to identify the weakest node or bus in the system associated to the minimum eigen value.

- 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.

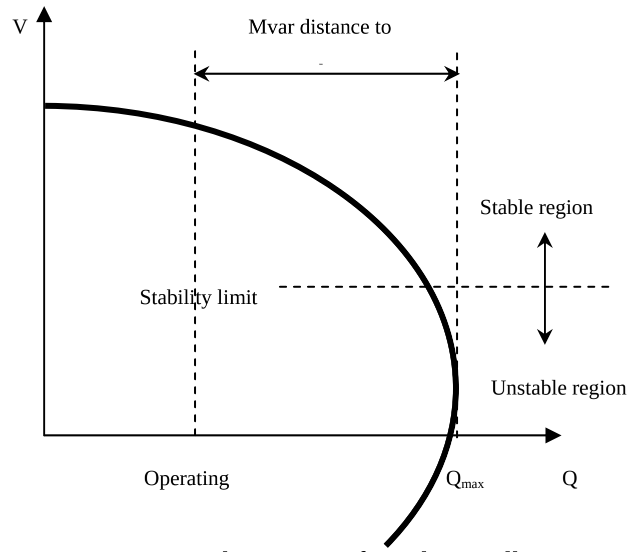

Figure 2. Typical Q-V curve for voltage collapse

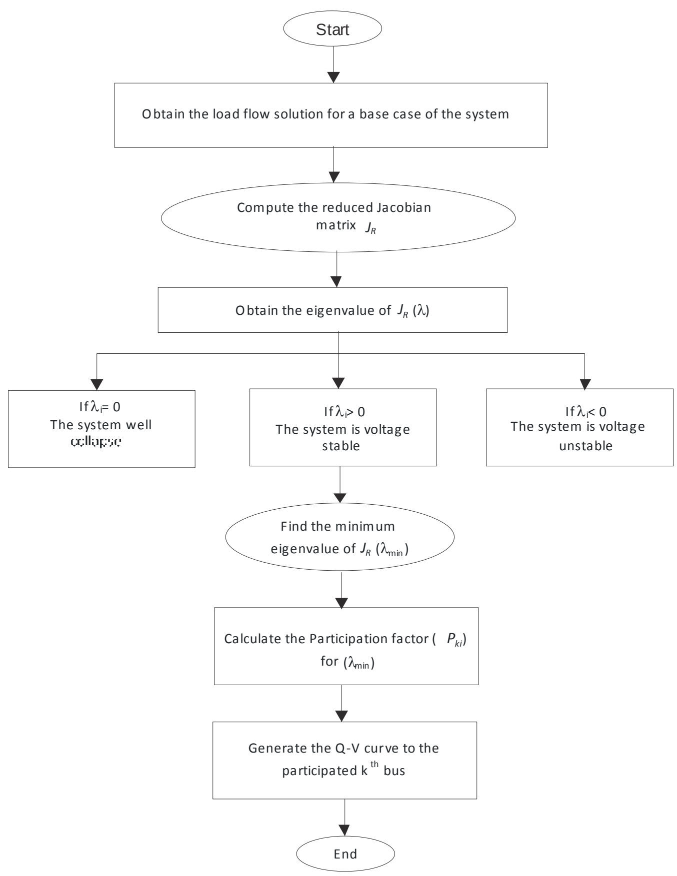

Figure 3. Flow chart of algorithm for the voltage stability analysis

Figure (3) shows flow chart of algorithm for the system voltage stability analysis, and the following steps [24]:

- Obtain the load flow solution for a base case of the EIEG studied power system
- Compute the reduced Jacobian matrix J_R, obtain the eigen value of $J_R(\lambda)$, and If $\lambda_i = 0$, the system well collapse
- Find the minimum eigen value of J_R
- Calculate the participation factor (P_{ki}) for (λ_{min})
- Generate the Q-V curve to the participated k^{th} bus

3. Studied System

Considering the continuous development in the EIEG power system during the past twenty years and the rapid increase of the electricity demand, which was clearly shown by the technical studies to predict the loads as a result of the continuous increase in population, urbanization, industrial and service projects, the problem of voltage stability gains more and more importance and studies as in everywhere [13-15]. The model analysis method has been successfully applied to EIEG power system. The Q-V cures are generated for selected buses in order to monitor the voltage stability margin. A load flow program based on MATLAB, and Power World Simulator PWS are developed to calculate the load flow solution, analyze the voltage stability based on model analysis, and generate the Q-V curves. The EIEG power system has been simulated and tested in this research to illustrate the proposed analysis methods. EIEG studied power system case 9-machines, and 32-bus system. The single line diagram is shown in Figure (4).

