A NEW MODIFICATION OF LINE STABILITY INDEX FOR VOLTAGE SECURITY IMPROVEMENT BASED ON CONSTRAINT OPTIMAL POWER FLOW

Layth AL-BAHRANI[1], Amel IBRAHIM[2], Wafaa SAEED[3], Virgil DUMBRAVA[4]

Modern power systems were designed to operate in their stability margins for more security. The quick growth of the cities and the continuous increase in the electrical demand may lead the system to be operated either close to the limit of stability or collapse the system. Line Stability Index Lnm is one of the most important factors that is used to predict the voltage security of the line. It depends on many parameters of the line such as the sending voltage, reactive power at the receiving side and the reactance of the line. The most important line in the system has the maximum value of line stability index. This article presents a modification of Lnm by including the effect of tap changer of the transformer when the line is represented by a transformer. The proposed algorithm has been tested on the systems of IEEE 14 bus and IEEE 30 bus to find the most important line according to the maximum Lnm of all the lines. This article enhances the voltage security of the system by minimizing the total sum of Line Stability Index based on Optimal Power Flow using the optimization technique of Particle Swarm Optimization keeping all the constraints in their margins.

Keywords: Line Stability Index; Voltage Collapse; Optimal Power Flow; Particle, Swarm Optimization

1. Introduction

Modern power systems go towards security, reliability, flexibility and smart grid. Voltage security of the transmission line becomes more important according to the voltage collapse of the line that may cause shutting down the system. Line stability index Lnm is one of the important parameters that refers to the security voltage of the line.

The limit of Line Stability Index is in between 1 and zero, where 1 refers to voltage collapse of the line and zero refer to the case of no load. Different techniques have been used to improve the line stability index. One of these techniques is the Optimal Power Flow OPF based on optimization technique [1].

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For operation and planning, it is necessary to improve the line stability index and prevent the system from collapsing voltage. Several indices of line stability index have been presented based on power flow to check the stability of the line [2]. Some of these indices depend on reactive power and others depend on active power although the voltage of sending side or receiving side [3]. The loadibility, security and the stability of the system can be improved by insertion the renewable energy sources of wind energy and solar cell at the most important node according to the stability index of the line [4]. Also, Facts Devise like TCSC or STATCOM or SVC can be insertion for the most important line (weakness line) according to this index of line stability in both ring system and radial distribution system to prevent the voltage collapse in the system [5, 6, 7]. Also, Distribution Generator DG or reactive power compensation can be used at the risk point according to this index to prevent the collapse of the system under different load condition [8]. The loadability of the system can be increased until the value of stability index of one of lines is equal to 1 or more than 1 (voltage collapse of the lines). Optimal Power Flow at this heavy load is used to minimize the stability index of the line and avoid the voltage collapse in the lines [9]. Also, maximum loadability can be used to recognize the weakness bus according to the stability index of line Lnm and Fast Voltage Stability Index FVSI [10]. Optimal location for power plants of wind energy can be inserted in any weak point in transmission line and distribution system based on the index of voltage stability of the line [11]. This article updates a new modification in the equation of voltage stability index of the line according to the effect of tap changer of the transformer, although this article used the constraint Optimal Power Flow based on particle swam optimization to prevent the voltage collapse in the lines at heavy load conditions.

2. Line Stability Index Lnm

It is one of the most important indices that used to represent the voltage stability of the line between two nodes as shown in Fig. (1).

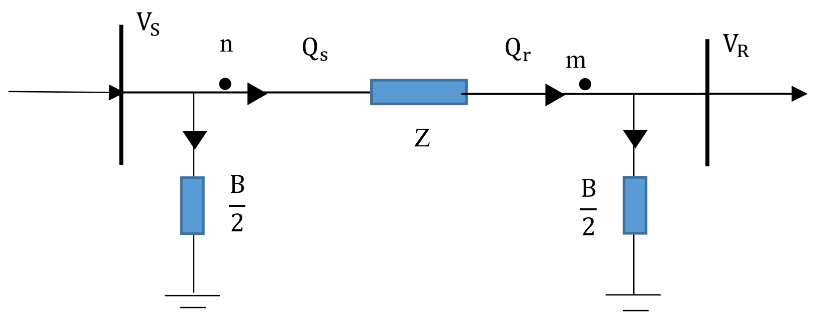

Fig.1 Transmission line of two buses including Z impedance and suspentance admittance

