International Journal of Engineering & Technology, 7 (4) (2018) 5612-5617

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.23652
Research paper

Maximum voltage gain index for distributed generators based on voltage power system profile

Aqeel S. Jaber *

Department of Electrical power Engineering techniques, Al-Mamoun University College, Baghdad, Iraq
**Corresponding author E-mail: aqe77el@yahoo.com*

Abstract

The challenges facing power systems have shown a growing tendency in the studies on distributed generation in the modernized world. One of the most important objectives of distributed generation systems is an improvement of the quality of power systems. Many indices have been proposed in the electrical power system literature. However, the previous criteria did not give a clear voltage advantage of the distributed generator's location. In this paper, a new index is proposed to gauge the placement of distributed generators (DGs) in a power system. The new index depends on the maximum voltage gain (MVG) in the system to overcome the position of the DG. The Gauss-Seidel load flow method is used to test the voltages of IEEE 30-bus standard after and before adding of DGs. The results show that MVG is more feasible than other indices such as cumulative voltage deviation (CVD) and voltage stability index (VSI) for calculating suitable locations for DGs.

Keywords: *CVD; VSI; Voltage Profile; DG.*

1. Introduction

With the penetration of distributed generators (DGs) into the electrical power system, the classical calculations on voltage and power are facing several challenges not only in providing a high-quality scheme, but also evaluation of the power system quality [1]. Generally, the researchers' goal is to develop guidelines for designers to choose a suitable site for the DG in the power system [2]. Many strategies have been introduced for determining the optimal location for DGs [2].

Most studies consider the transient response of transmission corridors for operators to estimate the quality of the system, such as stability, sag, and voltage swell [3-5]. Yosefi et al. optimized the control parameters by using the minimum voltage-sag index as a function of the static synchronous compensator [6]. Chakravorty et al. determined the critical points that are affected by voltage according to the voltage stability index for a radial distribution system [7], [8]. Ankit and Ashwani used the voltage deviation index as one of four objective functions to set the location and size of the DGs [9]. Other studies focus on state considerations to calculate a suitable site for the DG [10]. The gradient method, linear programming, and Kalman filter algorithm are three traditional methods utilized to predict the location of DGs [10-12]. In addition, the power flow is used as a tool to analyze the voltage stability in most studies owing to its ease of use [13-16]. However, the introduction of a DG makes these indices invalid as they cannot gauge the effect of a DG on the voltage profiles [1].

In this study, a novel index, called the maximum voltage gain (MVG) index, was developed and used to estimate the overall assessment of steady-state voltage in the case of different DGs being placed in multiple areas. This index depends on the calculation of the differences between the node voltages before and after DG placement. Thus, in this study, the new index was introduced and formulated for gauging the voltage of the system. Then, four types of DGs were considered to mitigate the problem of the DGs' location. Subsequently, an analysis of the IEEE standard was carried out by using the Gauss-Seidel method for load flow to find the voltage buses. Finally, a distribution network using the IEEE 30-bus test system was simulated in MATLAB to verify the effectiveness of the new index. The simulation results indicate that the proposed index is more feasible for calculating suitable locations for DGs than traditional indexes such as cumulative voltage deviation (CVD) and voltage stability index (VSI).

2. Theoretical background

2.1. Voltage indices

Two of the many indices that are presented using Thevenin's equivalent theorem are CVD and VSI. CVD is the sum of the deviations of voltage node value (which are calculated from load flow) from the desired value; normally the desired value is 1.0 p.u [17]. The CVD index is determined as follows:

$$CVD = \sum_{i=1}^{n}(1 - V_i) \quad (1)$$

Where n is the total number of nodes and V_i is the node voltage.

Elsewhere, VSI represents the typical index of stability for the voltage, which gives a view of the system stability for the suggested location of DGs. VSI can be calculated as [18], [19].

$$VSI(n2) = \|V(n1)\|^4 - 4.0\{P(n2)\,x(kk) - Q(n2)r(kk)\}^2 - 4.0\{P(n2)\,r(kk) - Q(n2)x(kk)\}\|V(n1)\|^2 \quad (2)$$

Where VSI(n2) is the voltage stability index for n2 (n2 = 2, 3, ...), kk is the branch number, r(kk) is the resistance of branch kk, x(kk) is reactance of branch jj, V(n1) is the voltage of node n1, V(n2) is the voltage of node n2, P(n2) is the real power load fed through node n2, and Q(n2) is the reactive power load fed through node n2.

