Reliability enhancement of radial distribution system by placing the reactive power compensators and distribution systems

Manjunatha Babu Pattabhi[1, 2], Krishna Shanmukha Sundar[3], Bengaluru Rangappa Lakshmikantha[4]
[1]BMS Institute of Technology and Management, Bengaluru, India
[2]Department of Electrical Engineering, Visveshwaraiah Technological University, Belagavi, India
[3]Department of Electrical and Electronics Engineering, Dayananda Sagar Academy of Technology and Management, Bengaluru, India
[4]Department of Electrical and Electronics Engineering, Visveshwaraiah Technological University, Belagavi, India

Article Info

Article history:

Received Aug 4, 2022
Revised Oct 6, 2022
Accepted Oct 24, 2022

Keywords:

AENS
CAIDI
Distributed generation
SAIDI
SAIFI

ABSTRACT

Distribution systems (DSs) are highly stressed with addition of newer loads like electric vehicle charging stations and lower scope for expansion due to urbanization. Any line outage could cause interruption to major loads. Reliability studies have gained importance for lowering the frequency and lowering the duration of interruption for supply systems. In this paper a bi-stage method for optimum placement of reactive power compensation devices and distributed generations (DGs) for enhancing voltage stability and system reliability. A new method named delta analysis method is used to optimally locate the reactive power compensation devices and DGs. IEEE-33 radial DS, which is taken as experimental system. Based on the study, the fixing of reactive power compensation devices and DGs are to increase voltage outline of buses and decrease power fatalities. After the placement of DGs, the enhancement in reliability indices following line contingency is studied using MATLAB simulation.

Corresponding Author:

Manjunatha Babu Pattabhi
BMS Institute of Technology and Management
Doddaballapur Main Road, Avalahalli, Yelahanka, Bengaluru, Karnataka 560064, India
Email: manjubabup@gmail.com

1. INTRODUCTION

Research by Thukaram *et al*. [1] forward and backward sweep power flow is used. According to Lohia *et al*. [2] genetic algorithm is intended for optimum setting and sizing of the capacitors for distributed system. The objective function used is cost minimization due to real power losses as well as reactive power compensation in system. Supply systems is normally self-possessed of feeders, different transmission erections, are circled. The best significant moments of expending radiated feeders are that many patrons are affected by the disaster of a particular element. Reliability valuation and optimization are two important modules to performance overall lessons for supply networks [3], [4]. In the past distribution systems (DS) were given lower importance in reliability studies compared to other networks. Currently, huge quantities of developments regarding dependable and reasonable operation of supply systems are being settled in [5]–[7]. Numerous practices constructed on systematic and typical practices have been advanced for the consistency evaluation in supply systems [8], [9].

Nowadays penetration of the distributed generation (DG) with photovoltaic (PV) on DS was maximized drastically [9]–[15]. When DG is installed it can solve numerous commercial and ecological problems, the reliability of the system also improves [13]. If the DG is installed at unsuitable location may prime to surge in power losses, and even the voltage magnitude will be affected [12]. The suitability of supply networks by reliability indices average failure rate λ, average outage period r and yearly outage period

U. The reliability are capacity indices of essential prominence in dependability study. Power system dependability acts a significant role in the DS that is more than eighty percent of customer disturbances occurs due to disasters in the DS [16]. Research by Gupta *et al*. [17] presents a performance on optimal reliability strategy of electrical DSs. DG connection in DS, the constancy and safeguard the distribution network performed a detailed exposition in [18].

