Automatic Voltage Stability Analysis In The Presence of Contingency

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Abstract—This paper present an automatic voltage stability analysis in the presence of contingency. In this case, the study was conducted under generator and/ or line outage contingency. The study aims to evaluate the bifurcation point when voltage stability is highly affected by reactive power generation saturation phenomena. The reactive power generation saturation of a unit can change the system voltage immediately from stable to unstable. The value is determined using MATLAB programming that uses fast voltage stability index (*FVSI*) as an indicator. The results of the index before and after the contingency are compared to show the effect of contingency to the system. The method was tested on the IEEE 30-Bus Reliability Test System (RTS) system and results have been compared using the V-Q curves.

Keywords- MATLAB, Fast Voltage Stability Index, Generator Outage, Line Outage, Voltage Stability, Voltage Collapse.

I. INTRODUCTION

In recent years, voltage stability has become rather important in power system. In fact, the systems are being operated close to their voltage stability limits [1]. There are some of fundamental concepts being discussed to understand how the voltage stability analysis or also known as voltage collapse problem is occurring. It is a well established fact that voltage collapse in power systems is associated with system demand increasing beyond certain limits, as well as with the lack or reactive power support in the system. This is caused by limitations in the generation or transmission of reactive power. Actually, voltage stability is defined as the characteristic for a power system to remain in state of equilibrium at normal operating conditions and to restore an acceptable state of equilibrium after a system disturbance [1]. It is important to know the meaning of the voltage stability that it concerns the ability of power system to maintain steady state acceptable voltage at all buses in the system under normal operating condition.

Generally, voltage stability consists of two categories. There are static and dynamic. Fast voltage stability index (*FVSI*) is one of the equations which can be used to assess voltage stability. This method is used as a fast way of computing the index of the lines in the system. Contingencies are affected by the line outage in the system. It is also known that contingencies are one of the contributing factors to the voltage collapse. Based on studies, there are many approaches towards predicting the occurrence of voltage collapse such as by using neural network or some of artificial intelligent technique such as artificial immune system (AIS). The authors in [7] studied the problem using the solution of the differential equations representing the power system as a reference to evaluate inherent approximations employed in the conventional load flow programs. In [3], the problem is analysed using the actual equilibrium point of the differential-algebraic equations (DAE) power system model.

A model for generator reactive power and voltage dynamics is incorporated in the load flow problem [4], where the generator voltage variations are accounted for in the calculation of the limits. In [2], the authors present a static model for the synchronous generators with voltage dependent reactive power limits. This generator model is included in an ordinary power flow program. However, it uses a simplified model of the generator disregarding the voltage regulator. The static and dynamic aspects of voltage collapse associated with generator reactive power limits are studied using bifurcation theory in [2]. In [8], a detailed analysis of hard limits in nonlinear dynamic systems is presented in state and parameter space. This work considers that, when a generator reaches its field voltage limit, the generator internal voltage can be treated as a constant value. The dynamics of the voltage regulator are not modelled in this case. In [6], the limits are represented by hyperbolic functions that allow obtaining an analytic formulation for the nonlinear equations.

In this research, the objective is mostly focus on fast voltage stability index which is used to predict the occurrence of voltage collapse cause by the line outage in a power system. The V-Q curve represents a proximity to voltage collapse. Whereas, other developed voltage stability index are used as voltage instability indicators. These indexes are tested on the IEEE 30-Bus RTS or a transmission line. Results obtained from the experiment indicated that the technique is feasible.

II. PROBLEM FORMULATION

The problem of voltage stability is an important issue in power system. One of the causes is contingency.

Contingencies analysis is important to study about voltage stability condition of a system.

A. Voltage Stability

Voltage stability is concerned with the ability of a power system to maintain steady voltage at all buses under normal operating condition and after being subjected to disturbance [5]. The voltage stability is depending on the ability to maintain equilibrium between load demand and load supply from the power system. While, the instability occurs in the form of a progressive fall or raise the voltage for some buses. The possible that voltage instability overcome when one of the transmission line (line outage) or generator outage is tripping or cut. The short-term voltage stability involves dynamic of fast acting load component where the voltage collapse in the order of several second and analysis requires solution of appropriate system differential equations. Long-term voltage stability involves slower acting equipment such as tap changing transformer. The study period of interest may extend to several or many minutes [9].