2.2. DG classification

DG planning is a very important issue in maximizing the benefits of DGs. Further, solving the problems related to the placement and sizing of DG units requires finding a suitable fitness function that optimizes the corresponding constraints. The ability of DGs to reduce power loss and voltage deviation is determined by three factors, viz., the type, location, and size of the DG. DG technology provides active and reactive power supply directly to the load center. It can be classified into four types as follows [20], [21]:

1) DG I: capable of injecting reactive power only
2) DG II: capable of injecting active power only
3) DG III: capable of injecting active and reactive power.
4) DG IV: capable of injecting active power but observing reactive power.

3. The proposed method

3.1. Simplified power system

The net power of the system, which is shown in Fig 1, must be equal to zero. The generated power is assumed positive, to be consistent with the equation YV=I.

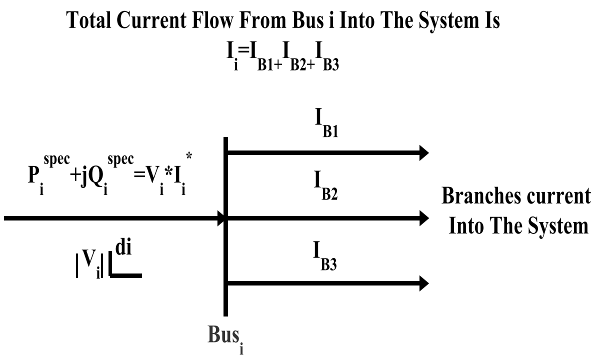

Fig. 1: Power Balance for Bus i.

The equation for every bus is

$$P_i^{spec} + jQ_i^{spec} = P_i^{calc} + jQ_i^{calc} = V_i I_i^* = V_i \left[\sum_{j=1}^{N} y_{i,j} V_j \right]^* \quad (3)$$

Separation into real and imaginary components yields two equations for bus i,

$$P_i^{spec} = \sum_{j=1}^{N} |V_i||y_{i,j}||V_j| \cos\left(\delta_i - \delta_j - \theta_{i,j}\right) \quad (4)$$

$$Q_i^{spec} = \sum_{j=1}^{N} |V_i||y_{i,j}||V_j| \sin\left(\delta_i - \delta_j - \theta_{i,j}\right) \quad (5)$$

Where

$$V_i = |V_i| \angle \delta_i \ , V_j = |V_j| \angle \delta_j \ , y_{i,j} = |y_{i,j}| \angle \theta_{i,j} \quad (6)$$

The Newton-Raphson method can be solved using Taylor's expansion; the first derivative in abbreviated form is

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (7)$$

So that

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{1}{|V|}\frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{1}{|V|}\frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix} \begin{bmatrix} |V| \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (8)$$

The partial derivatives are derived from

$$P_i^{calc} = \sum_{j=1}^{N} |V_i||y_{i,j}||V_j| \cos\left(\delta_i - \delta_j - \theta_{i,j}\right) \quad (9)$$

$$Q_i^{calc} = \sum_{j=1}^{N} |V_i||y_{i,j}||V_j| \sin\left(\delta_i - \delta_j - \theta_{i,j}\right) \quad (10)$$

3.1. Formulation of the proposed MVG index

The quantity of the voltages can be determined from the second and fourth Jacobean matrices for $J2$,

$$\begin{aligned} \frac{\partial P_i}{\partial |V_i|} &= \sum_{j=1, j\neq i}^{N} |y_{i,j}||V_j| \cos\left(\delta_i - \delta_j - \theta_{i,j}\right) + 2|V_i||y_{i,i}|\cos\left(-\theta_{i,i}\right) \\ \frac{\partial P_i}{\partial |V_k|} &= |V_i||y_{i,k}|\cos\left(\delta_i - \delta_k - \theta_{i,k}\right), \ k \neq i \ . \end{aligned} \quad (11)$$

