Journal of Engineering and Applied Sciences 14 (8): 2739-2744, 2019
ISSN: 1816-949X

Optimal Placement of FACTs Devices Using Hybrid Line Stability Index

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Abstract: The many of the power cuts in the electricity system in the last decade and in recent times indicate that much research yet necessarily to be done to address the instability voltage and the ensuing collapse. This study presents a method to find and select the optimum location of FACTs device using the Hybrid Line Stability Index (HLSI) that is appropriate for the prediction voltage collapse in power system networks. Such the HLSI was obtained by deriving expressions basics equivalent line stability index (Lmn) and Fast Voltage Stability Index (FVSI) and mix their through a switch logic based on the voltage angle difference where indicate the nearness voltage collapse. The HLSI has tested on IEEE 9-bus system it gives the same results as the other indicators (Lmn and FVSI). For the base state, IEEE 9-bus system was found to be stable with all the three indicators has approximately equal values <1 for all lines. The contingency state detect that ranks of bus 5 the weakest bus in the system with the lower maximum allowable reactive load of (120 MVar) and the line critical concerning bus 5, the line connecting bus 5-7. The values the three indicators, Lmn, FVSI and HSLI, approximately equal increasing the accuracy of HLSI.

Key words: Hybrid line stability index, FACTS device, voltage stability index, (Lmn), (FVSI), (HLSI)

INTRODUCTION

In years recent after dismantling and privatization of networks power systems their management has become increasingly difficulty take on the face of systems operating close to their safety limits due to increased demand for cargo along with the extending that is prohibited by economic and ecological limitation and the increasingly long transmission lines (Hasani and Parniani, 2005; Reddy and Manohar, 2012). The number of interruptions in the system over the past decade has been evidence of the way that all the more should be done to address the instability of the voltages and the ensuing collapse. The power system is foreseeable remain in equilibrium under normal conditions and requires that it respond to the restoration of the system state to agreeable conditions after a disturbance, i.e., voltage after the disturbance repaired to value close to the pre-disturbance state. Voltage instability occurs in the power system when a disturbance in the network leads to a gradual and uncontrollable reduction the voltage (Kumar *et al*., 2012). Emergencies such as line disruptions because of faults, outer factors an unexpected increase in load or untrue running of voltage control devices are causes of voltage instability. The inability of the system to meet the requirements of reactive power can also lead to voltage instability. If no gauges are taken to confirm this voltage instability it results in a decrease in system voltage and thus, voltage breakdown resulting in a partial or total blackout of system. All these things threaten essential service to provide a stable and reliable in the power supply for consumers (Pourbeik *et al*., 2006; Veleba and Nestorovic, 2013). Voltage stability as defined by Kundur *et al*. (2004), Kundur (1994) is "The ability of a power system network to maintain its voltage at permissible level without causing the network to collapse when subject to disturbance." A modal analysis of the voltage stability has been introduced by Moghavvem and Faruque (2000), Preedavichit and Srivastava (1998) with determine the placement of FACTS based on participation parameter. A voltage stability index has been proposed by Mansour *et al*. (1994) that is line load divided by the maximum load. This study proposes HLSI that is suitable for the prediction of voltage collapse in power system. The study will also identify the weak bus and critical lines in order to determine the optimum location of FACTS device with in the power system network.

MATERIALS AND METHODS

Voltage collapse prediction index: The voltage stability to a large degree have to do with transmission line parameters and system load parameters which show how close each transmission line is to voltage instability which has become gradually a main tool for assessing and controlling voltage stability by power system operators. This indices use for online or offline monitoring of the power system in seek to prophesy nearness to voltage instability or collapse.

Hybrid Line Stability Index (HLSI): In this study proposed the HLSI for power system networks to monitor

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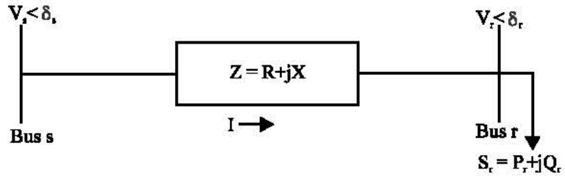

