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Determine Weakest Bus for IEEE 14 Bus Systems

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ABSTRACT
In this paper, a sudden growth of reactive power demand at a load bus accompanied with the single branch (power transformer or transmission line) outage contingency is studied to determine the critical line at which the weak bus is diagnosed with help of Fast Voltage Stability Index (FVSI).

The importance of this work is due to the fact that the power system which is operating under normal mode may be threatened as it may face a sudden increase demand contingency, which may lead to cascading outages, and/or violations of bus voltage which may lead to voltage collapse. This diagnosis of the weak bus is useful to determine the optimum location for shunt compensation required to improve

Keywords
Critical branch, Fast Voltage Stability Index (FVSI), weak bus, growth of reactive load bus, voltage collapse, worst case contingency, static voltage security, static security

1. INTRODUCTION
In recent years, power systems are becoming more and more complex due to limited power sources, weakened by transmission outages, and the growth in power demand [1]. Besides that, power system networks management has become increasingly more challenging in the face of systems being operated close to their security limits due increasing load demand coupled with restricted expansion due to economic and environmental constraints [2].

This means that the power system have been forced to operate closer to its stability limit (operate at its maximum capacity) and this may be lead to lose the ability of the system to reach a state within the specified secure region, because it may subjected to unstable or insecure operations [3,4].

So, voltage stability and voltage security problems have received increased attention over the last few years for the importance of the problem and several occurrences all around the world have shown that the problem may have serious consequences, such as excessive voltage drop or dynamic instability So, it is essential to locate a weakest bus in the power system in order to withstand the severe contingencies by strengthen this weak bus [5].

FVSI is some most important method which is used to find out the most sensitive line outage in the power system plus the most critical bus which can accept smallest maximum load [6].

FVSI is a line index derived from the general equation for the current in a line between two buses [2]. The ranges of FVSI from zero (no load system) to one (voltage collapse). To maintain a secure condition the value of FVSl should be kept well less than 1.00 [7].

If the value of FVSI is evaluated close to 1.00,then it indicates that the specific line is closed to its instability point which may lead to voltage collapse in the whole system and then the system is insecure,[4 and7].

The reactive power compensation close to the load centers as well as at the weak buses in the power system network is essential for overcoming voltage instability and insecurity. The suitable FACTS device with proper size can be located in the weak bus , to provide fast control and to improve the system stability [8].

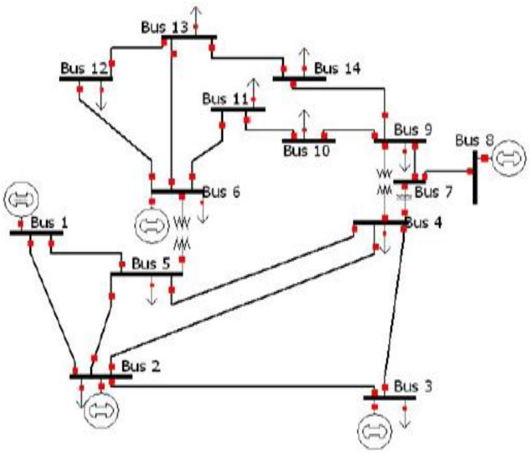

Fig 1: Single line diagram of IEEE-14bus test system

2. MATHEMATICAL EXPRESSION FOR FVSI
FVSI were computed on every outage for all cases. Results from every outage will be sorted in descending order. The outage that resulted the highest index exhibited the most severe contingency. [9]

With the help of Fig. (2), the formula of FVSI is derived from the general equation for the current in a line between two buses based on the measurements of voltage and reactive power [2,10].

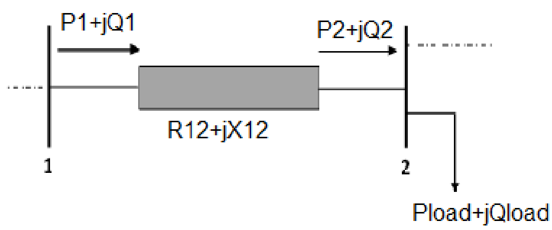

Fig 2: 2-Bus Power System Model

Taking the symbols ‘1’ as the sending bus and ‘2’ as the receiving bus, where:

The line impedance is noted as $Z_{12}= R_{12}+jX_{12}$ with the current that flows in the line between bus 1 and bus 2 can be present as:

$$I_{12} = \frac{\mathrm{V1}\angle\delta 1 - \mathrm{V2}\angle\delta 2}{\mathrm{R12} + \mathrm{jX12}} \;\; \ldots.(1)$$

The current can also be expressed in other forms as:

$$I_{12} = \left(\frac{S_2^*}{V_2^*}\right) = \frac{\mathrm{P}_2 - \mathrm{j}Q_2}{R_{12} + jX_{12}} \ldots.(2)$$

Equalizing the equations (1) and (2), produce:

$$\frac{V_1V_2\angle(\delta 1-\delta 2)-V_2^2}{\mathrm{R12+jX12}} = \mathrm{P}_2 - \mathrm{j}Q_2 \ldots(3)$$

V_1, V_2 = Voltage on sending and receiving buses,

P_1, Q_1 = Active and reactive power on the sending bus,

P_2, Q_2 = Active and reactive power on the receiving bus,

$\delta_{12} = \delta_1 - \delta_2$ = Angle difference between sending and receiving buses.