Junior *et al*. [19] explained that a new method was proposed to regulate the interval outcomes of a power system load flow for three-phase unbalanced distribution networks depends on three-phase current injection method (TPCIM) on state variables were deemed at rectangular coordinates. At presented method, the active and reactive powers at every busbar were modeled as interval values to account for its inherent uncertainties and Krawczyk operator was used on the power flow equations to deliver reliable interval three-phase outcomes. In addition, the usage of interval extensions and angular rotation system to overcome the overestimation issues related with interval solutions was presented. Chen *et al*. [20] elucidated a three-stage relaxation-weightsum-correction (TSRWC) based probabilistic reactive power optimization system to contract with the uncertainty and correlation of doubly fed induction generator (DFIG) fed wind generators on distribution network. Primarily, the inverse Nataf transformation, an enhanced point estimate system was presented to transform the uncertain wind speeds. Ali *et al*. [21] elucidated a novel system for optimal DS planning with DG systems. The penetration of DG in power systems is a method that has numerous benefits, like peak savings, reduction of losses and improvement of voltage profile. It is also intended to maximize system reliability, stability, and security. The main objective of optimal distributed generation (ODG) was a assurance to attain the aids mentioned above to maximize the general efficiency of the system. In the study, an improved wild horse optimization (IWHO) algorithm was presented as a novel metaheuristic system to solve optimization problems on electric power systems.

Numerous optimization systems have been proposed in the optimum location of the reactive power compensation devices. The proposed method is executed in the IEEE-33 radial distribution feeder. The efficiency of proposed method is established in MATLAB environment.

2. RADIAL STABILITY INDEX

Voltage stability index was proposed [22] depending on the existence of solutions for real as well as reactive power at the getting end. Relative strength index (RSI) in [23] is given in (1). Figure 1 describes the electrical equivalent.

$$RSI(r) = 2V_s^2V_r^2 - V_r^4 - 2V_r^2(PR + QX) - |Z|^2(P^2 + Q^2) \quad (1)$$

RSI(r). voltage constancy index of node r (r=2,3,4 ……)
For steady process of the radial distribution networks, RSI(r) ≥ 0 for r =2,3,4…….
Where,
Vs: implies sending end voltage
Vr: implies the getting end voltage
Z: implies the impedance of the branch
R: implies the resistance
X: implies the reactance
P: implies the real power load
Q: implies the reactive power load

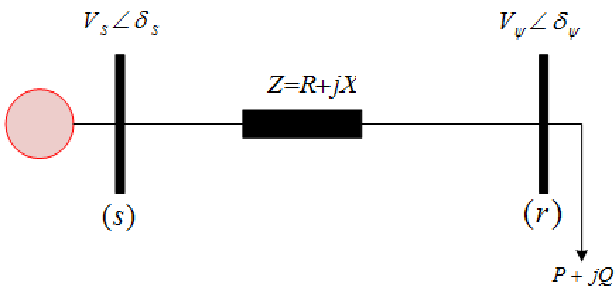

Figure 1. Electrical equivalent

2.1. Reliability indices

The system average interruptions frequency index (SAIFI):

$$SAIFI = \frac{\sum_i \lambda_i * N_i}{N_i} \quad (2)$$

Where λ_i is implies failure rate of i^{th} load and Ni represents the count of customers supplied at load. The system average interruption duration of index (SAIDI),

$$SAIDI = \frac{\sum_i U_i * N_i}{N_i} \quad (3)$$

Where U_i indicates unavailability of load I that is product of failure rate and repair rate of i^{th} load. Customer average interruption duration index (CAIDI) is,

$$CAIDI = \frac{SAIDI}{SAIFI} \quad (4)$$

Average energy not supplied index (AENS) is expressed by,

$$AENS = \frac{Total\ Energy\ not\ Supplied\ by\ the\ system}{Total\ number\ of\ customers\ served} \quad (5)$$

2.2. Derivation of proposed delta analysis system

A linearized power flow is expressed by,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{pmatrix} H & N \\ M & L \end{pmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad (6)$$

$$\Delta P = J_{11}\Delta\theta + J_{12}\Delta V \quad (7)$$

$$\Delta Q = J_{21}\Delta\theta + J_{22}\Delta V \quad (8)$$

Rewriting (6) we get,

$$\Delta\theta = J_{11}^{-1}\Delta P - J_{11}^{-1}J_{12}\Delta V \quad (9)$$

Substituting $\Delta\theta$ from (9) in (8) we get,

$$\Delta Q = J_{21}J_{11}^{-1}\Delta P - J_{21}J_{11}^{-1}J_{12}\Delta V + J_{22}\Delta V (J_{21}J_{11}^{-1}J_{12} - J_{22})\Delta V = J_{21}J_{11}^{-1}\Delta - \Delta Q$$
$$\Delta V = [J_{21}J_{11}^{-1}J_{12} - J_{22}]^{-1}[J_{21}J_{11}^{-1}\Delta P - \Delta Q] \quad (10)$$