For $J4$,

$$\begin{aligned} \frac{\partial Q_i}{\partial |V_i|} &= \sum_{j=1, j\neq i}^{N} |y_{i,j}||V_j| \sin\left(\delta_i - \delta_j - \theta_{i,j}\right) + 2|V_i||y_{i,i}|\sin\left(-\theta_{i,i}\right) \\ \frac{\partial Q_i}{\partial |V_k|} &= |V_i||y_{i,k}|\sin\left(\delta_i - \delta_k - \theta_{i,k}\right), \ k \neq i \ . \end{aligned} \quad (12)$$

Because the voltage decreases with distance, a generator placed farther from the main source typically provides better voltage support to the system. On the other hand, the sum of voltages indices does not give a good indication of the location because of the small changes in the index values. Therefore, the deviation between the voltages before and after the DGs is very important in the selection of size or location as shown below.

$$Voltage\ Gain(i) = \begin{cases} Vaf\ (i) - Vbf\ (i) & if \quad Vmax > Vaf(i) > V\,min \\ 0 & if \quad Vmin > Vaf(i) > \ \ Vmax \end{cases} \quad (13)$$

The second branch of equation (13) represents the voltage gain value if the voltage magnitude is out of the tolerance limit of the power system. In this paper, the tolerance voltage is assumed as ±10% of the base voltage. So; the proposed index is given as

$$MVG = Max\ (Voltage\ Gain) \quad (14)$$

Where Vmax and Vmin are the maximum and minimum voltage permissible limits, respectively. Vaf and Vbf are the voltages after and before the DGs, respectively

The minimum and maximum values of the proposed MVG index are 0 and 1, respectively.

The flowchart of the proposed method is shown in Fig 2.

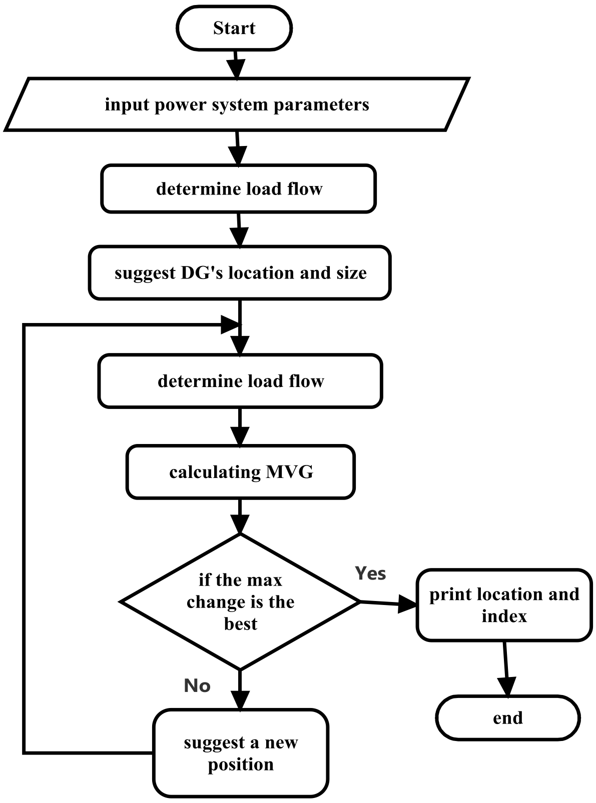

Fig. 2: MVG Flowchart.

4. Simulation results and discussion

The IEEE 30-bus system was selected to test the proposed method. Two DG scenarios (one and two DGs) were chosen to calculate the index on all possible generator locations. Further, the proposed method was applied to multiple classes and sizes of DGs to examine the effect of DG type on the indices.

The advantage of the clarity of change during the addition of DGs to the system was the main point of comparison among the three different indices using the simulation results. All the possible locations of DGs in the 30-bus IEEE system were considered and MVG, CVD, and VSI under multiple cases of DG sizes and types were calculated.

Figs 3–5 show the index values for the addition of a single generator with 10% of the IEEE base power of Type I DGs.