Line stability index of this line can be presented as shown in equation (1)

$$L_{nm} = \left| \frac{4X_T Q_r}{(|V_s| \sin(\theta - \delta_{SR}))^2} \right| \leq 1 \tag{1}$$

$$S_r = P_r + jQ_r = S_{mn} = V_R \times (I_{mn})^* \tag{2}$$

$$I_{mn} = (\frac{V_R - V_S}{Z}) \tag{3}$$

$$Q_r = -imag.(S_r) \tag{4}$$

Where L_{nm} L_{nm} is the Voltage Stability Index of the line; *Z*, *R*, *X*, *B/2* $\frac{B}{2}$ are the impedance, resistance, reactance and suspentance admittance of the line respectively where *Z=R+jX*; *n* is a node at the sending side before the impedance *Z* and after the suspentance admittance *B/2*$\frac{B}{2}$; *m* is a node at the receiving side after the impedance *Z* and before the suspentance admittance *B/2*; θ is the angle of the impedance *Z*; $\delta_{SR} = \delta_S - \delta_R$ $\delta_{SR} = \delta_S - \delta_R$; δ_S is the angle of the sending voltage V_S, where $V_S = |V_S \angle \delta_S|$ $V_S = |V_S| \llcorner \delta_S$; δ_R is the angle of the receiving voltage V_R, where $V_R = |V_R \angle \delta_R|$ $V_R = |V_R| \llcorner \delta_R$; S_r, P_r P_r and Q_r Q_r are the apparent, active and reactive power respectively at the receiving side (at the node *m*); S_{mn} S_{mn} apparent power flow from node *m* to node *n*; I_{nm} is the line current flow through the impedance *Z* from node *m* to node *n* [9, 12, 13].

This article presents a modification of voltage stability index when the line is represented by a transformer has a pure reactance of x_t and including tap changer of parameter (*a*) at the receiving side as shown in the Fig. (2).

An equivalent circuit of the transformer can be simulated in the transmission line as shown in Fig. (3). [14]

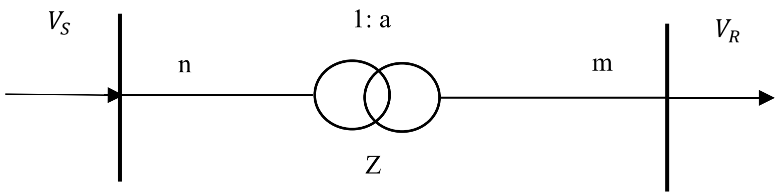

Fig. 2. Transformer between bus two buses has a tapping at the receiving side

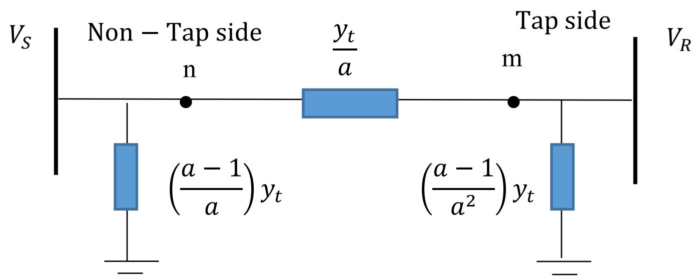

Fig. 3. Equivalent of transformer has tapping at the receiving side

The reactance of this line can be presented as shown in equation (5).

$$X_T = \frac{1}{\frac{y_t}{a}} = a.x_t \tag{5}$$

$$y_t = \frac{1}{x_t} \tag{6}$$

Where x_t x_t is pure reactance of the transformer without tapping; y_t y_t is the admittance of the pure reactance of the transformer; X_T X_T is the total reactance of the transformer with the effect of tap changer. The voltage stability index of the line that includes the transformer can be presented as shown in equation (8).

$$L_{nm} = \left| \frac{4aX_T Q_r}{(|V_s| \sin(\theta - \delta_{SR}))^2} \right| \leq 1 \tag{7}$$

Q_r Q_r has been calculated based on equations (2, 3, and 4).