Then, $\Delta RSI(r)$ is determined by,

$$\Delta RSI(r) = [4V_r - 4V_r^3 - 4V_r(PR + QX)]\left[[J_{21}J_{11}^{-1}J_{12} - J_{22}]^{-1}[J_{21}J_{11}^{-1}\Delta P - \Delta Q]\right] \quad (11)$$

In (11) gives the relationship between the alteration in RSI index with variation in P and Q. In (11) is utilized to detect the sensitivity of voltage stability indices using the reactive power injection at a specific bus.

2.3. Steps for optimal location of reactive power compensation devices

In order to maintain the voltage profile at each bus within an acceptable range, improve voltage stability, reduce power losses in lines, increase system reliability and security, network optimal usage is crucial with the modernization of power grids. These can be accomplished by integrating reactive power compensation devices into distribution or transmission networks. The steps for optimal location of reactive power compensation devices is described as follows,

- Run the power flow to obtain sending end and receiving end voltages.
- Calculate the radial stability index given in (1).
- From (11) obtain the matrix which gives the relationship between $\Delta RSI(r)$ and ΔQ (i.e.$\Delta P = 0$).
- Consider a limit to the radial stability index. The buses which have lower index value then the limit is considered as most prone to instability.
- Obtain the reduced sensitivity matrix by keeping only buses, which is more prone to the voltage instability.

– Route LP optimization technique using MATLAB to get location and size of reactive power compensation device.

2.4. Algorithm for optimal location of distributed energy resources

Small generating plants known as DG are connected to consumers through DSs to enhance voltage proficiency, voltage profile, stability, decrease of power losses, and economic benefits. The foregoing advantages are attained by optimally placing DGs. The steps for optimal location of distributed energy resources (DERs) is described as follows,

– Run the power flow to obtain sending end and receiving end voltages.
– Calculate the radial stability index given in (1).
– From (11) obtain the matrix which gives the relationship between $\Delta RSI(r)$ and ΔP (i.e. $\Delta Q = 0$).
– Consider a limit to the radial stability index. The buses which have lower index value then the limit is considered as most prone to instability.
– Obtain the reduced sensitivity matrix by keeping only buses, which is more prone to voltage instability.
– Route LP optimization technique using MATLAB to get the DERs location and size.

3. RESULTS AND DISCUSSION

3.1. Test case 1: optimal location of reactive power compensation devices

The method derived in section 1.1 is executed on IEEE-33 bus system. Table 1 displays voltages profile of IEEE 33 bus. The bus voltages before reactive power compensation are ranked and according to the ranking, the bus which is ranked -1 is said to be under voltage collapse and the other buses are ranked accordingly. Reactive power compensation devices are injected for voltage stability and we can see the voltage is improved.

Table 1. Comparison of voltage profiles before and after placement of reactive power compensator (RPC)

Bus No.	Voltages before RPC	Ranking	Voltages after RPC
1	1	33	1
2	0.995972408	32	0.997263756
3	0.976792583	27	0.985102731
4	0.966543652	25	0.980166008
5	0.956398113	22	0.975670554
6	0.931134752	21	0.97275448
7	0.926300556	19	0.980862179
8	0.907576634	16	0.986661427
9	0.898875669	15	0.993279639
10	0.890800666	12	1.001054439
11	0.889606272	11	1.001262548
12	0.887522748	10	1.001622252
13	0.879019895	6	1.013062311
14	0.875850947	5	1.020361776
15	0.873884726	4	1.024511889
16	0.871979941	3	1.027425034
17	0.869155953	2	1.034629845
18	0.868310362	1	1.035521801
19	0.995270827	31	0.996563093
20	0.990518897	30	0.991817401
21	0.989583078	29	0.990882811
22	0.988736298	28	0.990037145
23	0.971993533	26	0.980345454
24	0.963062486	24	0.971492315
25	0.958608723	23	0.967077563
26	0.928496683	20	0.971488216
27	0.924989344	18	0.969895293
28	0.909338255	17	0.966288128
29	0.898092062	14	0.964126355
30	0.893222104	13	0.962666983
31	0.887519848	9	0.96600412
32	0.886265327	8	0.96701465
33	0.885876585	7	0.968242216