The present installed capacity of the generation EIEG power system is about 13375MW, the maximum load on the network in 2010 was 13257MW, where linked network and insulated network contributed by 90% and 10% respectively. By 2010, the system of electrical transmission between the Egypt regions and Cities consist of three main elements are: stations, transformers of transmissions in additional to line of transmission networks. Where number stations of 500kV, and 220kV electricity transmissions. The system frequency is 50Hz.

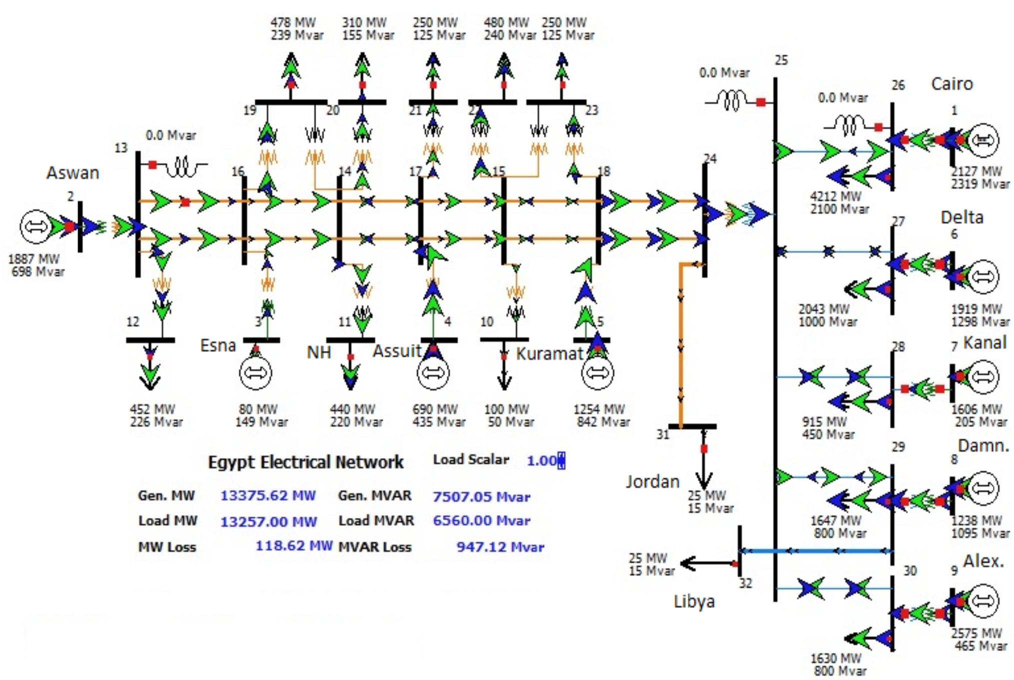

Figure 4. Single line diagram of an EIEG studied power system 9-machines, and 32-bus system

