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Analysis and Enhancement of Power System Stability Using Particle Swarm Optimization

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Abstract*— Voltage stability improvement is an important issue in power system planning and operation. Voltage stability margin is essential to be known in advance to avoid voltage collapse and system blackout. This paper discusses some important aspects related to voltage stability indices in electric power systems. Some techniques previously studied in the literature are analyzed and a comparison of the performance of several indices is presented. This paper proposes an improved voltage stability index (IVSI) for buses and Line Collapse Proximity Index (LCPI) lines. LCPI index is based upon exact model of transmission system and developed using ABCD parameters of network. One of the important features of the proposed index is that it incorporates the effects of relative directions of active and reactive power flows in the line to predict voltage collapse. The formulated index was tested on the IEEE 14-bus test system in order to verify the performance of the proposed indices.
***Keywords*— Power System Stability; Stability Indices for transmission lines; Stability indices for buses; PSO**

I. INTRODUCTION

Present day power systems are more heavily loaded than ever before because of the growing demand, maximum economic benefits and efficiency of usage of transmission capacity. This scenario makes the power systems more vulnerable to stability and security problems. Voltage stability has become a very important issue of power system analysis. Problems related to voltage stability in power systems are one of the major concerns in power system planning and operation.

Voltage stability is concerned with the ability of a power system to maintain steady acceptable voltages at all the buses in the system under normal operating conditions and/or after being subjected to a disturbance. A power system is said to have entered a state of voltage instability when a disturbance, increase in load demand, or a change in system condition causes a progressive and uncontrollable decrease in voltage level which can occur because of the inability of the network to meet the increasing demand for reactive power. Voltage instability is the cause of system collapse, in which the system voltage decays to a level from which it is unable to recover. As power systems become more complex and heavily loaded along with economical and environmental constraints, voltage instability becomes an increasingly serious problem, leading systems to operate close to their limits. Voltage instability is essentially a local phenomenon however its consequences may have widespread impact. Several large scale power system blackouts in the recent past years all over the globe have been the consequences of instabilities characterized by voltage collapse phenomena. Hence, a proper analysis of voltage stability is essential for successful operation and planning of the power systems. The voltage stability problem has become a major concern in power systems, especially for a system with heavier loading conditions and without sufficient transmission or generation enhancements. The condition of voltage stability in a power system can be known using voltage stability indices. These indices can either reveal the critical bus of a power system or the stability of each line connected between two buses in an interconnected network or evaluate the voltage stability margins of a system. The indices used to examine the system stability are briefly discussed in this project.

The stability index is the ratio of Thevenin's impedance to load impedance and is at a maximum of 1.0. Chakravorty and Das [8] showed that the load flow solution for radial distribution networks is unique, and presented a new voltage stability index VSI for radial distribution networks. Moghavvemi and Omar [2] presented an approach for calculating voltage stability factor based on a concept of power flow through a single line, and derived the voltage stability factor Lmn to examine system stability. Mohamed and Jasmon [3] derived a Line Stability Factor LQP based on the concept of power flow through a single line. Musirin and Rahman [5] proposed Fast Voltage Stability Index FVSI to predict the occurrence of voltage collapse. If the value of any of these indices exceeds the value of 1.00, the system will lose its stability and thus fall into contingency.

II. VOLTAGE STABILITY INDICES

At present, the evaluation of voltage stability assessment experiences sizeable anxiety in the safe operation of power systems. This is due to the complications of a strain power system. With the snowballing of power demand by the consumers and also the restricted amount of power sources, therefore, the system has to perform at its maximum proficiency. Consequently, the noteworthy to discover the maximum ability boundary prior to voltage collapse should be undertaken. A preliminary warning can be perceived to evade the interruption of power system's capacity. The effectiveness of voltage stability indices is differentiated in this project. The main purpose of the indices used is to predict the proximity of voltage instability of the electric power system. On the other hand, the indices are also able to decide the weakest load buses which are close to voltage collapse in the power system.

III. INDICES FOR TRANSMISSION LINES

The following indices are considered for transmission lines.

A. Line Stability Index (Lmn)

M.Moghavvemi and Omar derived a line stability index utilizing the concept of power flow in a single line. The discriminate of the voltage quadratic equation is set greater than or equal to zero to obtain real roots of voltage of the receiving end bus. If the discriminant is found to be less than zero, the roots will be imaginary, that means system will collapse due to voltage instability.
The Line Stability Index proposed by Moghavvemi and Omar [2] can be formulated as

$$L_{mn} = \frac{4Q_j X_{ij}}{\left[V_i \sin\left(\theta_{ij} - \delta_{ij}\right)\right]^2} \quad (1)$$

Where, $\delta_{ij}=\delta_i-\delta_j$, phase difference between sending end bus voltage and receiving end bus voltage, $\theta_{ij}$is the impedance angle of the line connected between buses i and j, X_{ij} is the reactance of the line connected between buses i and j, Q_j is the reactive power at the receiving end and V_i is the sending end bus voltage
L_{mn} is used to find the stability index for each line connected between two buses in an interconnected network. Based on the stability indices of lines, voltage collapse can be predicted. When the stability index L_{mn} is less than 1, the system is stable and when this index exceeds the value 1, the whole system loses its stability and voltage collapse occurs.