The system comprises of 33 nodules, 32 sections, and 5 tie switches. The immoral arrangement takes exposed lines 33 to 37. Minimal active and reactive load of system is 3.715 MW, 2.300 MVAr [24]. Figure 2 shows the bus voltages before and after RPC. The optimal location and size of reactive power compensation devices is provided to the Table 2. Power loss before and after placement of RPC is given on Table 3.

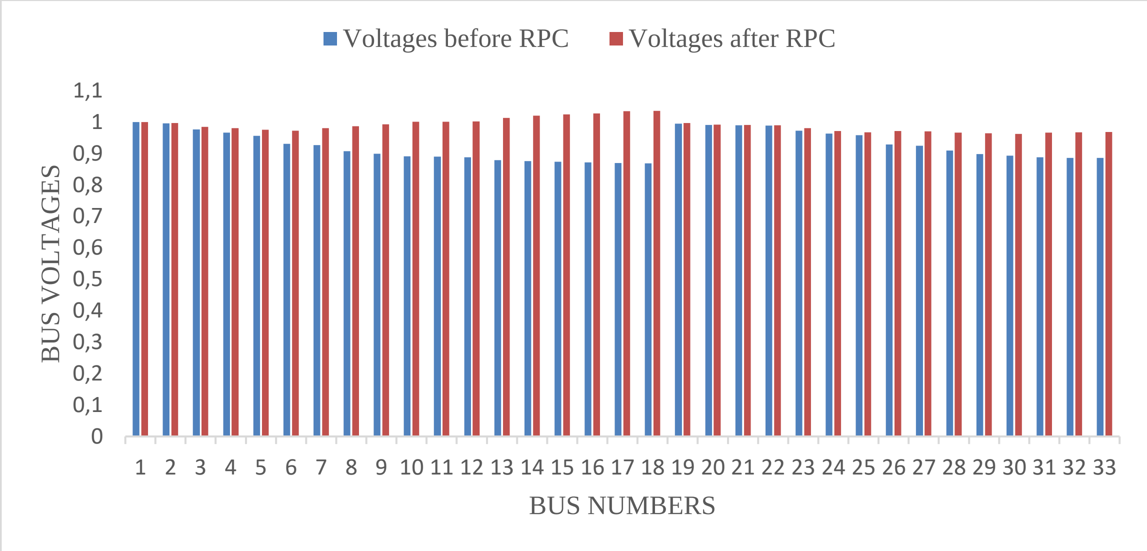

Figure 2. Bus voltages before and after RPC

Table 2. Location and size of the reactive SVC

Sl. No.	Bus No.	Size of the reactive power device in KVAr
1.	9	0
2.	10	0
3.	11	243.8
4.	12	350
5.	13	350
6.	14	350
7.	15	350
8.	16	350
9.	17	350
10.	18	350
11.	29	0
12.	30	350
13.	31	350
14.	32	350
15.	33	350

Table 3. Comparison of losses before and after SVC

	Active power loss	Reactive power loss
Before RPC	295.92	231.68
After RPC	200.84	163.36

From Table 3, it can be observed that out of 15 no buses which are below the index limit assumed only the placement of RPC at 10 buses only. From Table 4, it is perceived that the real power loss decreases by 69% and reactive power loss by 70.5%. According to Lohia *et al*. [2], after placement of capacitors active power loss decreases by 66.51%, reactive power loss decreases by 60.81%. Even though the losses due to delta analysis are little towards higher side, proposed number of reactive power devices are less than the method proposed in reference [2]. So, the expenditure incurred on installing the devices will come down. Delta analysis method is a very easy to implement as it uses conventional radial power flow and linear programming technique only. It may be viewed as Figure 3 that there is a substantial improvement in the bus voltages after reactive power compensation.