4. Results and Discussions

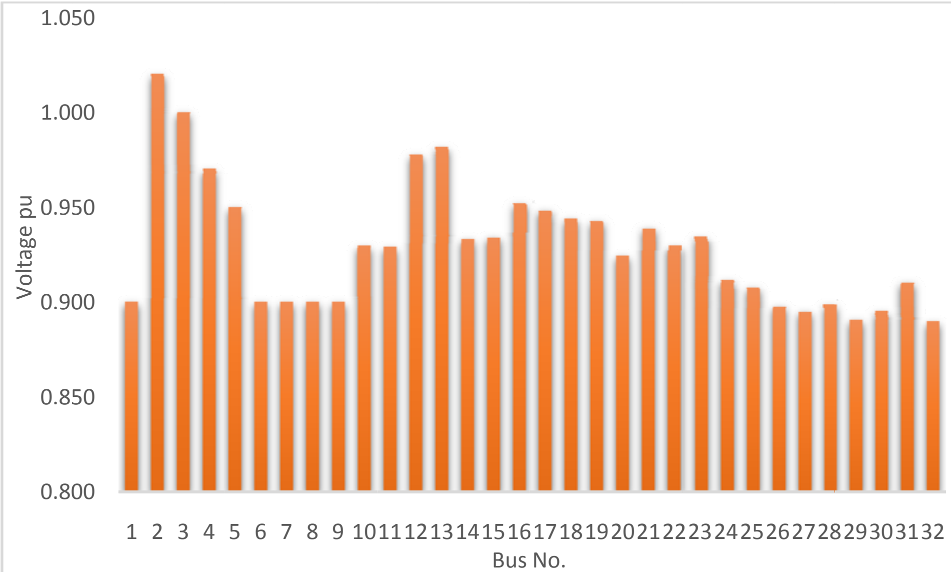

Figure 5. Voltage profiles of all buses of the EIEG power system

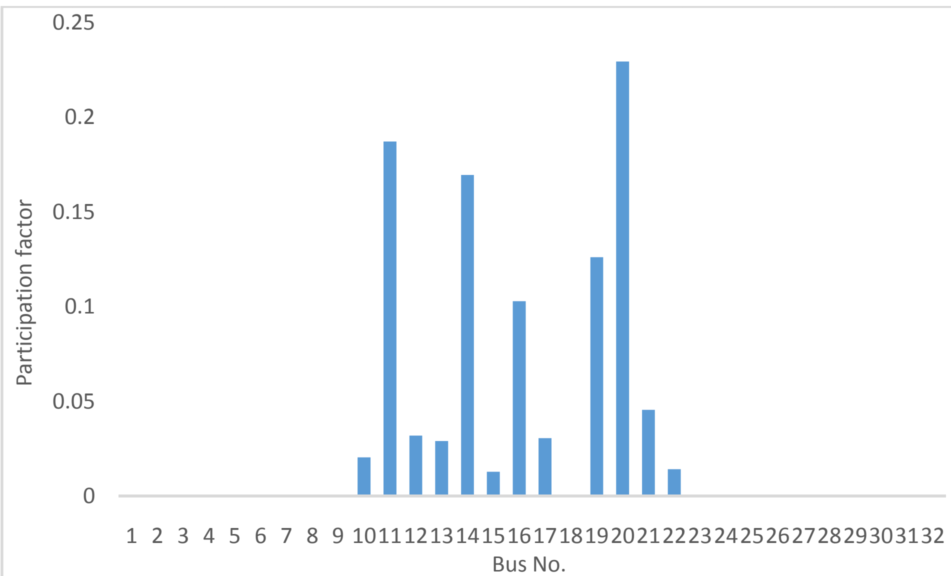

Figure 6.The participating factor of all buses for most critical mode of the EIEG power system

The modal analysis with constant impedance load, and the voltage profile of the buses is presented from the load flow simulation. 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. Figure (5) shows the voltage profile of all buses of the Egyptian 32-bus system as obtained from the load flow. It can be seen that all the bus voltages are within the acceptable level (±7%) except bus number 24 to 32, which is about 0.9 p.u. The lowest voltage compared to the other buses can be noticed in bus number 24 to 32. The participating factor for this mode has been calculated and the result is shown in Figure (6). The result shows that, the buses 11 (Naj-Hammadi), 19 (Qena) and 20 (Sohag) have the highest participation factors for the critical mode. The largest participation factor value (0.2294) at bus # 20 indicates the highest contribution of this bus to the voltage collapse.

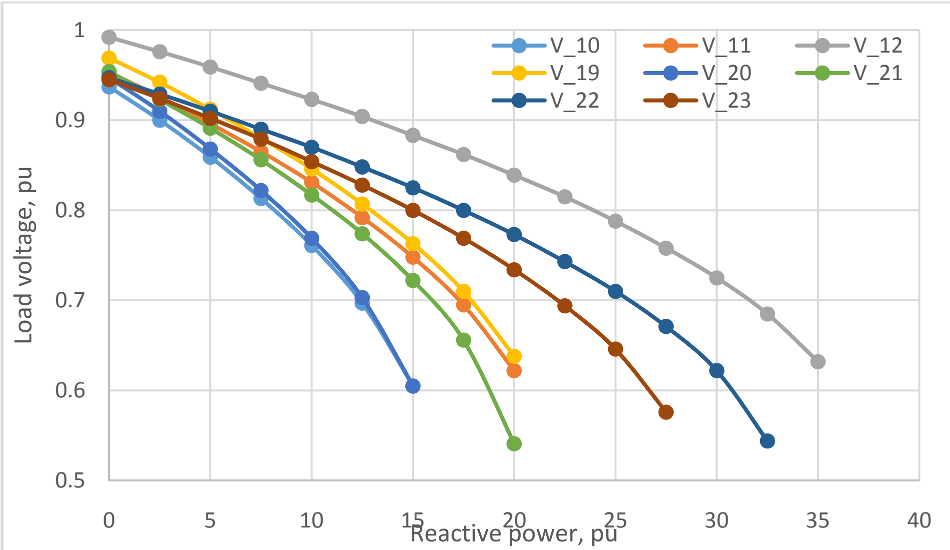

Figure 7. The Q-V curves at weakest buses of the critical mode of the EIEG power system