Separating the real and imaginary part, yields:

Real part:

$V_1V_2 \cos \delta_{12} - V_2^2 = P_2R_{12} + Q_2 X_{12}$ … (4)

Imaginary part:

$V_1V_2 \sin \delta_{12} = P_2X_{12} - Q_2 R_{12}$ … (5)

Thus, from the imaginary part (eq.5), P_2 can be expressed as:

$$P_2 = \frac{Q_2\, R_{12} + V_1V_2\, sin\delta_{12}}{X_{12}} \ldots(6)$$

Substitute equation (6) in (4), produce:

$$V_2^2 = \left[\frac{R_{12}}{X_{12}}\sin\delta_{12} + \cos\delta_{12}\right] V_1\, V_2 + \left(X_{12} + \frac{R_{12}^2}{X_{12}}\right) Q_2 = 0 \ldots(7)$$

It is quadratic equations where the root can be determine by using :

$$V_2 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \ldots(8)$$

Suppose,

a=1,

$$b = -\left[\frac{R_{12}}{X_{12}}\sin\delta_{12} + \cos\delta_{12}\right] V_1$$

$$c = \left(X_{12} + \frac{R_{12}^2}{X_{12}}\right) Q_2$$

Let k = -b $\mp\sqrt{b^2 - 4ac}$

$$\therefore k = \left[\frac{R_{12}}{X_{12}}\sin\delta_{12} + \cos\delta_{12}\right] V_1 \mp \sqrt{\left(\left[\frac{R_{12}}{X_{12}} sin\,\delta_{12} + cos\,\delta_{12}\right] V_1\right)^2 - 4\left(X_{12} + \frac{R_{12}^2}{X_{12}}\right) Q_2} \ldots(9)$$

$$\therefore \;\; V_2 = \frac{K}{2} \ldots.(10)$$

The term inside the square root must be always greater than or equal to zero, thus, the roots for V_2 will be:

$$\left(\left[\frac{R_{12}}{X_{12}} sin\,\delta_{12} + cos\,\delta_{12}\right] V_1\right)^2 - 4\left(X_{12} + \frac{R_{12}^2}{X_{12}}\right) Q_2 = 0 \ldots(11)$$

Solving the discriminate of the quadratic eq.11, the formula for FVSI is derived as:

$$FVSI = \frac{4Q_2X_{12}|Z_{12}|^2}{(R_{12}sin\delta_{12} + X_{12}cos\delta_{12})^2 {V_1}^2} \ldots.(12)$$

Since δ_{12} is normally very small then,

δ_{12} = ~ 0, $R_{12} \sin \delta_{12}$ = ~0, and $X_{12} \cos \delta_{12}$ = ~X_{12}

Hence, the fast voltage stability index, FVSI can be defined by[82]:

$$FVSI = \frac{4Q_2|Z_{12}|^2}{{V_1}^2 X_{12}} \ldots.(13)$$

Where:

Z_{12}: the line impedance;

X_{12}: the line reactance;

Q_2: the reactive power flow at the receiving end;

V_1: the sending end voltage .

As shown from equation (13), it is clear that FVSI is expressing the impact of reactive power to voltage collapse because the reactive power (Q) has significant influence on voltage value.

Here it could be observed that the value of FVSI could not be greater than unity. Also, when these values reach the unity value, the system becomes destabilized [11]

3. GROWTH REACTIVE LOAD AT BUS 9 & BUS 14

To get a worst contingency state, a single branch outage is studied, where the total number of branches in the IEEE-14 bus are 20, therefore, there are (20) possibilities of single line outage contingency. Simulation studies were done for load buses 5, 6, 9, 10, 11, 12, 13 and 14 by change the reactive load from 125% to 200% of its selected value for each single load bus.

In this case, as a sample demonstration, the reactive load at bus 9 is changed from 125% to200% of its selected value by step of 25%. This is done for all outages in the selected system at each change of reactive load at bus 9, FVSI values are as shown in figure (3).

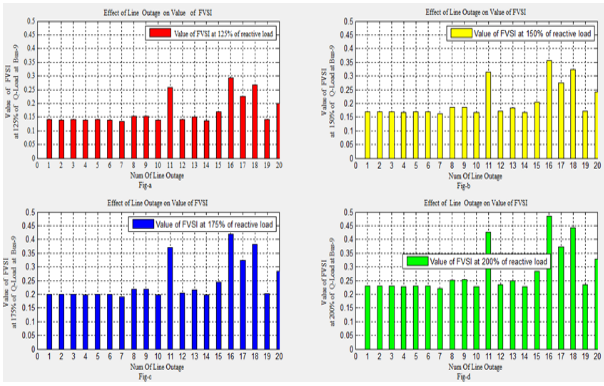

Fig 3: FVSI values for bus 9 when reactive load change from 125% to 200% at bus 9 with 20 single branch outage

Figure (3), shows that the worst case would occur when line 16 (line 9-10) is outage which give maximum FVSI for all steps of changing reactive load at bus 9.This means, at this case, that the critical line outage is line 16 and the weaker bus is bus 9.