Table 4. Comparison of voltages profile before and after placement of DERs

Bus No.	Voltages before placement of DERs	Voltages after placement of DERs	Bus No.	Voltages before placement of DERs	Voltages after placement of DERs
1	1	1	18	0.86831036	0.9591487
2	0.995972408	0.997293509	19	0.99527083	0.9965929
3	0.976792583	0.985186788	20	0.9905189	0.9918473
4	0.966543652	0.980167951	21	0.98958308	0.9909128
5	0.956398113	0.975474003	22	0.9887363	0.9900671
6	0.931134752	0.962207633	23	0.97199353	0.9804299
7	0.926300556	0.958882046	24	0.96306249	0.9715776
8	0.907576634	0.952291977	25	0.95860872	0.9671632
9	0.898875669	0.950780069	26	0.92849668	0.9610455
10	0.890800666	0.950960136	27	0.92498934	0.9596009
11	0.889606272	0.950112144	28	0.90933826	0.951816
12	0.887522748	0.950581342	29	0.89809206	0.95065576
13	0.879019895	0.952128798	30	0.8932221	0.95053653
14	0.875850947	0.952675298	31	0.88751985	0.95051215
15	0.873884726	0.954653347	32	0.88626533	0.95050306
16	0.871979941	0.956777269	33	0.88587658	0.95052623
17	0.869155953	0.958653112			

3.2. Test case 2: optimal location of distributed energy resources

The method derived in section 1.1 is tested on IEEE-33 bus system. Table 4 indicates the bus voltages before and after placement of DERs. Optimal position and size of the DERs is given in Table 5. Power loss previous and next placement of reactive power compensation devices is given in Table 6. It can be observed from Table 6 that even though 15 no of buses exceed the limit, optimal location of DERs is only 8 numbers. Active power loss and reactive power losses decreases by 43.50%, 43.2% which are lower compared to losses mentioned in reference [2]. It concludes that the optimal location of DERs would reduce the system losses and improve the bus voltages.

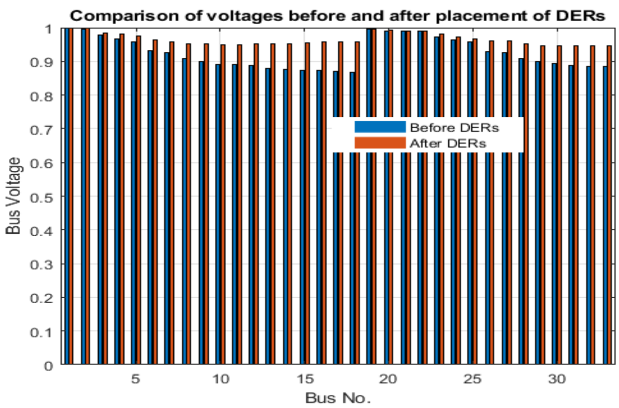

Figure 3. Bus voltages before and after placement DERs

Table 5. Location and size of the DERs

Sl. No.	Bus No.	Size of the reactive power device in KW
1.	9	0
2.	10	0
3.	11	0
4.	12	0
5.	13	0
6.	14	0
7.	15	141
8.	16	200
9.	17	200
10.	18	200
11.	29	0
12.	30	167
13.	31	200
14.	32	200
15.	33	200

Table 6. Comparison of losses before and after DER

	Active power loss	Reactive power loss
Before DER	295.92	200.84
After DER	128.73	86.843

4. RELIABILITY ASSESSMENT

Once after finding the optimum position and dimension of DG utilizing delta analysis method, the reliability system with DG is simulated by using MATLAB site. To study efficiency of proposed system, a line contingency is created by removing lines between buses 8 to 9 and between buses 28 to 29. Following the above said line contingencies the buses from 9 to 18 and buses 29 to 33 will be fed by the DG sets already installed. Reliability indices given in the section 1 are calculated before contingency and after contingency.

From the Table 7 it can be observed that the indices values have decreased which indicates that the reliability of system is improved. Average root mean square (ARMS) and relative errors of output calculation shown on Table 8. Efficiency comparison is provided on Figure 4.