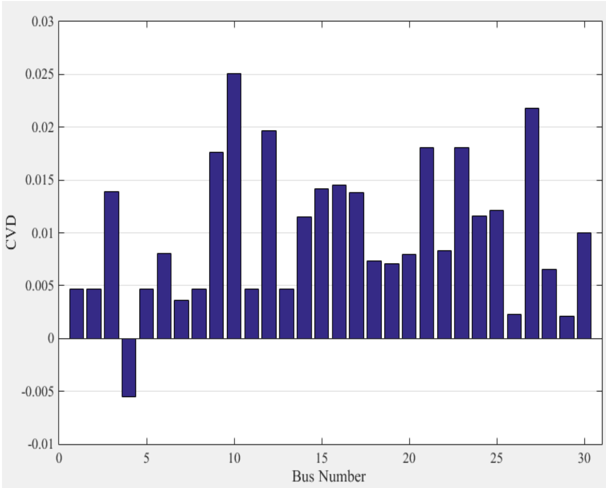

Fig. 3: CVD for Single DG and 0.1 P. U.

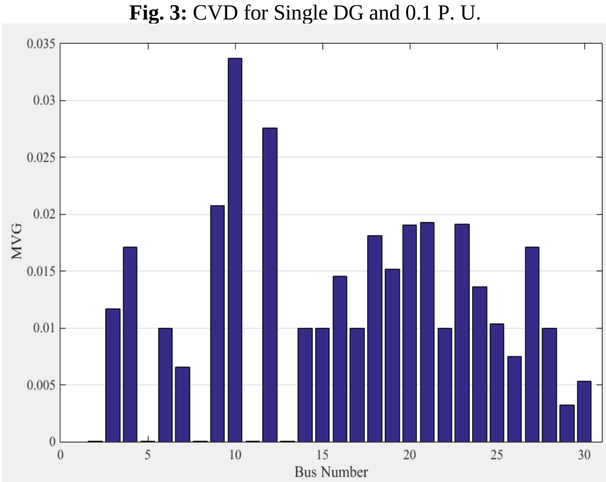

Fig. 4: MVG for Single DG and 0.1 P. U.

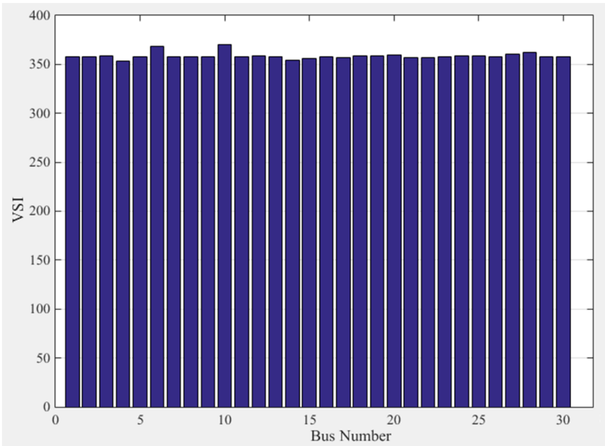

Fig. 5: VSI for Single DG and 0.1 P. U.

Table 1 lists the values of the indices; it can be noticed that bus 10 has the maximum value among all indices, but MVG is the clearest index among them. The differences between the highest and the lowest values of MVG can be seen in 10th and first buses.

50% of base power for a Type I DG was also applied to calculate the performance of the system; the results are given in Table 2.

Table 1: Indices Values for Single DG and P=10 P. U

Bus No.	MVG	CVD	VSI	Bus No.	MVG	CVD	VSI
1	0.0000	0.0047	358.2140	16	0.0145	0.0145	357.5764
2	0.0000	0.0047	358.2411	17	0.0100	0.0138	357.1245
3	0.0117	0.0139	358.3341	18	0.0182	0.0074	359.0380
4	0.0171	0.0055-	353.7826	19	0.0152	0.0070	358.6319
5	0.0000	0.0047	358.1256	20	0.0191	0.0079	359.7120
6	0.0100	0.0080	368.6701	21	0.0193	0.0180	357.0811
7	0.0065	0.0037	357.6354	22	0.0100	0.0083	356.7388
8	0.0000	0.0047	358.1926	23	0.0191	0.0181	357.5965
9	0.0207	0.0176	357.4722	24	0.0137	0.0116	358.5184
10	0.0338	0.0251	370.6721	25	0.0103	0.0121	358.4564
11	0.0000	0.0047	358.2969	26	0.0075	0.0022	357.8888
12	0.0276	0.0196	358.9748	27	0.0171	0.0218	360.3346
13	0.0000	0.0047	358.2680	28	0.0100	0.0066	362.0094
14	0.0100	0.0115	354.6692	29	0.0033	0.0021	357.8382
15	0.0100	0.0141	355.6580	30	0.0053	0.0100	357.7650