While, for change the reactive load at bus 14 and from figure (4), it appears that the worst case would occur when line 20 (line 13-14) is outage which give maximum FVSI for all steps of changing reactive load at bus 14. This means that line 20 is critical line outage.

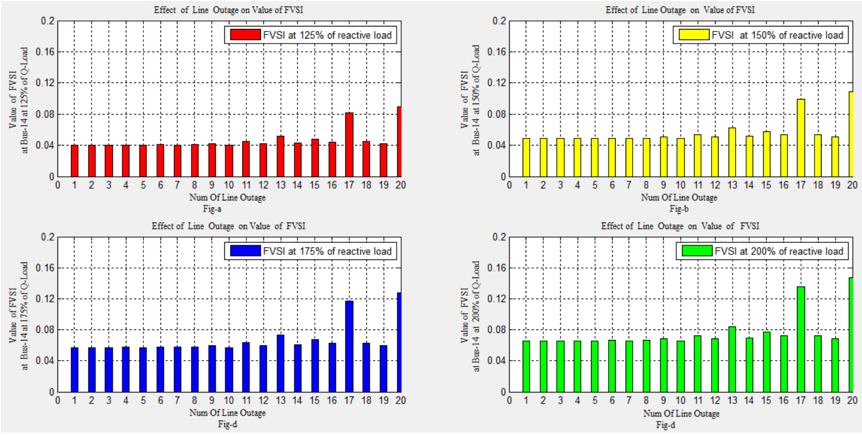

Fig 4: FVSI values for bus 14 when reactive load change from 125% to 200% at bus 14 with 20 single branch outage

4. SELECTING WEAKEST BUS

The process above, would thus be repeated frequently for the rest of load buses and the figure (5) shows the ranking the worst contingency cases for all load buses, where the critical outage line at line 16 and the weakest bus would be bus 9, where, the voltages at bus 9 for change of reactive load at this bus from 125% to 200% of the reactive load at this bus, are 0.9518, 0.9462, 0.9406 and 0.9351 p.u respectively.

According to maximum value of FVSI, the best location of shunt compensation is bus 9 and the size of injected reactive power at bus 9 is equal to 100% of inductive load at this bus which according load data of the tested system is equal to 16.6 MVAR or 0.166 p.u at MVA base equal to 100 MVA to prevent the system from collapse, maintain the secure operation of the tested system.

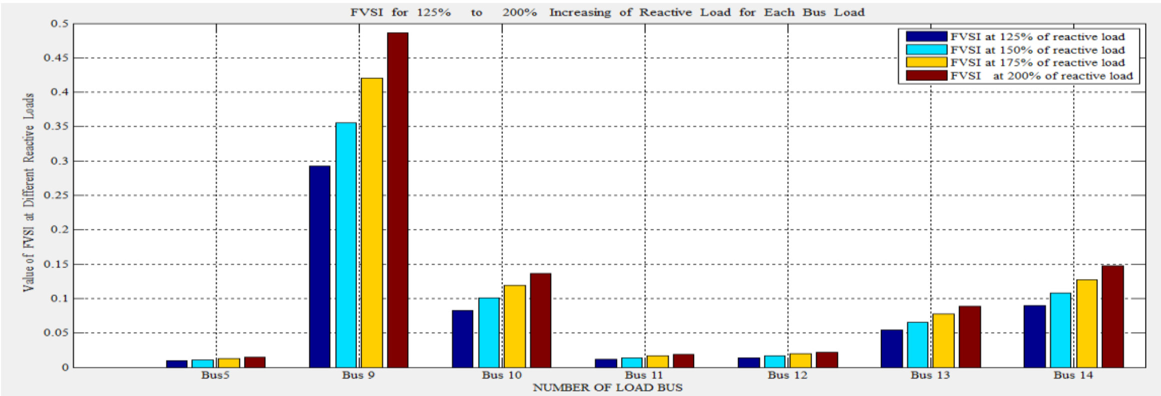

Fig 5: Ranking of FVSI for 125% to 200% of Reactive Load Change for each Load Bus

5. CONCLUSION

The individual greatest loadability obtained from the load buses will be sorted in ascending order with the least value being ranked uppermost. The highest rank implies the weakest bus in the system with low sustainable load. These are the possible locations for reactive power compensation devices and the value of wanted reactive injection power can be calculated according to value of increasing inductive load to support the critical bus load voltage.

Based on FVSI, simulation obtained by using MATLAB software for the IEEE-14 bus system determines the locations of reactive power devices for voltage control to maintain stability and security of this system can be determined. The use of FVSI is thus useful to identify the weakest load bus plus the critical line outage.

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