B. Line Stability Factor (LQP)

The Line Stability Factor LQP proposed by Mohamed and Jasmon [3] is defined as

$$LQP = 4\left(\frac{X_{ij}}{V_i^2}\right)\left(\frac{X_{ij} P_i^2}{V_i^2} + Q_j\right) \quad (2)$$

Where, P_i is the active power at the sending end, V_i represents the sending end bus voltage, Q_j is the reactive power at the receiving end, X_{ij} is the reactance of the line connected between buses i and j. LQP must be less than unity to maintain voltage stability of the system.

C. Fast Voltage Stability Index (FVSI)

The Fast Voltage Stability Index (FVSI) proposed by Musirin and Rahman [5], evaluates the margin of voltage stability of a particular line under given loading conditions. They considered a single line between two buses and derived FVSI for real roots of receiving end voltage by using voltage quadratic equation of the system.
For a typical transmission line, FVSI is calculated by using the equation

$$FVSI = \frac{4Z_{ij}^2 Q_j}{V_i^2 X_{ij}} \quad (3)$$

Where, Z_{ij} is the impedance of the line connected between buses i and j, Q_j is the reactive power at the receiving end, V_i represents the sending end bus voltage, X_{ij} is the reactance of the line connected between buses i and j
The line that gives index value closest to 1 will be the most critical line of the system and may lead to whole system instability i.e., one of the buses connected to the line experiences a sudden voltage drop leading to system collapse.

D. Proposed Line Collapse Proximity Index (LCPI)

The indices described in equations (1)–(3) have neglected the line charging reactance in deriving equations of indices. It is important to note that line charging reactance may support voltage stability. Therefore, methods which employ approximate model

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may give pessimistic prediction of voltage stability. Moreover, these indices have ignored the relative direction of active power flow in the line with respect to reactive power flow. This may lead to erroneous prediction of voltage stability in certain cases. Considering these limitations, an improved Line Collapse Proximity Index (LCPI) is developed which is not only based upon exact model of transmission line but also includes the effects of reactive as well as active power flow of line on voltage stability of the system. An exact model of transmission line is usually described by two-port equivalent circuit using ABCD-matrix. Therefore, the proposed index is derived using ABCD parameters of transmission line. The pie model of a transmission line of a two bus system is shown in Fig.2.1.

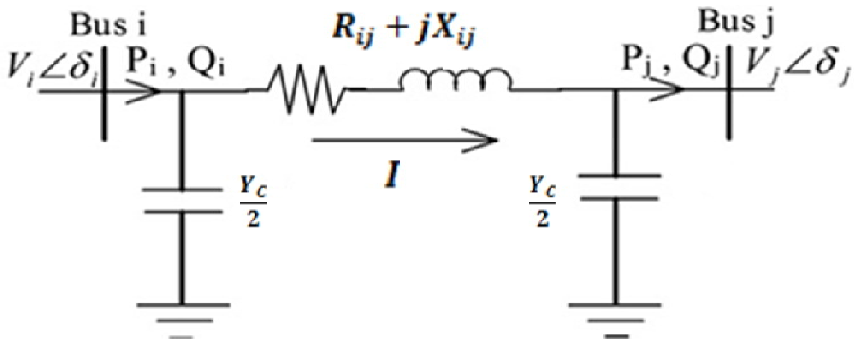

Fig.1. Typical single line diagram of transmission line

The relationship among the network parameters can be expressed as

$$\begin{bmatrix} V_i \\ I_i \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_j \\ I_j \end{bmatrix} \quad (4)$$

Where, A, B, C and D are known as the transmission parameters of the two-port network and they can be expressed as

$$A = 1 + \frac{Z_{ij}Y_C}{2} \ ; \ B = Z \ ; \ C = Y\left(1 + \frac{Z_{ij}Y_C}{4}\right) \ ; \ D = A$$

Where, Z_{ij} and Y_C denote the impedance and line charging admittance of line respectively.
The current at the receiving end of the line is expressed as

$$I_j = \frac{P_j - jQ_j}{V_j\angle -\delta_j} \quad (5)$$

Where, P_j and V_j are the active power and voltage at the receiving end respectively.
Using Equation (4) the sending end voltage V_i of the line can be written as

$$V_i\angle\delta_i = A\angle\alpha^* V_j\angle\delta_j + B\angle\beta^* I_j\angle 0 \quad (6)$$

Where, A and B are magnitudes and α and β are phase angles of parameters A and B respectively.
Substituting the value of I_j obtained from Equation (5) into Equation (6) we get

$$V_i\angle\delta_i = A\angle\alpha^* V_j\angle\delta_j + B\angle\beta^* \left(\frac{P_j - jQ_j}{V_j\angle -\delta_j}\right) \quad (7)$$

Rearranging the above equation yields

$$V_i V_j\angle\delta_{ij} = A\angle\alpha^* V_j^2 + B\angle\beta^* \left(P_j - jQ_j\right) \quad (8)$$

Where, $\delta_{ij}=\delta_i-\delta_j$; phase difference between sending end bus voltage and receiving end bus voltage.
Separating Equation (8) into real and imaginary parts, we obtain the following quadratic equation from real part

$$V_j^2(A\cos\alpha) - V_j\left(V_i\cos\delta_{ij}\right) + \left(P_j B\cos\beta + Q_j\sin\beta\right) = 0 \quad (9)$$