Table 7. Comparison of voltages profile before and after placement of RPC

Index	Before DG	After DG
SAIFI	0.384242424	0.281818182
SAIDI	0.29530303	0.212727273
CAIDI	0.768533123	0.75483871
AENS	31065.15152	23793.93939

Table 8. ARMS and relative errors of output calculation

Error terms (%)	Parameters	Average		Maximum	
		[25]	Proposed	[25]	Proposed
+	Mean calculation	0.08	0.071	0.013	0.07
	SD calculation	1.06	1.01	1.39	1.111
ARMS error	Cumulative distribution function (CDF) estimation	0.085	0.075	0.124	0.108

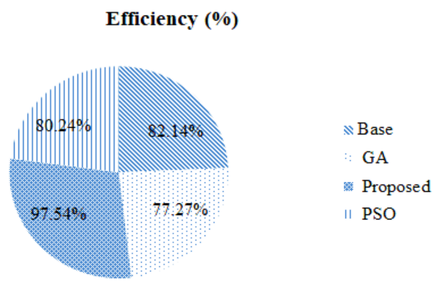

Figure 4. Efficiency comparison

5. CONCLUSION

In this paper, the presentation of delta analysis method is utilized for enhancing voltage stability and moderate power losses in system by using optimization technique, the location and size of reactive power compensation devices and DG units are used for improving voltage stability. Also, the study is mainly concerned with assessment of reliability under contingency condition by placement of DGs. Thus, the objectives of this paper are realized. It is detected from the delta analysis method is prevailing and easy tool to optimally locate both reactive power compensation devices and DGs.

REFERENCES

[1] D. Thukaram, H. M. W. Banda, and J. Jerome, “A robust three phase power flow algorithm for radial distribution systems,” *Electric Power Systems Research*, vol. 50, no. 3, pp. 227–236, Jun. 1999, doi: 10.1016/S0378-7796(98)00150-3.

[2] S. Lohia, O. P. Mahela, and S. R. Ola, “Optimal capacitor placement in distribution system using genetic algorithm,” in *2016 IEEE 7th Power India International Conference (PIICON)*, Nov. 2016, pp. 1–6, doi: 10.1109/POWERI.2016.8077355.

[3] B. Singh and G. Agrawal, "Enhancement of voltage profile by incorporation of SVC in power system networks by using optimal load flow method in MATLAB/Simulink environments", *Energy Reports*, vol. 4, pp. 418-434, 2018, doi: 10.1016/j.egyr.2018.07.004.

[4] P. D. Reddy, V. C. Reddy, and T. G. Manohar, “Whale optimization algorithm for optimal sizing of renewable resources for loss reduction in Distribution Systems,” *Renewables: Wind, Water, and Solar*, vol. 4, no. 1, 2017, doi: 10.1186/s40807-017-0040-1.

[5] D. Elmakias, *New computational methods in power system reliability*. Berlin: Springer Science & Business Media, 2008, doi: 10.1007/978-3-540-77812-7.

[6] R. Allan and R. Billinton, “Probabilistic assessment of power systems,” *Proceedings of the IEEE*, vol. 88, no. 2, pp. 140–162, Feb. 2000, doi: 10.1109/5.823995.

[7] P. M. Costa and M. A. Matos, “Assessing the contribution of microgrids to the reliability of distribution networks,” *Electric Power Systems Research*, vol. 79, no. 2, pp. 382–389, Feb. 2009, doi: 10.1016/j.epsr.2008.07.009.

[8] A. Volkanovski, M. Čepin, and B. Mavko, “Application of the fault tree analysis for assessment of power system reliability,” *Reliability Engineering & System Safety*, vol. 94, no. 6, pp. 1116–1127, Jun. 2009, doi: 10.1016/j.ress.2009.01.004.

[9] L. Goel, R. Gupta, “Reliability impacts of subtransmission and radial configurations on the distribution system,” *Electric Machines & Power Systems*, vol. 27, no. 7, pp. 721–736, Jun. 1999, doi: 10.1080/073135699268975.

[10] Y. Lamalem, S. Hamida, Y. Tazouti, O. El Gannour, K. Housni, and B. Cherradi, “Evaluating multi-state systems reliability with a new improved method,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 3, pp. 1568–1576, Jun. 2022, doi: 10.11591/eei.v11i3.3509.