3. Optimal Power Flow OPF

OPF can be represented by the flowing equations

$$Min.\ F(x,y);\ G(x,y)\ ;\ H(x,y) \leq 0 \tag{8}$$

Where *F(x,y)* is the objective function that will be minimized: *G(x,y)* is the equality constraints; *H (x, y)* is the inequality constraints; *x* is the state variables and *y* is the control variables. OPF try to find the optimal objective function by re-adjusting the value of control variables from their maximum and minimum limits keeping the constraint of the state variables in their limits. [15, 16]

3.1 Constraints

There are two types of OPF constraints, the equality constraints and inequality constraints

- **Equality constrain**

Load flow equality constraints are shown in equations (12) and (13).

$$P_i = P_{Gi} - P_{Li} = V_i \sum_{j=1}^{N_B} V_j [G_{ij} \cos\theta_{ij} - B_{ij} \sin\theta_{ij}] \quad (9)$$

$$Q_i = Q_{Gi} - Q_{Li} = V_i \sum_{j=1}^{N_B} V_j [G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}] \quad (10)$$

Where *i* and *j =1,2,3,….., N_B* N_B; N_B, N_B is the number of buses; P_i P_i and Q_i are the injection active and reactive power into bus *i* respectively; P_{Gi} P_{Gi} and Q_{Gi} Q_{Gi} the generator active and reactive power at bus *i* respectively; P_{Li} P_{Li} and Q_{Li} Q_{Li} are the load active and reactive power at bus *i* respectively; G_{ij} G_{ij} and B_{ij} B_{ij} are the conductance and susceptance connecting terminal *i* and terminal *j* respectively. [17, 18]

- **Inequality constrain**

It can be classified into two types: the control variables and the state variable constraints

(i) Control Variables Constraints

This article has been used four type of the control variables, which are the generator magnitude voltage V_G V_G, Tap changer of the transformer *Tap* , shunt injection capacitance Q_C in MVAr and active power of generator except the slack bus P_G . The inequality constant of control variables are presented as below limits:

$$V_{G_i}^{min} \le V_{G_i} \le V_{G_i}^{max} \quad i = 1,2,\dots,N_G \quad V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max} \quad i=1,2,\dots\dots, N_G$$

$$Tap_j^{min} \le Tap_j \le Tap_j^{max} \quad j=1,2,\dots\dots, N_{Ta} \quad Q_{C_k}^{min} \le Q_{C_k} \le Q_{C_k}^{max} \quad k = 1,\dots,N_C$$

$$Q_{Ck}^{min} \le Q_{Ck} \le Q_{Ck}^{max} \quad k=1,2,\dots, N_C$$

$$P_{Gx}^{min} \le P_{Gx} \le P_{Gx}^{max} \text{ Where } x=1,\dots, N_G \text{ except slack active power.}$$

N_G N_G is total number of generators; N_{Ta} is total number of transformers; N_C is total number of shunt capacitance.

(ii) State Variables Constraints

The state variables that are used in this article are the slack active power P_{GS}, load voltage V_L and generator reactive power Q_G Q_G. The inequality constraint of state variables can be presented as below limits.

$$P_{GS}^{\min} \le P_{GS} \le P_{GS}^{\max} \quad Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad i = 1,2,\dots,N_G$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad i=1,2,\dots\dots,\ N_G \quad V_{Lk}^{\min} \le V_{Lk} \le V_{Lk}^{\max} \quad k = 1,2,\dots,N_L$$

$$V_{LK}^{\min} \le V_{LK} \le V_{LK}^{\max} \quad k=1,2,\dots\dots,\ N_L$$

Where N_L N_L is number of transmission lines. [17, 18]