Fig. 1: Single line diagram of two buses

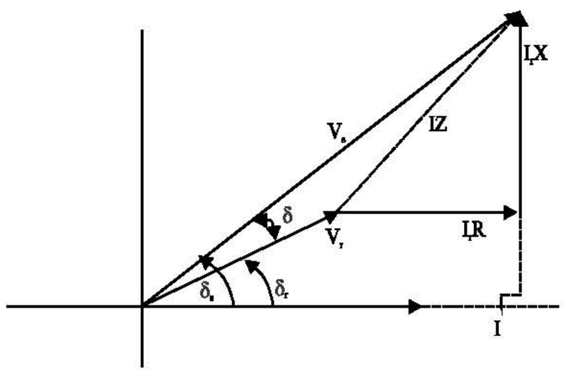

Fig. 2: The phasor diagram of two bus transmission line

voltage stability state and/or for voltage collapse prediction. To derive the mathematical formulation for HLSI we first derive, line stability index (Lmn) (Moghavvemi and Omar, 1998) and the Fast Voltage Stability Index (FVSI) (Musirin and Rahman, 2002) and mix them based on a seeing that the FVSI is an approximation of the Lmn under voltage angle conditions, so that, the HLSI takes advantages of improved prediction rigor and speed. The single line diagram of two buses had shown Fig. 1. The all parameters and variables are in per unit. Can be defined the power flowing at Bus r (Fig. 2):

$$S_r = P_r+jQ_r \quad (1)$$

$$S_r = V_r I_r^* \quad (2)$$

Where:

$$\bar{I}_r = \frac{V_s\angle\delta_s - V_r\angle\delta_r}{Z\angle\theta} \quad (3)$$

Therefore:

$$S_r = \frac{|V_s||V_r|}{|Z|}\angle(\theta+\delta_r-\delta_s) - \frac{|V_r|^2}{|Z|}\angle\theta \quad (4)$$

Expressing S_r in describe of its real and imaginary parts, Eq. 4 becomes:

$$S_r = \frac{|V_s||V_r|}{|Z|}\cos(\theta+\delta_r-\delta_s)+j\frac{|V_s||V_r|}{|Z|}\sin(\theta+\delta_r-\delta_s)-\frac{|V_r|^2}{|Z|}\cos\theta+j\frac{|V_r|^2}{|Z|}\sin\theta \quad (5)$$

Rearrange Eq. 5 gives:

$$S_r = \frac{|V_s||V_r|}{|Z|}\cos(\theta+\delta_r-\delta_s)-\frac{|V_r|^2}{|Z|}\cos\theta+j\left(\frac{|V_s||V_r|}{|Z|}\sin(\theta+\delta_r-\delta_s)-\frac{|V_r|^2}{|Z|}\sin\theta\right) \quad (6)$$

Then comparing parts on both sides real and imaginary gives:

$$P_r = \frac{|V_s||V_r|}{|Z|}\cos(\theta\_\delta_s+\delta_r)\_\frac{|V_r|^2}{|Z|}\cos\theta \quad (7)$$

$$Q_r = \frac{|V_s||V_r|}{|Z|}\sin(\theta\_\delta_s+\delta_r)\_\frac{|V_r|^2}{|Z|}\sin\theta \quad (8)$$

Substituting $\delta = \delta_r-\delta_s$ and finding roots equation in terms of Q_r in Eq. 8 gives:

$$\frac{|Vr|^2}{|Z|}\sin\theta-\frac{|V_s||V_r|}{|Z|}\sin(\theta\_\delta)+Q_{r=0} \quad (9)$$

Therefore, quadratic equation voltage shows as follows:

$$\frac{\sin\theta}{|Z|}V_r^2-|V_r|\frac{|V_s|\sin(\theta-\delta)}{|Z|}+Q_{r=0} \quad (10)$$

Then by solving V_r gives:

$$V_r = \frac{\frac{|V_s|\sin(\theta\_\delta)}{|Z|}\pm\sqrt{\left(\frac{(|V_s|\sin(\theta-\delta))}{|Z|}\right)^2-4\frac{\sin\theta}{|Z|}Q_r}}{2\frac{\sin\theta}{|Z|}} \quad (11)$$

Discriminant of Eq. 11 must be larger than or equal to zero for the stability:

$$\frac{(|V_s|^2\sin^2(\theta\_\delta))}{|Z|^2}\_4\frac{\sin\theta}{|Z|^2}Q_r \geq 0 \quad (12)$$