Upon simplifying the roots, the Line Collapse Proximity Index (LCPI) is now defined as

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$$LCPI = \frac{4A\cos\alpha\left(P_j B\cos\beta + Q_j \sin\beta\right)}{\left(V_i \cos\delta_{ij}\right)^2} \quad (10)$$

To maintain the voltage stability of the system the proposed index must be less than unity i.e., LCPI < 1

The term $P_j B\cos\beta$ in Equation (10) is equal to resistance of line, therefore first term of Equation (10) represents resistive voltage drop produced by active power (Pj) in the line. Similarly, second term $Q_j B\sin\beta$ of Equation (10) denotes reactive voltage drop created by reactive power (Qj) of the line. If Pj and Qj flow in same direction, both of the terms will be additive while sign of these terms will be opposite if active and reactive power of receiving end flow in opposite directions. Therefore, index LCPI takes into account both magnitudes and relative directions of real and reactive powers of receiving end. Moreover, parameters A and B of Equation (10) include the effects of line resistance and shunt admittance which were neglected by indices given in Equations (1)–(3). The maximum value of LCPI of a line will be close to unity in a stage when the line is at the verge of voltage collapse.

IV. INDICES FOR BUSES

A. *Voltage Stability Index (VSI) by Chakravorty*

Consider the single line of a radial distribution system shown in Fig.2, which is part of a radial distribution system. Chakravorty and Das [8] derived a voltage stability index VSI can be expressed as follows:

$$VSI_i = \sum_{j=1}^{n}\left(\frac{4Z_{ij}^2\left(P_{ji}^2 + Q_{ji}^2\right)}{\left(2R_{ij}P_{ji} + 2X_{ij}Q_{ji} + |V_i|^2\right)}\right) \le 1 \quad (11)$$

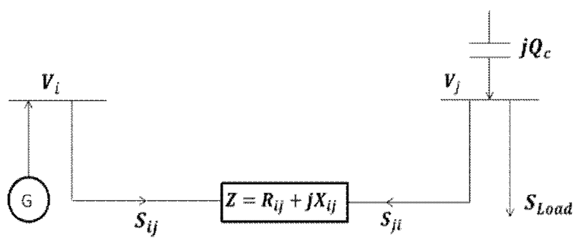

Fig.2. Single line diagram to develop VSI

B. *Proposed Improved Voltage Stability Index (IVSI)*

Here, an Improved Voltage Stability Index IVSI is developed using a network system is proposed. It is suitable application to both radial and network systems.

Considering a network shown in Fig.3, it is easy to develop the power flow formulas which can be expressed as

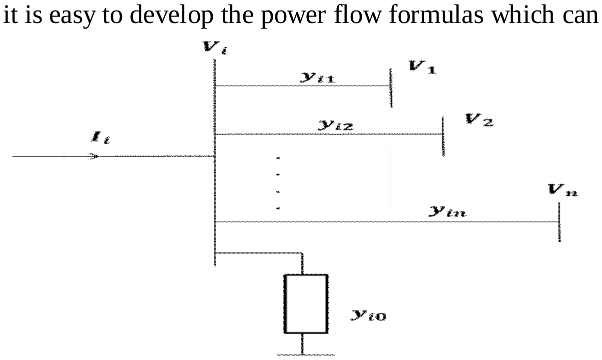

Fig.3. Network representation to develop IVSI

The proposed Improved Voltage Stability Index (IVSI) is given by

$$IVSI = \frac{-4\sum_{j=0}^{n}\left(G_{ij} - B_{ij}\right)\left(P_i + Q_i\right)}{\left[\sum_{j=1}^{n}|V_j|\left[G_{ij}\left(\cos\delta_{ij} + \sin\delta_{ij}\right) - B_{ij}\left(\cos\delta_{ij} - \sin\delta_{ij}\right)\right]\right]^2} \le 1 \quad (12)$$

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For an N-bus system, the total number of voltage stability indexes IVSIs is N for all buses of the system. The index IVSI is used in the same way as index VSI.As the IVSI index for every bus in the system is close to 0, the system is stable. But as long as the IVSI index for any bus in the system is close to 1.0, the system is unstable and voltage collapse may occur. Moreover, the proposed IVSI index is suitable application to both radial and network systems.

V. OPF PROBLEM FORMULATION

The OPF problem aims to minimize the power system objects by adjusting the system control variables while satisfying a set of operational constraints. Therefore, the OPF problem can be formulated as follows:

$$Minimize \quad J(x,u)$$

Subjected to g(x,u)=0; h(x,u)≤0

where 'g' and 'h' are the equality and inequality constraints respectively and 'x' is a state vector of dependent variables such as slack bus active power generation (PG1), load bus voltage magnitudes (VL) and generator reactive power outputs (QG) and apparent power flow in lines (Sl) and 'u' is a control vector of independent variables such as generator active power output (PG), generator voltages (VG), transformer tap ratios (T) and reactive power output of VAr sources (Qsh).