Table 2: Index Values for Single DG and P= 0.5 P. U

Bus No.	MVG	CVD	VSI	Bus No.	MVG	CVD	VSI
1	0	0.0047	358.2140	16	0.0100	0.0145	357.1189
2	0.0000	0.0047	358.3493	17	0.0182	0.0138	356.5184
3	0.0117	0.0139	358.0135	18	0.0152	0.0074	358.5214
4	0.0171	0.0055-	354.1518	19	0.0191	0.0071	358.3312
5	0.0000	0.0047	357.7718	20	0.0193	0.0080	359.0807
6	0.0100	0.0080	369.0467	21	0.0100	0.0181	356.9096
7	0.0065	0.0036	357.2265	22	0.0191	0.0084	356.4050
8	0.0000	0.0047	358.1068	23	0.0137	0.0181	357.0569
9	0.0207	0.0176	357.1546	24	0.0103	0.0117	357.3891
10	0.0338	0.0251	369.6708	25	0.0075	0.0123	358.0753
11	0.0001	0.0047	358.6284	26	0.0171	0.0025	356.9133
12	0.0276	0.0196	358.5878	27	0.0100	0.0218	359.2383
13	0.0001	0.0047	358.4838	28	0.0100	0.0145	357.1189
14	0.0100	0.0116	354.1526	29	0.0182	0.0138	356.5184
15	0.0100	0.0142	354.6857	30	0.0152	0.0074	358.5214

Table 3: Index Values for Two Dgs, and P=0.1 P. U Type I

Bus No.	MVG	CVD	VSI	Bus No.	MVG	CVD	VSI
1	0	0.0047	358.2140	16	0.01449	0.0145	357.6908
2	0.00001	0.0047	358.2140	17	0.01001	0.0138	357.2759
3	0.0117	0.0139	358.4143	18	0.01819	0.0074	359.1671
4	0.0172	0.0055-	353.6903	19	0.01522	0.0070	358.7071
5	0.0000	0.0047	358.2140	20	0.01911	0.0079	359.8697
6	0.0101	0.0080	368.5760	21	0.019۲۸	0.0180	357.1240
7	0.0065	0.0037	357.7376	22	0.01011	0.0083	356.8222
8	0.00002	0.0047	358.2140	23	0.01909	0.0181	357.7313
9	0.0207۱	0.0176	357.5516	24	0.01371	0.0116	358.8004
10	0.03373	0.0251	370.9224	25	0.01037	0.0121	358.6597
11	0.00000	0.0047	358.2140	26	0.00752	0.0022	358.1316
12	0.0276	0.0196	359.0715	27	0.01691	0.0218	360.6086
13	0.00001	0.0047	358.2140	28	0.0100	0.0066	361.8873
14	0.0100	0.0115	354.7980	29	0.00331	0.0021	358.0765
15	0.0999	0.0141	355.9006	30	0.00542	0.0100	358.4025

To validate the method, two generators with 10% power of the base value for the IEEE 30-bus system were examined.

Table 3 lists the change in index values for all methods in DGs of Type I

All the possible locations of DGs were suggested for the first generator, and random locations were suggested for the second generator, as given in Tables 4 and 5, for two types of DGs.

Table 4: DG2 Location for Type I

Bus No.	The location									
1–10	24	27	4	27	19	3	9	16	28	28
11–20	5	29	28	15	24	5	13	27	23	28
21–30	20	2	25	28	20	22	22	12	20	5

Table 5: DG2 Location for Type II

Bus No.	location									
1–10	21	1	9	2	3	24	21	10	28	1
11–20	13	12	23	24	6	15	13	19	21	22
21–30	9	20	19	5	4	15	28	10	17	7

Table 6 lists the improvement in the proposed method for two DGs of Type I

From Tables 1, 2, 4, and 6 and Figs 3–5, the differences between the minimum and maximum values of each index can be noted. The percentage difference of each case can give the intelligibility of the index, and it can be calculated as

$$intelligibility = \frac{maximum\ index - minimum\ index}{maximum\ index} \quad (15)$$

Table 7 lists all the values of the intelligibility for the indices of Type I DG. This table clearly proves the ability of the proposed method to gauge the system and give suitable guidelines to the workers for power system operation, especially in the case of multi-objective functions.