Stability is usually determined by the resulting outage of equipment, rather than the severity of the initial disturbance. Instability is due to the loss of long term equilibrium when loads try to restore their power beyond the capability of the transmission network and connected generation. In many cases, static analysis can be used to estimate stability margins, identify factors influencing stability and screen a wide range of system conditions and a large number of scenarios. The relation between the reactive power consumed in the monitored area and the corresponding voltage is expressed so called V-Q curve. The increase values of the reactive power are accompanied by a decrease of voltage. When the reactive power is further increased, the maximum loadability point is reached, from which no additional reactive power can be transmitted to the load under those condition.

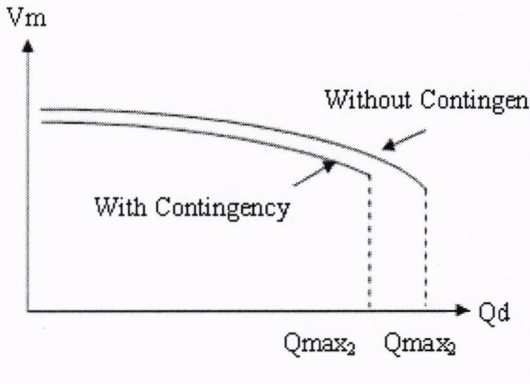

Figure 1. V-Q Curve for Load Variation

Fig.1 illustrates the relationship between voltage profile and reactive power coaching at a particular load bus. The presence of contingency in a system has caused lower in a system. This voltage profile as also led to lower. Qmax of the load bus as indicated in the figure.

B. Fast Voltage Stability Index (FVSI)

Fast voltage stability index is referred to a line which is formulated in this study as the measuring instrument in predicting the voltage stability condition in the system. The implementation of the fast voltage stability index will results in a set of data known as the line index. The index is obtained by calculation using the fast voltage stability index formula. The faster way of doing the calculation is needed and it is by using fast voltage stability index formula. Fast voltage stability index is the approach towards predicting the occurrence of voltage collapse which is caused by the line outage in a power system. In order to consider voltage collapse of the system, the mathematical equation of fast voltage stability index can be explained and derives in the following section.

Derivation of FVSI

Generally it started with the current equation to form the power or voltage quadratic equations. Voltage collapse may occur in the system if the discriminant is less than zero. The line index that is evaluated must be close to 1.00 to indicate the limit of voltage instability [10]. In this case, *FVSI* is used to evaluate stability condition of a line in the system.

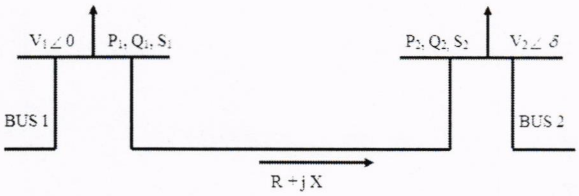

Figure 2. A 2-Bus Power System

V1, V2 = voltage on sending and receiving bus.
P1, Q1 = active and reactive power on the sending bus
P2, Q2 = active and reactive power on the receiving bus
S1, S2 = apparent power on the sending and receiving end
δ = δ 1 - δ 2, is the angle difference between sending and receiving end
Z = R+jX is the line impedance

The receiving end voltage can be represented in the form of quadratic equation;

$$V_2^{\,2} - \left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1V_2 + \left(X + \frac{R^2}{X}\right)Q_2 = 0 \qquad (1)$$

The roots for V_2 will be;

$$V_2 = \frac{\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1 \pm \sqrt{\left[\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1\right]^2 - 4\left(X + \frac{R^2}{X}\right)Q_2}}{2} \qquad (2)$$

In order to obtain real roots for V_2, the discriminant($b^2 - 4ac$) the above equation is set greater than orequal to 0. Hence,

$$\left[\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1\right]^2 - 4\left(X + \frac{R^2}{X}\right)Q_2 \geq 0 \qquad (3)$$

Then re-arranging the (3) equation,

$$\frac{4Z^2Q_2X}{V_1{}^2(R\sin\delta + X\cos\delta)^2} \qquad (4)$$

Since $\delta$is normally very small then,

$\delta\approx0$, $R\sin\delta\approx0$ *and* $X\cos\delta\approx X$ (5)

Taking the symbols *i* as the sending bus and *j* as thereceiving bus. Hence, the fast voltage stability index,*FVSI* can be defined as;

$$FVSI_{ij} = \frac{4Z^2Q_j}{V_i{}^2X} \qquad (6)$$

Where,

Z = line impedance
X = line reactance
Q_j= reactive power at the receiving end
V_i= sending end voltage

*FVSI*value for each line in the system will be computed to indicate the voltage stability condition of the respective line in the system. If *FVSI*value computed on any line exceeds unity, the system loses its stability condition leading to sudden voltage drop and hence, voltage collapse.