The state and control vectors can be mathematically expressed as

$$x^T = \left[P_{G_1}, V_{L_1}, ...V_{L_{NL}}, Q_{G_1}, ...Q_{G_{NG}}, S_{l_1}, ...S_{l_{nl}}\right]$$

$$u^T = \left[P_{G_2}, ...P_{G_{NG}}, V_{G_1}, ...V_{G_{NG}}, Q_{sh_1}, ...Q_{sh_{NC}}, T_1, ...T_{NT}\right]$$

where, 'NL', 'NG', 'nl', 'NC' and 'NT' are the total number of load buses, generator buses, transmission lines, VAr sources and regulating transformers respectively.

A. *Objective formulation*

The stability indices formulated for buses and lines are considered as objective function needs to be minimized. By minimizing these objectives while satisfying system constraints; the system security can be enhanced.

B. *Constraints*

The OPF problem has two categories of constraints:

1) *Equality constraints*

$$P_{Gk} - P_{Dm} - \sum_{m=1}^{NB} |V_k||V_m||Y_{km}|\cos(\theta_{km} - \delta_k + \delta_m) = 0 \qquad (13)$$

$$Q_{Gk} - Q_{Dm} + \sum_{m=1}^{NB} |V_k||V_m||Y_{km}|\sin(\theta_{km} - \delta_k + \delta_m) = 0 \qquad (14)$$

where, 'P_{Gk}, Q_{Gk}' are the active and reactive power generations at k^{th} bus, 'P_{Dm}, Q_{Dm}' are the active and reactive power demands at m^{th} bus, 'NB' is number of buses, $|V_k|$, $|V_m|$ are the voltage magnitudes at k^{th} and m^{th} buses, 'δ_k, δ_m' are the phase angles of voltages at k^{th} and m^{th} buses, $|Y_{km}|$, θ_{km} are the bus admittance magnitude and its angle between k^{th} and m^{th} buses.

2) *Inequality constraints: The inequality constraints are the system operating limits. The inequality constraints are*

Generator bus voltage limits:

$$V_{G_i}^{\min} \le V_{G_i} \le V_{G_i}^{\max}; \quad \forall i \in NG$$

Active Power Generation limits:

$$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max}; \quad \forall i \in NG$$

Transformers tap setting limits:

$$T_i^{\min} \le T_i \le T_i^{\max}; \quad i = 1,2,...,n_t$$

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Capacitor reactive power generation limits:

$$Q_{Sh_i}^{min} \le Q_{Sh_i} \le Q_{Sh_i}^{max}; \quad i = 1,2,.....,n_C$$

Transmission line flow limit:

$$S_{l_i} \le S_{l_i}^{max}; \quad i = 1,2,....,N_{line}$$

Reactive Power Generation limits:

$$Q_{G_i}^{min} \le Q_{G_i} \le Q_{G_i}^{max}; \quad \forall i \in NG$$

Load bus voltage magnitude limits:

$$V_i^{min} \le V_i \le V_i^{max} \quad i = 1,2,....,N_{load}$$

C. Particle Swarm Optimization

Kennedy and Eberhart first introduced PSO in year 1995. PSO is motivated from the simulation of the behaviour of social systems such as fish schooling and birds flocking. The basic assumption behind the PSO algorithm is, birds find flocking and not individually, this leads to the assumption that information is exchange among the flocking. Basic flow chart is shown in Fig.4

Let P is particle (position) and V is velocity in a search space. The particle position can be represented as Gbest. The velocity is represented as V_{ij}. The modified velocity of each particle can be calculated by using, the current velocity, the distance between the current position and Pbest and the distance between the current position and Gbest.

This can be formulated as an equation:

$$Vel_{ij}^{k+1} = W \times Vel_{ij}^{k} + C_1 \times rand_1 \times \left(Local_{ij}^{best} - X_{ij}^{k}\right) + C_2 \times rand_2 \times \left(Global_i^{best} - X_{ij}^{k}\right) \quad (15)$$

$$X_{ij}^{k+1} = X_{ij}^{k} + Vel_{ij}^{k+1} \quad (16)$$

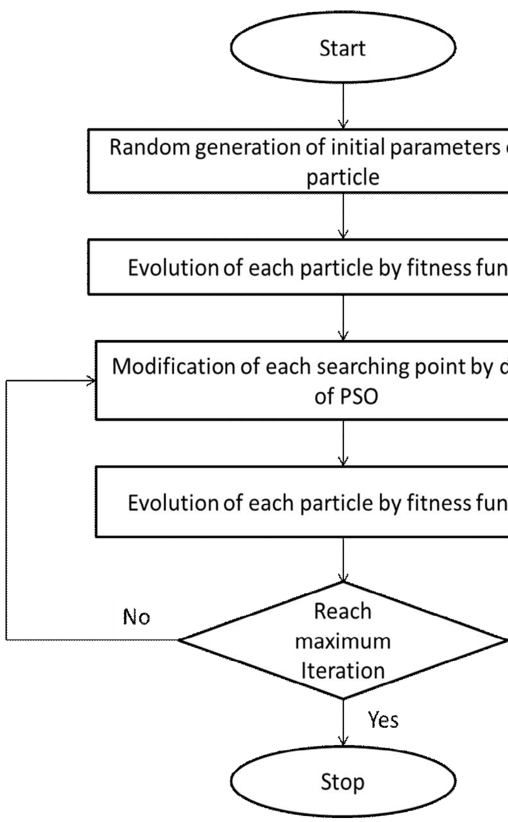

Fig.4. Flowchart of particle swarm optimization

VI. RESULTS AND ANALYSIS

In this section, the proposed methodology is implemented on standard 14-bus test systems. The analysis part is performed in the following two scenarios:

In the first scenario, by increasing reactive load at load buses gradually from 100% to 140% in steps of 10% and the variation of voltage magnitude at buses is identified. From this, the bus, which has the highest impact on voltage deviation, is identified and this is considered to be the most sensitive bus in a given system. Then, the proposed stability indices given in section 4 are evaluated at all load buses. From this, the index which shows the criticality of the system more precisely is identified as the sensitive index. Using this index, the system stability can be predicted more accurately when compared to the remaining indices. Similar procedure can be implemented to identify the most critical line in a given system. After this, the existing and proposed line indices given in section 3 are evaluated for all transmission lines, finally, the index which highlights the criticality of the system is considered to be the best index to analyze the stability of the system.

In the second scenario, optimal power flow (OPF) is performed to minimize the sensitive index for buses and lines obtained from scenario-1, with this, the system stability is enhanced.

In this, IEEE 14-bus system with five generators and twenty transmission lines is considered. Generators are connected at buses 1,2,3,6 and 8 and the remaining buses are load buses.

A. *Scenario-1*

At first, the variation of voltage magnitude at all buses for the reactive load increments is shown in Fig.5. From this figure, it is identified that, bus-14 has major voltage variation when compared to other buses.

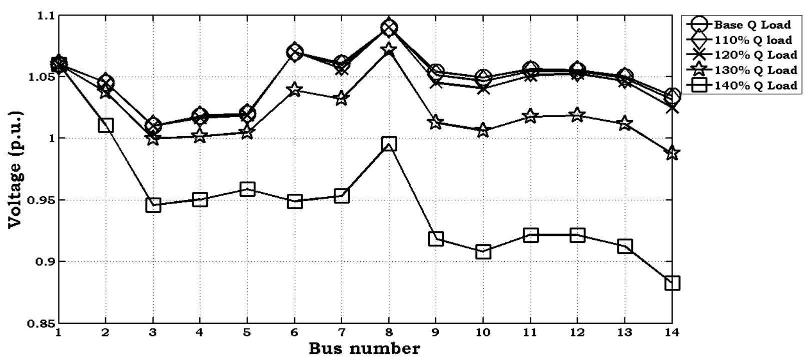

Fig.5. Voltage variation at buses for IEEE 14-bus system

Finally, from this analysis, it is identified that, bus-14 is the most sensitive bus for the load variations, and the existing VSI and proposed IVSI given in section 2.3 are evaluated at this bus and the respective variations is shown in Fig.6.

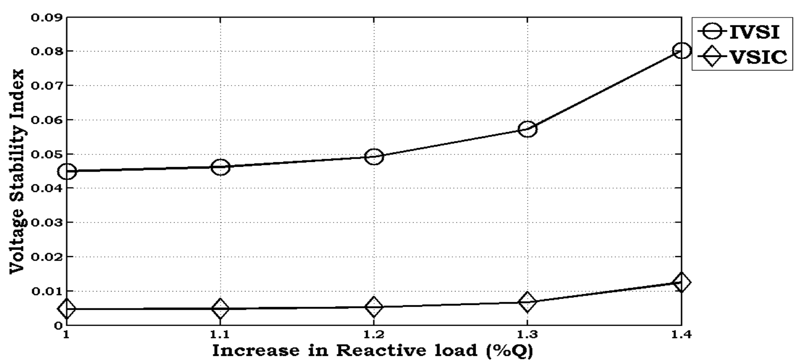

Fig.6. Bus Indices variation at bus 14 for IEEE 14-bus system

Fig.6 shows the variation of VSI and IVSI values at bus-14 for the reactive load increments. From this figure, it is identified that, as the load increases, the values of VSI and IVSI are also increasing from minimum value to maximum value. As per the criterion, the safest operation is towards minimum values. Here, at maximum reactive load, the voltage drop is very high leads to voltage collapse

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condition. To predict this, at this load, the proposed IVSI gives highest value when compared to existing VSI. With this, the severity of the system can be predicted easily and the necessary measures can be taken to improve the stability of the system. From this analysis it is identified that, proposed IVSI indicates the stability of the system in terms of voltage variations for the reactive load increments more accurately when compared to the existing VSI. It is also observed that, bus-14 has major voltage variation and this bus can be considered to be the most sensitive bus.

Similarly, the power flow in the transmission lines for the reactive load increments is shown in Fig.7.