4. Particle Swarm Optimization PSO

PSO is one of the evolutionary optimization techniques that are inspired from the movement of birds or fish. It depends on two parts, velocity and position. Each bird or fish represents a particle has a candidate of solutions. These particles are updated in the swarm searching space according to the optimal velocity and position to find the best solution (best objective function).

$$V_{ij}^{T} = W.V_{ij}^{T-1} + C_1 \times Rand_1 \times (pbest_{ij}^{T-1} - X_{ij}^{T-1}) + C_2 \times Rand_2 \times (gbest_{ij}^{T-1} - X_{ij}^{T-1}) \tag{11}$$

$$X_{ij}^{T} = X_{ij}^{T-1} + V_{ij}^{T} \tag{12}$$

$$W = W_{\max.} - [\frac{W_{\max.} - W_{\min.}}{T_T}] \times T \tag{13}$$

Where *i* =1, 2,…, *N*; *j* =1, 2,…, *M*; *N* is the number of particles (each particle represents control variable); *M* is the number candidate of each particle; *T* is the currently iteration number; V_{ij}^{T-1} V_{ij}^{T-1} is the particle velocity at iteration *T-1*; *pbest* is the best position of each particle; *gbest* is the best position of all *pbest* in the swarm; C_1 & C_2 are the acceleration constants; $Rand_1$ $Rand_1$ & $Rand_2$ are randomly constant in the limit of (0 and 1); X_{ij}^{T-1} X_{ij}^{T-1} is the particle position at iteration *T-1*; *W* is the function of the weight; $W_{max.}$ is the maximum weight and it is equal to 0.9; $W_{min.}$ is the minimum weight and it is equal to 0.4; *T* *T* is the currently iteration; T_T T_T is the maximum iteration; X_{ij}^{T} X_{ij}^{T} is the particle position at new iteration *T*.

The program will be stopped if the iteration number is reached the maximum number of iterations. [19, 20, 21].

5. The result and discussion

This article used the systems of IEEE 14 [15] bus and IEEE 30 bus [22] to test the objective function of total sum of line stability index Lnm for each line. The system of IEEE 14 bus 20 lines. This system also has 12 control variables, which are: five generator magnitude voltage, three Tap changer of transformer and four active power of generator except slack bus. The state variables (S.V) of this system are the slack active power, generator reactive power and load voltage.

Table 1 shows the initial and optimal of both Control Variables (C.V.) and State Variables (S.V.) with their constraints. Optimal control variables have been calculated based on PSO technique keeping the state variables in their limit as shown in table 1. PSO minimizes the objective function of total sum of Lnm from the initial case of 1.2215 to optimal case of 0.3106 and reduced the maximum Lnm from 0.22984 at line (5-6) for the initial case to 0.0535 at line (9-14) for optimal case with reduction of 76.74 %. Fig. 4 show the initial and optimal Lnm of IEEE 14 bus at base load with respect of the total 20 lines for the IEEE 14 bus. Fig. 5 shows the objective function of total sum of Lnm for IEEE 14 bus with respect to the number of iterations based on PSO technique.

Table 1

Initial and optimal Control Variables (C.V.) and State Variables (S.V.) of IEEE 14 bus

	Type of Variables		Limit		Initial Case	Optimal case
			Min.	Max.		
Control variables (C.V.)	Generator magnitude voltage in per unit	V_{G1}	0.95	1.1	1.060	1.1000
		V_{G2}	0.95	1.1	1.045	1.0994
		V_{G3}	0.95	1.1	1.010	1.0803
		V_{G6}	0.95	1.1	1.070	1.0841
		V_{G8}	0.95	1.1	1.090	1.0786
	Tap changer of the transformer	T_{4-7}	0.9	1.1	0.978	0.9843
		T_{4-9}	0.9	1.1	0.969	0.9045
		T_{5-6}	0.9	1.1	0.932	1.0088
	Active power of generator except the slack bus in MW	P_{G2}	20	80	40	80.000
		P_{G3}	15	50	0	48.996
		P_{G6}	10	35	0	34.146
		P_{G8}	10	30	0	21.388
	Slack active power in MW	P_{G1}	-100	250	232.50	77.706
		Q_{G1}	-50	100	-22.34	-24.61