III. RESULTS AND DISCUSSION

The algorithm for voltage stability analysis is shown in Fig.3. The process starts by choosing the load bus for the test. Loading condition is set so that loadflow results can be obtained at the specific loading condition. Results from the load flow will be utilised to calculate *FVSI* during contingencies and without contingencies.

The voltage stability analysis is conducted on the IEEE on the IEEE 30-Bus RTS. The system has 5 voltage control buses, 24 load buses, 41 transmission line, 1 slack bus and 4 transformer tap changers with 100MVA base power. The concept of this project is to calculate the line of stability index by the of use *FVSI* index. In this case, the line outage and generator outage are considered to come out with various contingencies that affect the bifurcation point. The load variation is performed at the load buses in terms of reactive loading.

For the result of the effects of load increment to bus voltage, system voltage limit, maximum permissible load, effects of contingency, effects of generator outage and comparison of various contingencies are tabulated and shown in the Table 1, Fig.4, Fig.5, Fig.6, Fig.7, and Fig.8

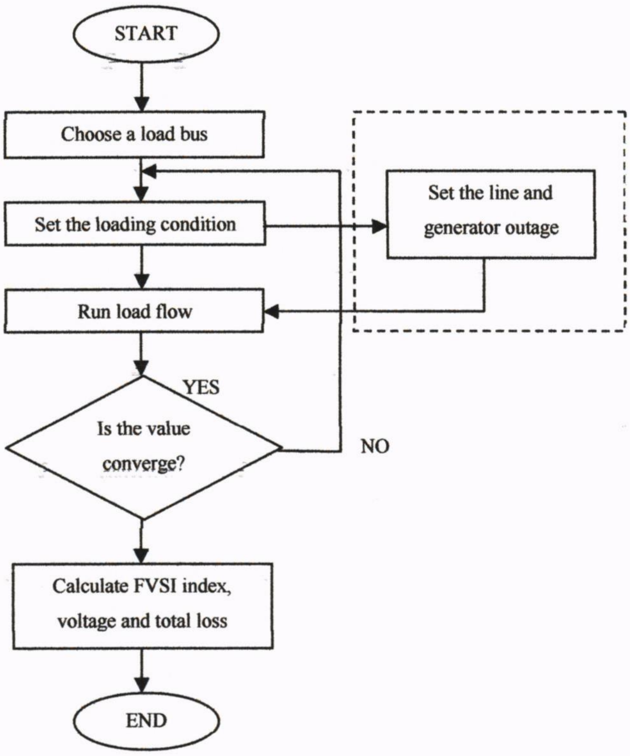

Figure 3.Flowchart of Whole Research.

TABLE I. DATA LOADABILITY BASED FVSI FOR BUS 20

Qd	Vm	FVSI	Losses
0	1.0308	0.2097	0.1636
5	1.0197	0.2029	0.1637
10	1.0065	0.2047	0.1614
15	0.9949	0.1977	0.1616
20	0.9829	0.1905	0.1619
25	0.9706	0.1943	0.1623
30	0.9579	0.2273	0.1627
35	0.9448	0.2604	0.1633
40	0.9278	0.2969	0.1640
45	0.9137	0.3299	0.1648
50	0.8991	0.3629	0.1656
55	0.8726	0.4012	0.1674
60	0.8556	0.4339	0.1685
65	0.8344	0.4699	0.1700
70	0.8120	0.5016	0.1722
75	0.7858	0.5373	0.1750
80	0.7587	0.5688	0.1778
85	0.7344	0.6015	0.1805
90	0.7069	0.6342	0.1839
95	0.6747	0.6668	0.2050
100	0.6257	0.6984	0.2611

The result for maximum voltage level, fast voltage stability index and transmission loss when was subjected to Bus 20 is shown separately in Table I. From the table, it can be shown that the voltage levels have been decreased and the losses have been increased.

TABLE II. DATA MAXIMUM VOLTAGE LIMIT FOR BUS 15, 16, 17 AND 18

Qd	**Vm**			
	15	**16**	**17**	**18**
0	1.0411	1.0477	1.0477	1.0300
5	1.0344	1.0392	1.0403	1.0183
10	1.0276	1.0305	1.0328	1.0064
15	1.0189	1.0200	1.0252	0.9922
20	1.0119	1.0110	1.0156	0.9796
25	1.0047	1.0018	1.0077	0.9665
30	0.9924	0.9879	0.9996	0.9487
35	0.9850	0.9783	0.9915	0.9346
40	0.9774	0.9684	0.9831	0.9200
45	0.9646	0.9537	0.9715	0.9003
50	0.9514	0.9432	0.9629	0.8843
55	0.9380	0.9278	0.9540	0.8544
60	0.9243	0.9089	0.9449	0.8306
65	0.9130	0.8924	0.9257	0.8112
70	0.9042	0.8798	0.9155	0.7885
75	0.8951	0.8673	0.9056	0.7616
80	0.8853	0.8544	0.8884	0.7361
85	0.8758	0.8360	0.8778	0.7012
90	0.8645	0.8218	0.8618	0.6659
95	0.8513	0.8068	0.8459	0.6190
100	0.8408	0.7867	0.8340	