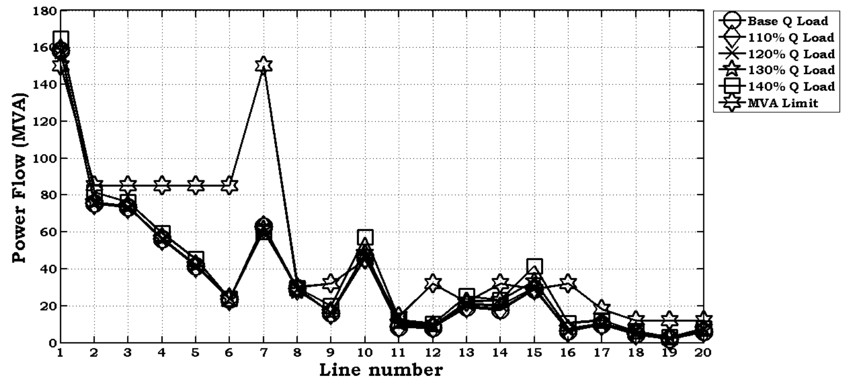

Fig.7. Variation of power flow in lines for IEEE 14-bus system

From this figure, it is identified that, line-15 connected between buses 7 and 9 is the most critical one as the power flow in this line is exceeded its maximum limit. The existing and the proposed line indices discussed in section 3 are evaluated for this line and the respective variations are shown in Figs.8.

From Fig.8, it is identified that, the proposed LCPI indicates the criticality of the transmission line with highest index value when compared to other indices. From these variations, it is identified that, highest index variation is observed in line-15. Out of all indices, the proposed LCPI value is high when compared to other indices. Hence, this line can be considered to be the most critical line in a given system.

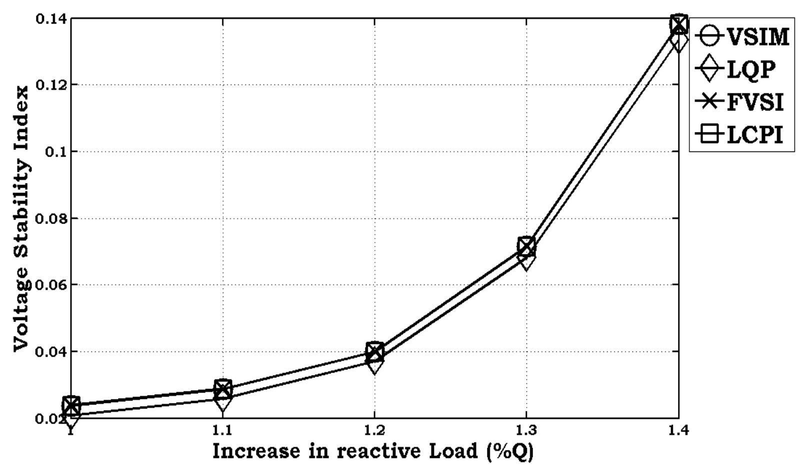

Fig.8. Line Indices variation for line between buses 7 and 9 for IEEE 14-bus system

B. Scenario-2

In this scenario, the OPF problem is solved by minimizing the IVSI and LCPI as objective functions. At first, the PSO algorithm with all control variables is solved for IVSI objective for the considered reactive load increments and the obtained OPF results are tabulated in Table.1. From this table, it is observed that, as the reactive load increases the IVSI value is increasing, similarly, the active and reactive power losses are also increasing. It is also observed that, at all loads, highest IVSI value is obtained at bus-4 and this value is tabulated.

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TABLE.1 OPF RESULTS OF IVSI MINIMIZATION WITH INCREASE IN REACTIVE LOAD Q (MVAR) FOR IEEE 14-BUS SYSTEM

Control parameters	Base load	110% load	120% load	130% load	140% load
PG1 (MW)	98.32194	103.3377	63.82963	112.4375	69.60775
PG2 (MW)	74.44906	76.07253	78.39341	48.69017	106.006
PG3 (MW)	44.94756	51.72885	60	60	60
PG6 (MW)	41.08147	23.26498	41.87436	30.58821	25.82292
PG8 (MW)	5	9.262356	18.76003	12.41281	5
VG1 (p.u)	1.1	1.080806	1.1	1.011736	1.1
VG2 (p.u)	0.939734	0.946656	1.004725	0.983735	0.94302
VG3 (p.u)	0.965328	1.097567	0.904309	0.983099	1.076089
VG6 (p.u)	0.919105	1.051919	1.068606	0.969434	0.978921
VG8 (p.u)	0.990621	1.042484	0.970799	0.973561	0.902596
Tap 4-7	1.039652	1.068393	0.965257	1.052567	0.975722
Tap 4-9	0.986602	0.913442	0.906245	0.903242	0.900855
Tap 5-6	1.030526	1.003741	0.990856	1.008962	0.99214
Qc9 (MVAr)	16.32646	18.15478	30	18.46347	30
IVSI	0.011462	0.035947	0.012021	0.014473	0.015698
Bus No	4	2	4	4	4
P loss (MW)	4.800022	4.666376	3.857427	5.128666	7.436655
Q loss (MVAr)	-10.7884	-7.1637	-14.1087	-0.97556	5.805864

For the sake of explanation, obtained IVSI values using load flow and OPF are tabulated in Table.2. From this table, it is observed that, IVSI value is decreased with OPF when compared to conventional load flow; this is because of the optimizing the control parameters in a given system. The variation of IVSI values at the sensitive bus (i.e. bus-4) is shown in Fig.9