State Variables (S.V.)	Generator reactive power in MVAr	Q_{G2}	-40	50	35.248	14.032
		Q_{G3}	0	40	23.012	15.500
		Q_{G6}	-6	24	20.198	21.934
		Q_{G8}	-6	24	23.962	0
	Load voltage		0.95	1.1	With limit	With limit
	Objective function of Total sum of Lnm				1.2215	0.3106
	Maximum Lnm				0.22984	0.0535

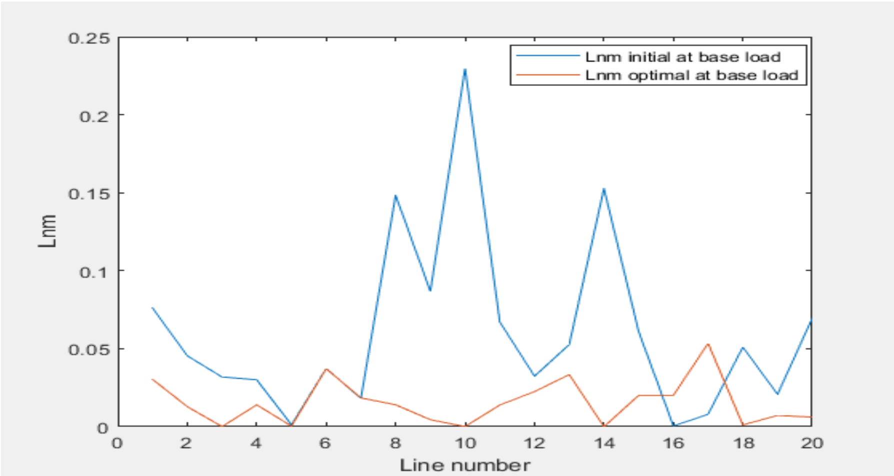

Fig. 4. Initial and optimal Lnm for the 20 lines of 14 bus

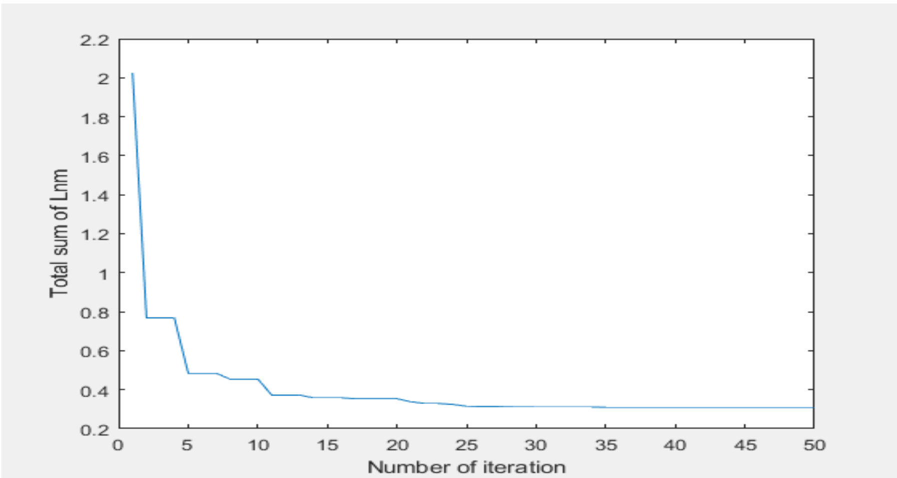

Fig. 5. Total sum of Lnm for IEEE 14 bus system based on PSO

IEEE 30 bus has 24 control variables, which are: six generator magnitude voltage, four Tap changer of the transformer, nine shunt injection capacitance in MVAr and five active power of generator except the slack bus. The state variables are the slack active power, generator reactive power and load voltage. Table 2 shows the initial and optimal of both Control Variables (C.V.) and State Variables (S.V.) with its constraints. Optimal control variables have been calculated based on PSO technique, keeping the state variables in their limit.