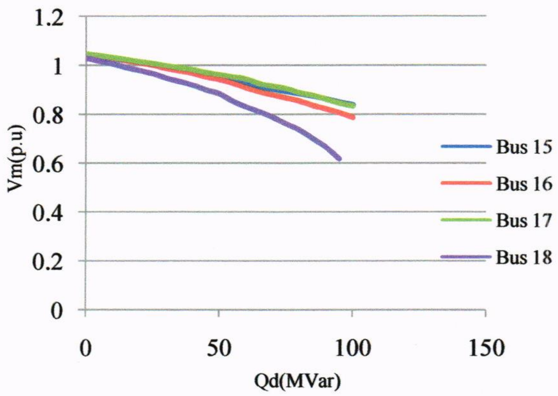

Figure 4. Maximum Voltage Limit for Bus 15, 16, 17 and 18

Fig.4 illustrates the profile for voltage variation with respect to the increment of reactive power loading at bus 15, 16, 17 and 18. The two parameters are clearly improved since the injected reactive power in stages has led to the decrease in voltage level and increase the fast voltage stability index. For the note, further increase of the reactive power may cause voltage collapse.

The actual amount of maximum voltage level for the IEEE 30-Bus RTS which indicated at loading condition is tabulated in Fig.5.

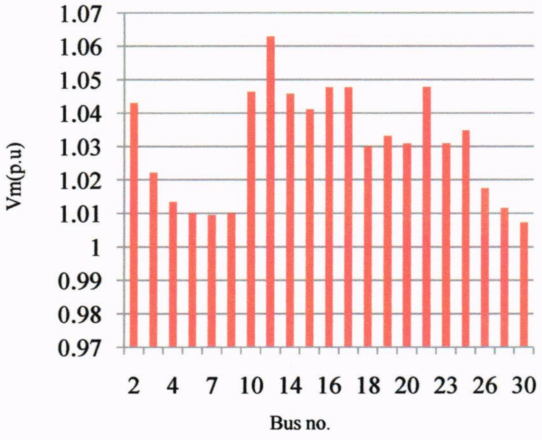

Figure 5. Maximum Permissible Load Point for IEEE 30-BUS RTS

The voltage profiles for bus 20 when load variation is subjected to this bus for the contingency scenario is shown in Fig. 6. It is pretty obvious that the presence of contingency has reduced the voltage profile at this bus.

TABLE III. VOLTAGE PROFILE WITH THE PRESENCE OF CONTINGENCY POINT FOR BUS 20

Qd	**Without Contingency**	**With Contingency**
0	1.0308	1.0201
5	1.0197	1.0089
10	1.0065	0.9974
15	0.9949	0.9856
20	0.9829	0.9700
25	0.9706	0.9540
30	0.9579	0.9375
35	0.9448	0.9205
40	0.9278	0.9064
45	0.9137	0.8856
50	0.8991	0.8658
55	0.8726	0.8456
60	0.8556	0.8284
65	0.8344	0.8101
70	0.8120	0.7862
75	0.7858	0.7619
80	0.7587	0.7384
85	0.7344	0.7067
90	0.7069	0.6757
95	0.6747	0.6374
100	0.6257	0.5808

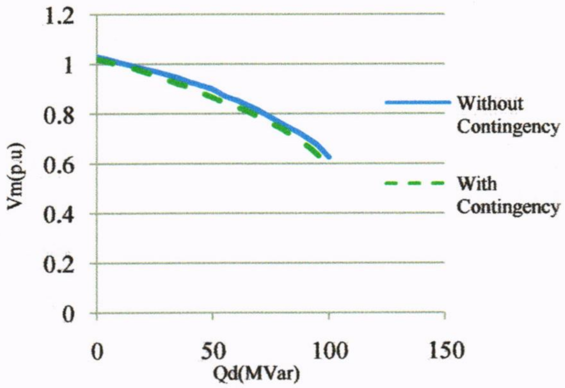

Figure 6.Contingency Point for Bus 20

Based on the results from the tested at transmission line, the association of voltage level observed is higher as compare to the one which is remove one line.