On the other hand, for two DGs of Type II the values of the intelligibility of VSI, CVD, and MVG are 0.0455, 1.2191, and 1, respectively.

Table 6: Index Values for Two Dgs, Type II, and P=0.1 P. U

Bus No.	MVG	CVD	VSI	Bus No.	MVG	CVD	VSI
1	0.0000	0.0047	358.2140	16	0.0146	0.0145	357.5764
2	0.0001	0.0047	358.2411	17	0.0102	0.0138	357.1245
3	0.0127	0.0139	358.3341	18	0.0184	0.0074	359.0380
4	0.0173	0.0055-	353.7826	19	0.0155	0.0070	358.6319
5	0.0000	0.0047	358.1256	20	0.0197	0.0079	359.7120
6	0.0101	0.0080	368.6701	21	0.0192	0.0180	357.0811
7	0.0067	0.0037	357.6354	22	0.0098	0.0083	356.7388
8	0.0001	0.0047	358.1926	23	0.0193	0.0181	357.5965
9	0.0217	0.0176	357.4722	24	0.0138	0.0116	358.5184
10	0.0339	0.0251	370.6721	25	0.0101	0.0121	358.4564
11	0.0000	0.0047	358.2969	26	0.0072	0.0022	357.8888
12	0.0277	0.0196	358.9748	27	0.0175	0.0218	360.3346
13	0.0000	0.0047	358.2680	28	0.0109	0.0066	362.0094
14	0.0100	0.0115	354.6692	29	0.0040	0.0021	357.8382
15	0.0101	0.0141	355.6580	30	0.0052	0.0100	357.7650

Table 7: Intelligibility of the Indices

1DG-10% power			1DG-50%power			2DG-10%power		
VSI	CVD	MVG	VSI	CVD	MVG	VSI	CVD	MVG
0.0456	1.2209	1	0.0420	1.2206	1	0.0465	1.2210	1

5. Conclusion

This work involved an in-depth analysis and monitoring of the system voltages in multiple cases of adding various numbers of DGs, and proposal of a new index called MVG. This study was conducted based on a review of major convenient voltage indices available, which represent the selection of an appropriate voltage index for DG locations in the IEEE 30-bus system. A multi-objective function that combines a reduction of real power loss, voltage profile, security margin, and capacity, is a very common method in power system gauge and operation. The results prove that the MVG index is suitable for describing a DG's location in a power system because of the range of minimum to maximum values.

Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Data availability

Previously reported (IEEE 14 bus system) data were used to support this study and are available at reference [20].

Funding statement

This research received no external funding.

References

[1] Z. Zhou, Q. Shan, and J. An, "Analysis of Transient Voltage Stability in a Low Voltage Distribution Network Using SST for the Integration of," *J. Electr. Comput. Eng.*, vol. 2018, 2018.

[2] N. Izzri, O. H. Mehdi, A. N. Abdalla, A. S. Jaber, N. A. Shalash, and Y. N. Lafta, "Fast prediction of power transfer stability index based on radial basis function neural network," *Int. J. Phys. Sci.*, vol. 6, no. 35, pp. 7978–7984, 2011.

[3] Y. Zeng and Y. Sun, "Application of hybrid MOPSO algorithm to optimal reactive power dispatch problem considering voltage stability," *J. Electr. Comput. Eng.*, vol. 2014, 2014.

[4] S. M. Ashraf, A. Gupta, D. K. Choudhary, and S. Chakrabarti, "Voltage stability monitoring of power systems using reduced network and artificial neural network," *Int. J. Electr. Power Energy Syst.*, vol. 87, pp. 43–51, 2017. https://doi.org/10.1016/j.ijepes.2016.11.008.

[5] S. J. Chuang, C. M. Hong, and C. H. Chen, "Improvement of integrated transmission line transfer index for power system voltage stability," *Int. J. Electr. Power Energy Syst.*, vol. 78, pp. 830–836, 2016. https://doi.org/10.1016/j.ijepes.2015.11.111.

[6] T. Yosefi, F. Arasteh, M. Bayati, and A. Ghadiri, "Probabilistic power quality indices for an electric grid with wind energy conversion system and STATCOM," in *2017 25th Iranian Conference on Electrical Engineering, ICEE 2017*, 2017, pp. 1395–1399.