Table 2

Initial and optimal Control Variables (C.V.) and State Variables (S.V) of IEEE 30

	Type of variables		Limit		Initial case	Opt. cases
			Min.	Max.		
Control Variables (C.V.)	Gen. magnitude voltage in per unit	V_{G1}	0.95	1.1	1.05	1.1000
		V_{G2}	0.95	1.1	1.04	1.0830
		V_{G5}	0.95	1.1	1.01	1.0524
		V_{G8}	0.95	1.1	1.01	1.0670
		V_{G11}	0.95	1.1	1.05	1.0606
		V_{G13}	0.95	1.1	1.05	1.0867
	Tap changer of the transformer	T_{4-12}	0.9	1.1	1.078	1.0146
		T_{6-9}	0.9	1.1	1.069	1.0033
		T_{6-10}	0.9	1.1	1.032	0.9448
		T_{28-27}	0.9	1.1	1.068	0.9946
	Shunt injection capacitance in MVAr	Q_{C10}	0	5	0	4.2595
		Q_{C12}	0	5	0	2.8007
		Q_{C15}	0	5	0	4.3327
		Q_{C17}	0	5	0	4.3268
		Q_{C20}	0	5	0	4.3470
		Q_{C21}	0	5	0	4.3513
		Q_{C23}	0	5	0	3.3531
		Q_{C24}	0	5	0	5.0000
		Q_{C29}	0	5	0	4.4916
	Active power of generator except the slack bus in MW	P_{G2}	20	80	80	50.450
		P_{G5}	15	50	50	22.899
		P_{G8}	10	35	20	32.038
		P_{G11}	10	30	20	21.318
		P_{G13}	12	40	20	25.719

State Variables (S.V.)	Slack active power in MW	P_{G1}	50	200	99.23	137.33
	Gen. reactive power in MVAr	Q_{G1}	-20	200	5.27	9.47
		Q_{G2}	-20	100	27.58	21.25
		Q_{G5}	-15	80	21.43	27.07
		Q_{G8}	-15	60	22.59	44.18
		Q_{G11}	-10	50	39.49	0.088
		Q_{G13}	-15	60	40.19	13.72
	Load voltages		0.95	1.1	With limit	With limit
Objective function of total sum of Lnm for all lines					2.4112	0.4951
Maximum Lnm					0.3325	0.0672