Multiply both sides with $|Z|^2$ we have:

$$|V_s|^2\sin^2(\theta\_\delta)-4|Z|\sin\theta\, Q_r \geq 0 \quad (13)$$

However, X = | Z | sinθ from relevance impedance triangle show as follows, replace X into Eq. 13 then:

$$V_s^2\sin^2(\theta\_\delta)\_4XQ_r \geq 0 \quad (14)$$

Divided both sides by $|V_s|^2 \sin^2(\theta\text{-}\delta)$ there after Eq. 14 becomes:

$$1-\frac{4XQ_r}{V_S^2\sin^2(\theta-\delta)}\geq 0 \quad (15)$$

Then Lmn is obtained as:

$$Lmn=\frac{4XQ_r}{|V_s|^2\sin^2(\theta-\delta)}\leq 1 \quad (16)$$

Equation 16 when $\delta \approx 0$ can be inferred that:

$$\frac{4XQ_r}{|V_s|^2(\sin\theta)^2}\leq 1 \quad (17)$$

The power triangle that $X = |Z| \sin\theta$ which suggests:

$$\sin\theta=\frac{X}{|Z|} \quad (18)$$

Replacing Eq. 18 into Eq. 17 and simplify yields term for voltage stability with δ negligibly small:

$$FVSI=\frac{4Q_r(|Z|)^2}{|V_s|^2X}\leq 1 \quad (19)$$

Therefore, we suggest mix Eq. 16 and 9 equation single to calculate nearness the voltage collapse according to the conversion function μ shown Eq. 20. Computed δ in the load-flow program at each against the threshold value δc is tested in order to find whether μ is (1, 0). For a hybrid stability indicator it obtains stability and accuracy with better stability:

$$HLSI=\frac{4Q_r}{|V_s|^2}\left[\frac{(|Z|)^2}{X}\mu-\frac{X}{\sin^2(\theta-\delta)}(\mu-1)\right]\leq 1$$
$$\mu=\begin{cases}1 & \delta < \delta_C\\ 0 & \delta \geq \delta_C\end{cases} \quad (20)$$

"μ" is a function which value conversion depends on if difference angle δ very small or not. The large voltage angle difference between the two loading buses indicates on that a power system loaded or there are increased resistance between bus loading. Then, the voltage angle difference, delta 'δ' cannot be ignored exactly as it did in the mathematical formulation of FVSI.

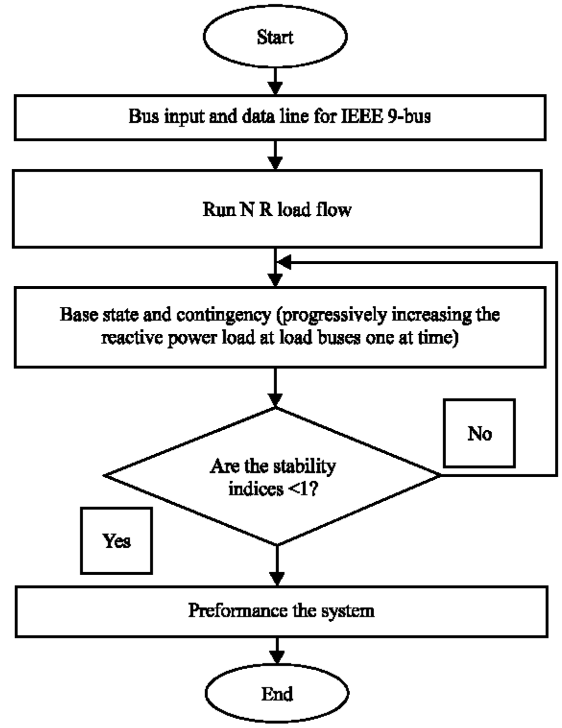

Fig. 3: Flow chart of the calculating the voltage stability indicator

When the HLSI is <1, the system is static. The nearer the value of 1, the system was unstable and the near voltage collapsed.

Determination of the load-ability and identification of weak bus: Prediction of the voltage collapse is summarizing in the determination of the maximum load-ability identification of the weakest bus for the network and the critical line with respect to load buses. This information is useful optimally locate possible points of placement of FACTs devices to combat voltage collapse in power system networks. Figure 3 shows the flowchart to calculate voltage stability indicators which taken into account in this study.