The Q-V curves were computed for the weakest buses of the critical mode in the Egyptian 32 bus system as expected by the modal analysis method. The curves are shown in Figure (7), and Figure (8). Q-V curves, verifies the results obtained previously by modal analysis method. It can be seen clearly that bus # 20 (Sohag) is the most critical bus compared the other buses, where any more increase in the reactive power demand in that bus will cause a voltage collapse as shown in Figure (7). Also, for interconnected or linked buses with Jordan, and Libya as shown in Figure (8).

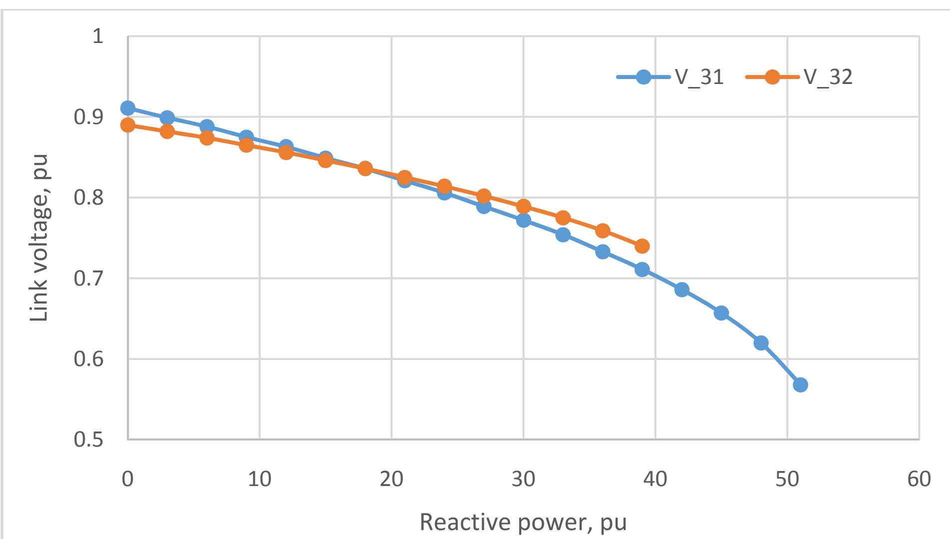

Figure 8. The Q-V curves at Labya and Jordan interconnect of the EIEG power system

Table (2) shows evaluation of the buses 11, 19, and 20 Q-V curves. These results can be used effectively in planning or operation of this system. Since there are 32 buses among which there is one swing bus and 8 PV buses, then the total number of eigenvalues of the reduced Jacobian matrix $J_R$is expected to be 23 as shown in Table (3). Note that all the eigenvalues are positive which means that the system voltage is stable. From Table (3), it can be noticed that the minimum eigenvalue (λ=22.46) is the most critical mode.

Table 2. Voltage and reactive power margins for the EIEG power system

	Operating Point		Maximum withstand	
	V in (p.u)	Q in (p.u)	V in (p.u)	Q in (p.u)
Bus # 11	0.929	2.20	0.622	20
Bus # 19	0.943	2.39	0.638	20
Bus # 20	0.943	2.39	0.605	15

Table 3.EIEG power systemeigenvalues sorted by ascending values

Bus #	Eigenvalues	Bus #	Eigenvalues	Bus #	Eigenvalues
10	9155.56	18	1253.00	26	258.27
11	2811.79	19	1315.11	27	82.05
12	2251.95	20	912.74	28	94.64
13	1695.28	21	717.18	29	118.97
14	1658.75	22	511.90	30	194.03
15	1552.26	23	356.01	31	186.73
16	1360.59	24	22.46	32	157.65
17	1217.23	25	47.13		

5. Conclusion

The modal analysis technique is applied to investigate the EIEG power system simulated power flow by PWS program, and stability, these method computes the smallest eigen value and the associated eigenvectors of the reduced Jacobian matrix using the steady state system model. The magnitude of the smallest eigen value 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 eigen value. 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 in EIEG power system.

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