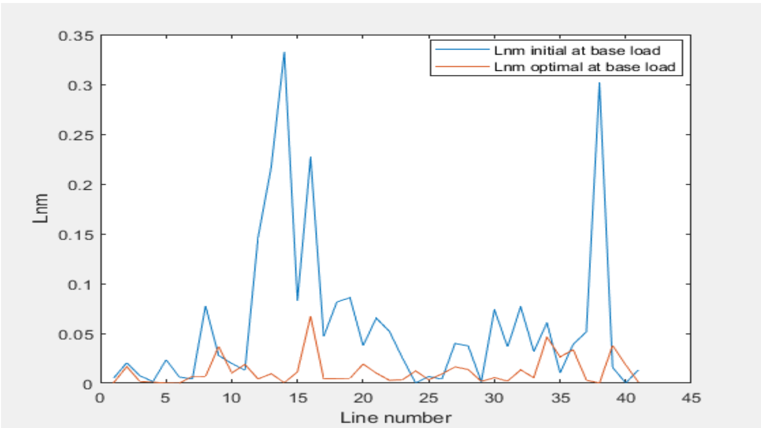

Fig. 6. Initial and optimal Lnm for the 41 lines of IEEE 30 bus

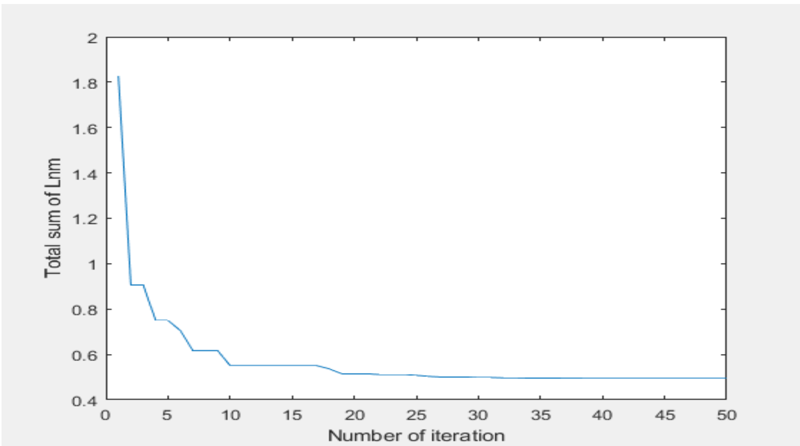

Fig.7. Total sum of Lnm for IEEE 30 bus system based on PSO optimization techniques

6. Conclusion

This article deals with the voltage stability of the line and presents a modification of Line Stability Index Lnm by including the effect of tap changer of the transformer in the equation of Lnm. Voltage Stability Index of the line has been tested for both systems of IEEE 14 bus and IEEE 30 bus. The most important line in this system has the maximum value of Lnm.

Voltage stability Index Lnm is one of the most important technique that is used to predict the voltage stability of the system. It is simple in analysis, fast in calculation and accurate in result. Voltage collapse in the transmission line may cause shutting down the system. Voltage collapse in the system will occur when voltage stability index Lnm of one of the lines is equal or more than 1.

Optimal Power Flow has been used based on Particle Swarm Optimization to prevent the collapse of the system at heavy load and reduce the maximum value of Lnm from (0.22984 to 0.0535) for IEEE 14 bus and from (0.3325 to 0.0672) for IEEE 30 bus keeping the constraint state variables of Optimal Power Flow in their limit. Enhancement the Lnm increase the system security voltage of the line and make the system more reliable and efficient for sudden heavy increase in the load or losing some of the generation units.

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R E F E R E N C E S

[1]. *S. Khunkitti and S.Premrudeepreechacharn*, "Voltage Stability Improvement Using Voltage Stability Index Optimization'', 2020 International Conference on Power, Energy and Innovations (ICPEI), IEEE Xplore, Chiangmai, Thailand, 2021, pp. 193-196.

[2]. *P. K. Kushwaha and C. Bhattacharjee*, " A Research on Selection of Appropriate Stability Index under Adverse System Conditions for the Assessment of Voltage Stability of an IEEE 14 Bus Power System'', European Journal of Electrical Engineering, Vol. 22, No. 6, December, 2020, pp. 435-446.

[3]. *S. Mokred, Y. Wang and T. Chen*, "A novel collapse prediction index for voltage stability analysis and contingency ranking in power systems'', Protection and Control of Modern Power Systems, 8:7, 2023, pp. 1-27.

[4]. *S. K. Gupta and S.K. Mallik*, "Voltage Stability Assessment of Power System Using Line Indices with Wind System and Solar Photovoltaic Generation Integration", Journal of Operation and Automation in Power Engineering, Dec. 2022. pp. 1-12

[5]. *M. Mathew, S. Ghosh, D. S. Babu, and A.A. Ansari*, "An Assessment of Voltage Stability based on Line Voltage Stability Indices and its Enhancement Using TCSC", IOSR Journal of Electrical and Electronics Engineering, Vol. 10, Issue 6, Ver. I, Dec. 2015. pp. 81-88.