RESULTS AND DISCUSSION

HLSI mix two existing stability indicators the Lmn and FVSI taking feature of the punctuality of Lmn indicator and the constancy of FVSI indicator. In order to validate this HLSI it was used both with the Lmn and the FVSI check the stability of the 9-bus system. The single-line diagram of the IEEE 9 bus system shown in Fig. 4 is considered for analysis and the data of the system is given in Table 1 and 2 the network under

Table 1: Line data

Bus from	Bus to	Voltage rating (kV)	Frequency rating (Hz)	R (p.u)	X (p.u)	B (p.u)
1	4	16.5	60	0.0000	0.0576	0.000
2	7	18.0	60	0.0000	0.0625	0.000
3	9	13.8	60	0.0000	0.0586	0.000
4	5	230	60	0.0100	0.0850	0.176
4	6	230	60	0.0170	0.0920	0.158
5	7	230	60	0.0320	0.1610	0.306
6	9	230	60	0.0390	0.1700	0.358
7	8	230	60	0.0085	0.0720	0.149
8	9	230	60	0.0119	0.1008	0.209

Table 2: Bus data

Bus No.	V (p.u)	P_L (MW)	Q_L (MVar)	P_G(MW)
1	1.04	0	0	-
2	1.025	0	0	163
3	1.025	0	0	85
4	1	0	0	0
5	1	125	50	0
6	1	90	30	0
7	1	0	0	0
8	1	100	35	0
9	1	0	0	0

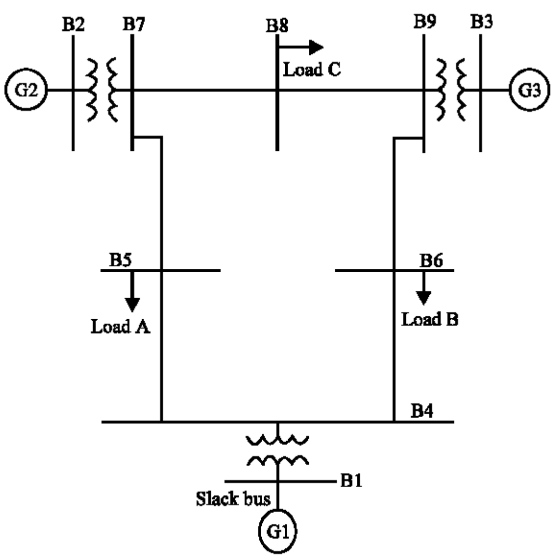

Fig. 4: IEEE 9-bus bar test system

consideration consists of 6 transmission lines and 9 buses with three generation buses and three load buses.

Result simulation for both scenarios: Base state and contingency are discussed. The base state values of the line stability indices in Table 3 and the charts bar about Lmn, FVSI and HLSI versus line No. in Fig. 5, i.e., the six interconnected lines of the 9-bus. At base state, the simulation was carried out to obtain the voltage stability indexes, the Lmn, FVSI and HLSI by utilize Eq. 16, 19 and 20, respectively. Table 3 and Fig. 5 it is observed that the three indexes. Values are almost equal, the system is stable as nobody of the indices of each line is near one.

Table 3: The base state for the 9-bus

No. of line	Bus from	Bus to	Stability index Lmn	FVSI	HLSI
1	9	8	0.09861	0.09713	0.09713
2	7	8	0.20217	0.20940	0.20217
3	9	6	0.32607	0.33766	0.32607
4	5	7	0.13501	0.13426	0.13426
5	4	5	0.10961	0.10850	0.10961
6	4	6	0.16515	0.16380	0.16380

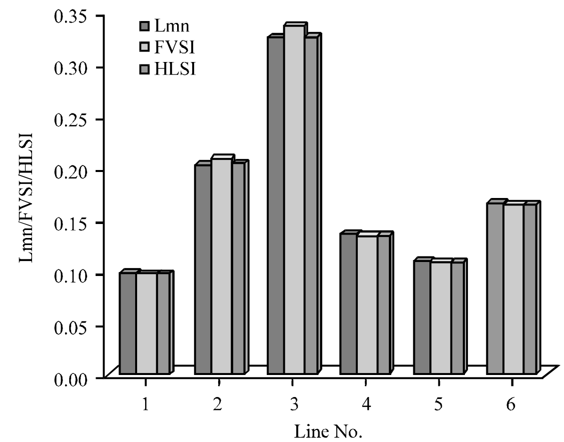

Fig. 5: The Lmn, FVSI and HLSI vs. Line No. for the base state

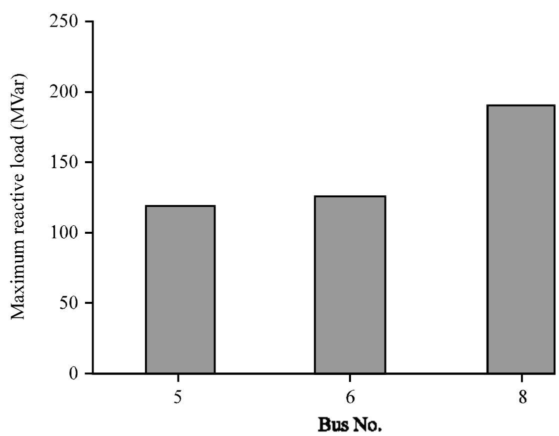

Fig. 6: Maximum reactive on buses load

This observed that the three indexes values are almost equal. This support the fact that the HLSI index developed can be utilized in place of the other two indexes.