[7] M. Chakravorty and D. Das, "Voltage stability analysis of radial distribution networks," *Int. J. Electr. Power Energy Syst.*, vol. 23, no. 2, pp. 129–135, 2001. https://doi.org/10.1016/S0142-0615(00)00040-5.

[8] R. Ranjan and D. Das, "Voltage Stability Analysis of Radial Distribution Networks," *Electr. Power Components Syst.*, vol. 31, no. 5, pp. 501–511, 2003. https://doi.org/10.1080/15325000390127011.

[9] A. Uniyal and A. Kumar, "Optimal Distributed Generation Placement with Multiple Objectives Considering Probabilistic Load," in *Procedia Computer Science*, vol. 125, pp. 382–388, 2018. https://doi.org/10.1016/j.procs.2017.12.050.

[10] R. Ishak, A. Mohamed, A. N. Abdalla, and M. Z. Che Wanik, "Optimal placement and sizing of distributed generators based on a novel MPSI index," *Int. J. Electr. Power Energy Syst.*, vol. 60, pp. 389–398, 2014. https://doi.org/10.1016/j.ijepes.2014.03.044.

[11] S. H. Lee and J. W. Park, "Selection of optimal location and size of multiple distributed generations by using Kalman Filter algorithm," *IEEE Trans. Power Syst.*, vol. 24, no. 3, pp. 1393–1400, 2009. https://doi.org/10.1109/TPWRS.2009.2016540.

[12] A. Kumar and W. Gao, "Optimal distributed generation location using mixed integer non-linear programming in hybrid electricity markets," *Gener. Transm. Distrib. IET*, vol. 4, no. 2, pp. 281–298, 2010. https://doi.org/10.1049/iet-gtd.2009.0026.

[13] V. Ajjarapu and C. Christy, "The continuation power flow: A tool for steady state voltage stability analysis," *IEEE Trans. Power Syst.*, vol. 7, no. 1, pp. 416–423, 1992. https://doi.org/10.1109/59.141737.

[14] C. A. Canizares and F.L. Alvarado, "Point of collapse and continuation methods for large ac/dc systems," *IEEE Trans. Power Syst.*, vol. 8, no. 1, pp. 1–8, 1993. https://doi.org/10.1109/59.221241.

[15] H. D. Chiang, A. J. Flueck, K. S. Shah, and N. Balu, "CPFLOW: A Practical Tool for Tracing Power System Steady-State Stationary Behavior Due to Load and Generation Variations," *IEEE Trans. Power Syst.*, vol. 10, no. 2, pp. 623–634, 1995. https://doi.org/10.1109/59.387897.

[16] G.C. Ejebe, J. Tong, W. F. T. J.G. Waight, and X. Wang, "Available transfer capability calculations," *IEEE Trans.Power Syst.*, vol. 13, no. 4, pp. 1521–1527, 1998. https://doi.org/10.1109/59.736300.

[17] [R. K. Soni, D Agarwal, and P Kumawat, "Optimal Allocation of DG to Radial Distribution Using GA. Overview of Different Approaches," *Int. J. Latest Trends Eng. Technol.*, vol. 5, no. 4, pp. 86–93, 2015.

[18] S. Pérez-Londoño, L. F. Rodríguez, and G. Olivar, "A simplified voltage stability index (SVSI)," *Int. J. Electr. Power Energy Syst.*, vol. 63, pp. 806–813, 2014. https://doi.org/10.1016/j.ijepes.2014.06.044.

[19] AA Ali, AN Abdalla, R Ishat "EFFECT of DG Optimizing on overload Transmission line Stability" MATEC Web of Conferences 225, 03023, 2018. https://doi.org/10.1051/matecconf/201822503023.

[20] Umar, Firdaus, M. Ashari, and O. Penangsang, "Optimal location, size and type of DGs to reduce power losses and voltage deviation considering THD in radial unbalanced distribution systems," in *Proceeding - 2016 International Seminar on Intelligent Technology and Its Application, ISITIA 2016: Recent Trends in Intelligent Computational Technologies for Sustainable Energy*, pp. 577–582, 2017.

[21] S. Kodsi and C. Canizares, "Modeling and simulation of IEEE 14-bus system with FACTS controllers," *Tech. Rep. 2003−3 E&CE, Univ. Waterloo*, vol. 3, 2003.