TABLE IV.DATA GENERATOR OUTAGE POINT FOR BUS 20

Qd	Without Contingency	With Contingency
0	1.0308	1.0183
5	1.0197	1.0055
10	1.0065	0.9924
15	0.9949	0.9788
20	0.9829	0.9648
25	0.9706	0.9504
30	0.9579	0.9354
35	0.9448	0.9148
40	0.9278	0.8975
45	0.9137	0.8804
50	0.8991	0.8532
55	0.8726	0.8337
60	0.8556	0.8070
65	0.8344	0.7843
70	0.8120	0.7525
75	0.7858	0.7241
80	0.7587	0.6853
85	0.7344	0.6316
90	0.7069	0.5457
95	0.6747	
100	0.6257	

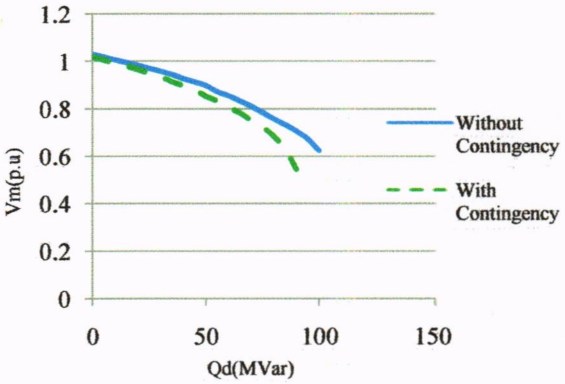

Figure 7.Generator Outage Point for Bus 20

The result for voltage level at Bus 20 is shown in Fig. 7 there was a fast voltage drop as the reactive power which is increased during the outage at the generator at bus 20. It is observed that the maximum injected reactive power for the generator outage is much lower than the maximum injected reactive power without generator outage.

TABLE V.DATA COMPARISON OF VARIOUS CONTINGENCIES POINT FOR BUS 20

Qd	Without contingencies	Generator outage	With line outage
0	1.0308	1.0183	1.0201
5	1.0197	1.0055	1.0089
10	1.0065	0.9924	0.9974
15	0.9949	0.9788	0.9856
20	0.9829	0.9648	0.9700
25	0.9706	0.9504	0.9540
30	0.9579	0.9354	0.9375
35	0.9448	0.9148	0.9205
40	0.9278	0.8975	0.9064
45	0.9137	0.8804	0.8856
50	0.8991	0.8532	0.8658
55	0.8726	0.8337	0.8456
60	0.8556	0.8070	0.8284
65	0.8344	0.7843	0.8101
70	0.8120	0.7525	0.7862
75	0.7858	0.7241	0.7619
80	0.7587	0.6853	0.7384
85	0.7344	0.6316	0.7067
90	0.7069	0.5457	0.6757
95	0.6747		0.6374
100	0.6257		0.5808

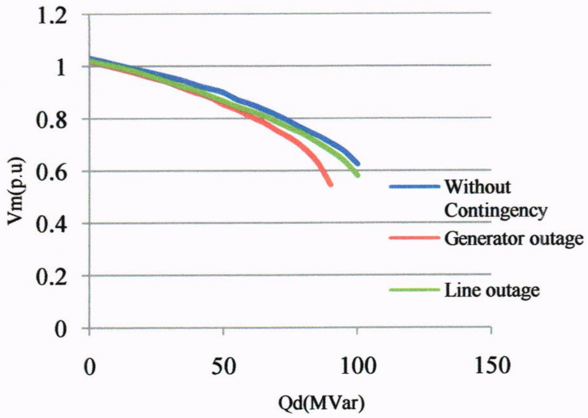

Figure 8. Comparison of Various Contingencies Point for Bus 20

There are many causes for the voltage instability. One of the causes is the contingency. Contingencies are referred to as the stressed of the load and also the unpredictable events that occur in the power system. These contingencies are effect by the line outage and generator outage in the system. Based on studies carried out for contingencies and voltage collapse analysis, it was found that both analysis prediction simulations are similar to the procedure of line outage simulation included in the contingencies analysis.

IV. CONCLUSION

This paper has presented the voltage stability analysis under contingency scenario. In this study, *FVSI*, a voltage stability index is used as an indicator to voltage stability condition of a system. The proposed technique was tested on the IEEE-30 BUS RTS. The information can be obtained from the comparison results of V-Q curve for all participating load buses. For future purpose, the technique used in this paper can be expanding both in terms of reactive power and in arresting voltage collapse.

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