TABLE.2 COMPARISON TABLE OF IVSI VALUES IN BOTH SCENARIOS FOR IEEE 14-BUS SYSTEM

IVSI	IVSI(OPF)
0.015343	0.011462
0.052043	0.035947
0.015778	0.012021
0.016534	0.014473
0.0185724	0.015698

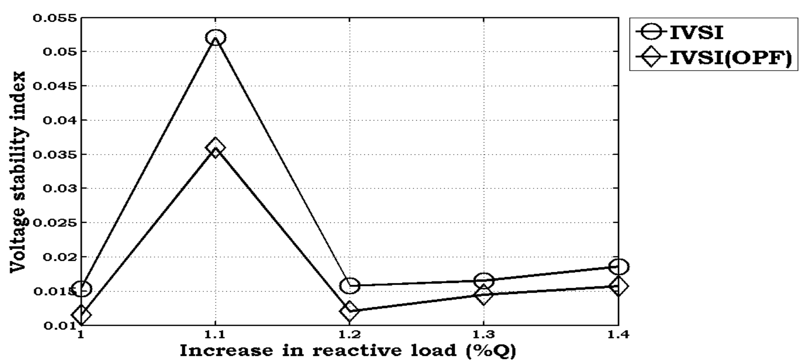

Fig.9. Variation of IVSI values in both scenarios for IEEE 14-bus system

Next, the PSO algorithm with all control variables is solved for LCPI objective for the considered reactive load increments and the obtained OPF results are tabulated in Table.3. From this table, it is observed that, as the reactive load increases the LCPI value is increasing, similarly, the active and reactive power losses are also increasing. It is also observed that, at all loads, highest LCPI value is obtained in line 9 connected between buses 4 and 9 and this value is tabulated.

TABLE.3 OPF RESULTS OF LCPI MINIMIZATION WITH INCREASE IN REACTIVE LOAD Q (MVAR) FOR IEEE 14-BUS SYSTEM

Control parameters	Base load	110% load	120% load	130% load	140% load
PG1 (MW)	12.45884	10.66147	11.26985	10.34106	13.4717
PG2 (MW)	116.6003	125.8155	119.2729	148.3421	161.5679
PG3 (MW)	56.77494	58.72792	60	59.91686	58.97045
PG6 (MW)	48.01323	46.10347	50	30.08702	24.91111
PG8 (MW)	27.62827	20.40521	21.16156	14.34853	5
VG1 (p.u)	1.1	1.1	1.1	1.1	1.1
VG2 (p.u)	0.9	0.940127	0.907513	0.929224	1.1
VG3 (p.u)	1.042176	1.076074	0.966441	0.95197	1.059222
VG6 (p.u)	0.984578	1.049082	0.9	0.992467	0.984453
VG8 (p.u)	0.952188	1.043379	1.035573	0.922179	0.9
Tap 4-7	1.027387	1.1	1.039624	1.040398	0.987238
Tap 4-9	1.051556	0.990841	0.971822	0.993172	0.912667
Tap 5-6	1.012908	1.058549	0.954615	1.035127	0.996155
Qc9 (MVAr)	23.84749	5	30	30	30
LCPI	0.01863	0.01256	0.001	0.04765	0.15908
Line	4-9	4-9	4-9	4-9	4-9
P loss (MW)	2.475563	2.71352	2.704291	4.035527	4.92119
Q loss (MVAr)	-21.6692	-18.7299	-18.2265	-12.873	-5.37099

For the sake of explanation, obtained LCPI values using load flow and OPF are tabulated in Table.4. From this table, it is observed that, LCPI value is decreased with OPF when compared to conventional load flow; this is because of the optimizing the control parameters in a given system. The variation of LCPI values in critical line (i.e. line-9) is shown in Fig.10.