[6]. *B. Ismail, M. M. Naain, N. I. Abdul Wahab, L. J. Awalin, I. Alhamrouni and M. F. Abd Rahim*, "Optimal Placement of DSTATCOM in Distribution Network Based on Load Flow and Voltage Stability Indices Studies'', 2017 International Conference on Engineering

Technology and Technopreneurship (ICE2T), Kuala Lumpur, Malaysia, IEEE Xplore**,** 18 Dec., 2017.
[7]. *A. K. Sharma, A. Saxena and R. Tiwari*, "Voltage Stability Assessment using GVSM and Preventive Control using SVC'', *International Journal of Computer Applications*, Vol. 142 – No.11, May 2016, pp.23-31.
[8]. *B. Ismail, N. I. Abdul Wahab, M. L. Othman, M. A. M. Radzi, K. N. Uvijayakumar, M. K. Rahmat and M. N. Mat Naain*, "New Line Voltage Stability Index (BVSI) for Voltage Stability Assessment in Power System: The Comparative Studies'', IEEE Access, Vol. 10, Oct. 2022 pp.103906-103931.
[9]. *W. Saeed and L. Tawfeeq*, "Ultimate Loadability Improvement based on Contingency Ranking and Line Voltage Stability using Genetic Algorithm'', International Journal of Electrical and Electronics Engineering Research (IJEEER), Vol. 7, Issue 3, Jun. 2017.
[10]. *N. Shekhawat, A. K. Gupta and A. K. Sharma*, "Voltage Stability Assessment Using Line Stability Indices", 3rd International Conference and Workshops on Recent Advances and Innovations in Engineering, 22-25 Nov. 2018.
[11]. *B. Ismail, M. M. Naain, N. I. Abdul Wahab, N. S. M. Shaberon, L. J. Awalin, I. Alhamrouni,* "Voltage Stability Indices Studies on Optimal Location of Wind Farm in Distribution Networkm"
[12]. *C. Valuva, S. Chinnamuthu, T. Khurshaid and K. Kim*, "A Comprehensive Review on the Modelling and Significance of Stability Indices in Power System Instability Problems'', *Energies*,16, 6718, 2023, pp. 1-45.
[13]. *I. A. Samuel, J. Katende, C. O. A. Awosope and A. A. Awelewa*, "Prediction of Voltage Collapse in Electrical Power System Networks using a New Voltage Stability Index'', International Journal of Applied Engineering Research, Vol. 12, No. 2, 2017.
[14]. *H. Sadat*, "Power system analysis" , 1999, McGraw Hill, New York; ISBN 978-0984543809.
[15]. *L. T. Al-Bahrani* "Optimal Power Flow (OPF) with different Objective Function based on modern heuristic optimization techniques'', PhD Thesis, University POLITEHNICA of Bucharest, Romania, 2015.
[16]. *L. T. Al-Bahrani, and V. Dumbrava*, "Optimal Power Flow based on Particle Swarm Optimization", U.P.B. Sci. Bull., Series C, Vol. 78, Iss. 3, 2016, pp 253-264.
[17]. *L. T. Al-Bahrani, M. Al-Kaabi, M. Al-Saadi and V. Dumbrava*, "Optimal Power Flow based on Differential Evolution Optimization Technique", U.P.B. Sci. Bull., Series C, Vol. 82, Iss. 1, 2020, pp 247-258.
[18]. *L. Al-Bahrani, M. Al-Kaabi and J. Al- Hasheme*, "Solving Optimal Power Flow Problem Using Improved Differential Evolution Algorithm", International Journal of Electrical and Electronic Engineering & Telecommunications*,* Vol. 11, No. 2, March 2022.
[19]. *L. T. Al-Bahrani*, "Transient Stability Improvement based on Optimal Power Flow using Particle Swarm Optimization'', IOP Conf. Series: Materials Science and Engineering*,* 870, 012118, 2020,
[20]. *Wafaa Saeed, Layth Tawfeeq*, "Voltage Collapse Optimization for the Iraqi Extra High Voltage 400 kV Grid based on Particle Swarm Optimization", Iraq J. Electrical and Electronic Engineering, Vol. 13. No.1, 2017.
[21]. *L. T. Al-Bahran*, "Transient Stability Optimization based on increasing the Critical Clearing Time using Particle Swarm Optimization", *International Journal of Engineering & Technology*, (4.19), 2018.
[22]. *K. Y. Lee, Y. M. Park and J. L. Ortiz*, "A united approach to optimal real and reactive power dispatch", IEEE trans. on Power apparatus and systems, vol. PAS-104, No 5, 1985. pp 1147-1153.