The simulation of a contingency state considered is the difference in the demand for reactive power. The reveals load bus 5 is the weakest and most vulnerable to the bus because it has the lowest maximum permissible reactive load of (120 MVar) as shown in Fig. 6. This bus has two connected lines and the line critical with respect to load bus 5 is the line 5-7. The means that

Table 4: Q (MVar) differences on bus 5

	Bus 5-1st weakest bus (5-7)			
Q (MVar)	Vmag.(p.u)	Lmn	FVSI	HLSI
50	0.996	0.13501	0.13426	0.13426
60	0.986	0.39858	0.41276	0.39858
70	0.977	0.47395	0.49081	0.47395
80	0.968	0.55239	0.57205	0.55239
90	0.958	0.63413	0.65673	0.63415
100	0.948	0.71953	0.74516	0.71953
110	0.932	0.85507	0.88555	0.85507
120	0.921	0.96082	0.99509	0.96082

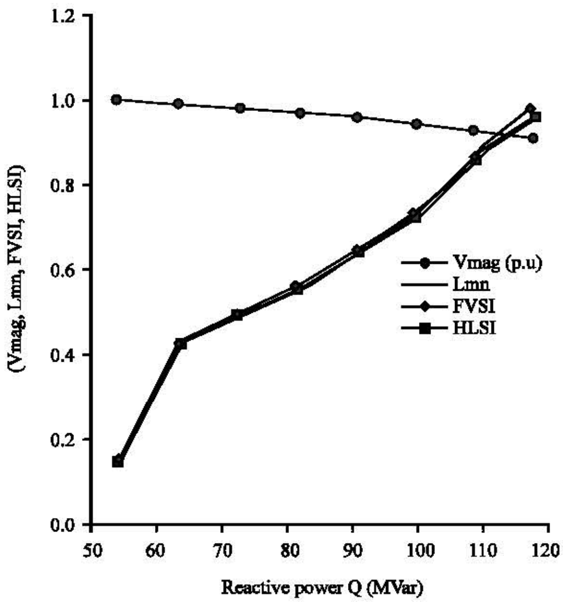

Fig. 7: The load variation on bus 5

any addition to the reactive load will cause the voltage collapse on the system. Bus 8 has the maximum load-ability and optional reactive load of around (192 MVar).

The power reactive variation on bus 5 was performed to investigate indicators with load reactive and voltage characteristics. The simulation results are as in Table 4 while Fig. 7 presented the diagram of voltage magnitude and voltage stability indexes (Lmn, FVSI and HLSI) versus to Q (MVar) variation for bus it is worthy of note that the diagram of Lmn and HLSI concur this gives HLSI index acceptance.

Figure 7 for bus 5 it is observed that the curve of the voltage magnitude drops as the Q (Mvar) increased whilst the voltage stability indices also increase even voltage collapse occurs. Table 5 tabulated as shown maximum load-ability of each bus load, line critical, most stable line with respect to a specific load bus specific.

Table 5: Load bus most stable and critical line for 9-bus

Bus No.	Max. load (MVar)	Most stable line	HLSI	Critical line	HLSI	Ranking
5	120	4-5	0.43989	5-7	0.96082	1
6	126	4-6	0.46265	6-9	0.97624	2
8	192	7-8	0.60564	8-9	0.99867	3

CONCLUSION

The HLSI mix two present voltage stability indexes: The Lmn and FVSI taking merit the thoroughness the Lmn index and the constancy the FVSI index. For confirm this HLSI it was utilized both with Lmn and FVSI to check voltage stability of 9-bus system for two probable states, the base state and the contingency analysis i.e., difference of reactive load on load buses one at a time. The simulatiPons for test system appear, base state system is stable because the three indicators values are approximately equal and are far least than one. But regarding contingency state bus 5 detects weakest bus as the indicators values are very close to one. Such means closeness to voltage collapse and it has smallest maximum (120 MVar). So, optimal location for placement of a FACTs device on bus 5 improvement the voltage at that bus as gauge against voltage collapses. The critical line is 5-7 of system values the three stability indices of this line are extremely close to one and nearly equal.

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