TABLE.4 COMPARISON TABLE OF LCPI VALUES IN BOTH SCENARIOS FOR IEEE 14-BUS SYSTEM

LCPI	LCPI(OPF)
0.027185	0.01863
0.018264	0.01256
0.001591	0.00100
0.069853	0.04765
0.236967	0.15908

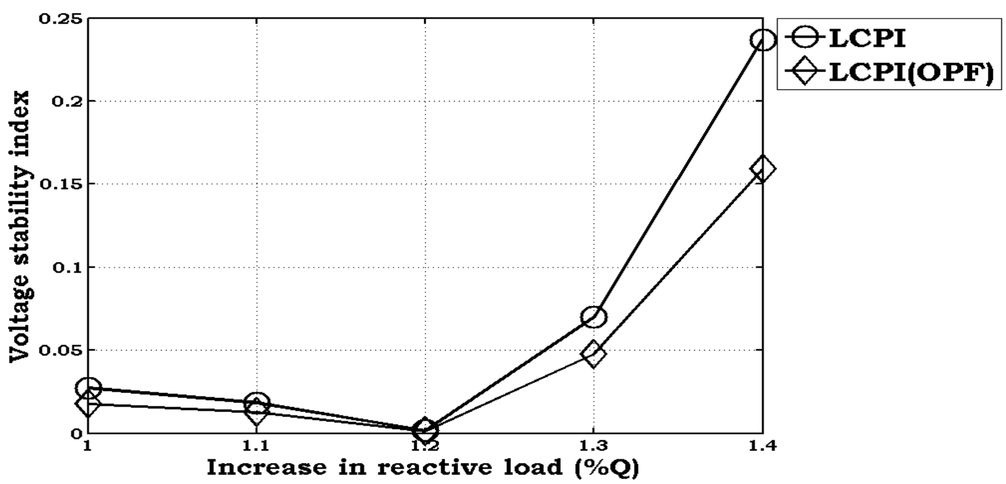

Fig.10. Variation of LCPI values in both scenarios for IEEE 14-bus system

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VII. CONCLUSIONS

In this paper a new voltage stability index, Line Collapse Proximity Index (LCPI) for lines and Improved Voltage Stability Index (IVSI) for buses has been developed and proposed for voltage stability assessment. This project first proposes the indices IVSI and LCPI which can be used satisfactorily for predicting voltage stability of every bus and line in the given power system. This paper then presents a method to enhance the voltage stability and to minimize the proposed voltage stability index using the Particle Swarm Optimization technique. The effectiveness of the proposed index has been thoroughly investigated and compared with other existing indices. The proposed index takes the directions and magnitudes of real and reactive powers into account for assessment of voltage stability status of the system and therefore, it is capable of providing accurate results in comparison to other indices. The application results of the proposed index on IEEE 14-bus system under different reactive loading conditions give that the proposed index can accurately predict voltage stability of power systems under all operating conditions. The proposed index can a priori predict the stressed condition of the lines and voltage-weak areas accurately. From the results, we can confer that near the voltage collapse point the value of proposed index approaches unity unlike other indices which are far away from unity and hence do not give true indication of relative voltage stability in certain cases. The proposed index gives accurate value of relative stability. The comprehensive application results on test system show that the proposed voltage stability index may serve as a promising tool for voltage stability assessment under all operating conditions.

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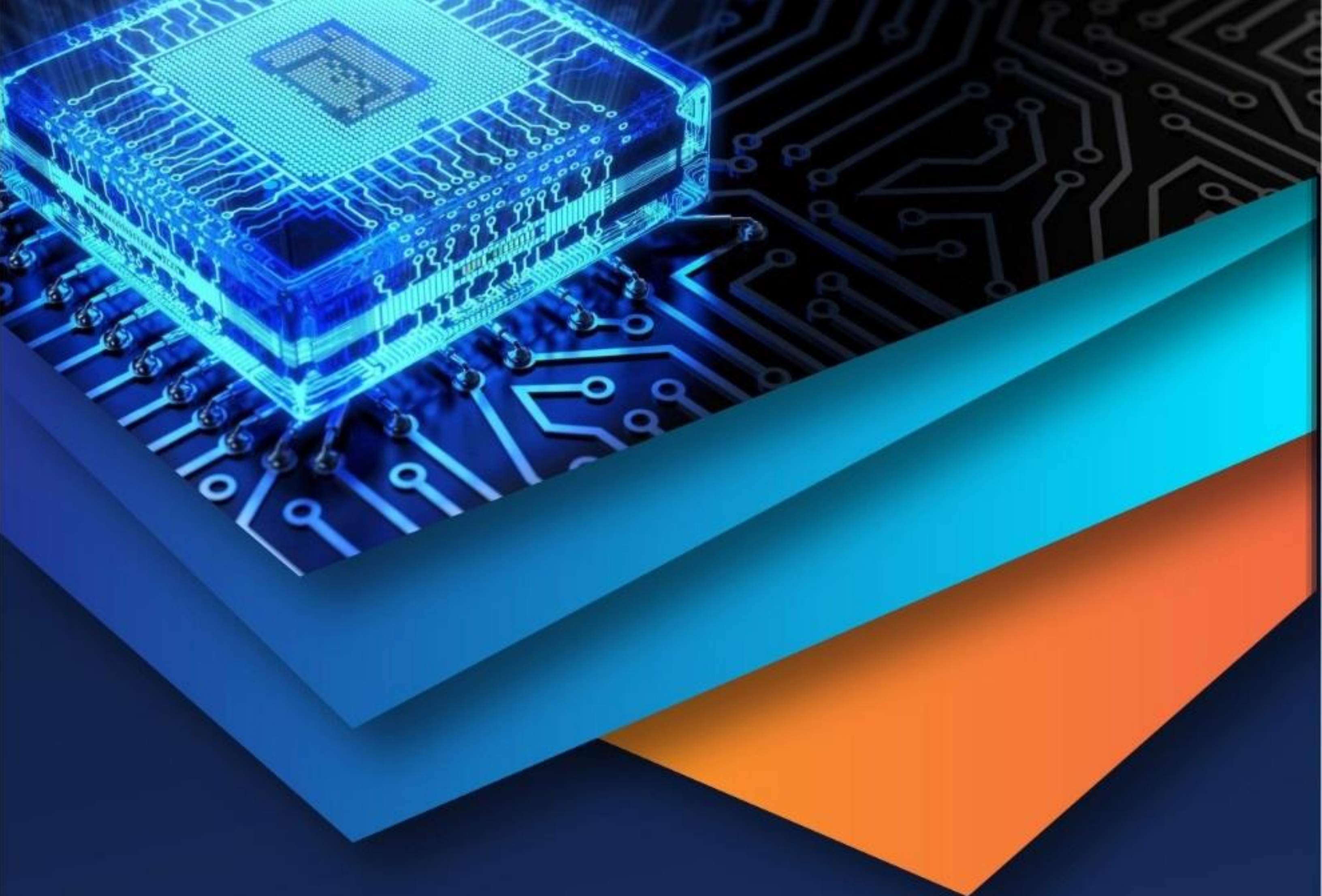

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