[11] S. Impram, S. V. Nese, and B. Oral, “Challenges of renewable energy penetration on power system flexibility: a survey,” *Energy Strategy Reviews*, vol. 31, pp. 1–12, Sep. 2020, doi: 10.1016/j.esr.2020.100539.

[12] P. Karimyan, G. B. Gharehpetian, M. Abedi, and A. Gavili, “Long term scheduling for optimal allocation and sizing of DG unit considering load variations and DG type,” *Int. J. of Electrical Power & Energy Sys.*, vol. 54, pp. 277–287, Jan. 2014, doi: 10.1016/j.ijepes.2013.07.016.

[13] U. Sultana, A. B. Khairuddin, M. M. Aman, A. S. Mokhtar, and N. Zareen, “A review of optimum DG placement based on minimization of power losses and voltage stability enhancement of distribution system,” *Renewable and Sustainable Energy Reviews*, vol. 63, pp. 363–378, Sep. 2016, doi: 10.1016/j.rser.2016.05.056.

[14] Y. Kifle, B. Khan, and P. Singh, “Assessment and enhancement of distribution system reliability by renewable energy sources and

energy storage," *Journal of Green Engineering*, vol. 8, no. 3, pp. 219–262, 2018, doi: 10.13052/jge1904-4720.832.
[15] S.-A. Yin and C.-N. Lu, "Distribution feeder scheduling considering variable load profile and outage costs," *IEEE Transactions on Power Systems*, vol. 24, no. 2, pp. 652–660, May 2009, doi: 10.1109/TPWRS.2009.2016300.
[16] A. A. Chowdhury and D. O. Koval, *Power distribution system reliability: practical methods and applications*. Hoboken: John Wiley & Sons, Inc., 2009, doi: 10.1002/9780470459355.
[17] N. Gupta, A. Swarnkar, and K. R. Niazi, "Distribution network reconfiguration for power quality and reliability improvement using Genetic Algorithms," *International Journal of Electrical Power & Energy Systems*, vol. 54, pp. 664–671, Jan. 2014, doi: 10.1016/j.ijepes.2013.08.016.
[18] Y. Juan, S. Ming, and D. Bo, "Research about impact of DGs in distribution networks," in *2008 China International Conference on Electricity Distribution*, Dec. 2008, pp. 1–6, doi: 10.1109/CICED.2008.5211807.
[19] H. M. R. Junior, I. D. Melo, and E. G. Nepomuceno, "An interval power flow for unbalanced distribution systems based on the Three-Phase Current Injection Method," *International Journal of Electrical Power & Energy Systems*, vol. 139, p. 107921, Jul. 2022, doi: 10.1016/j.ijepes.2021.107921.
[20] S. Chen, W. Hu, Y. Du, S. Wang, C. Zhang, and Z. Chen, "Three-stage relaxation-weightsum-correction based probabilistic reactive power optimization in the distribution network with multiple wind generators," *International Journal of Electrical Power & Energy Systems*, vol. 141, p. 108146, Oct. 2022, doi: 10.1016/j.ijepes.2022.108146.
[21] M. H. Ali, S. Kamel, M. H. Hassan, M. Tostado-Véliz, and H. M. Zawbaa, "An improved wild horse optimization algorithm for reliability based optimal DG planning of radial distribution networks," *Energy Reports*, vol. 8, pp. 582–604, Nov. 2022, doi: 10.1016/j.egyr.2021.12.023.
[22] M. B. P, B. R. Lakshmikantha, and K. S. Sundar, "A novel method for assessment of voltage stability improvement of radial distribution system using SVC at optimal location," in *2018 International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT)*, Dec. 2018, pp. 602–606, doi: 10.1109/ICEECCOT43722.2018.9001380.
[23] U. Eminoglu and M. H. Hocaoglu, "A voltage stability index for radial distribution networks," in *2007 42nd International Universities Power Engineering Conference*, Sep. 2007, pp. 408–413, doi: 10.1109/UPEC.2007.4468982.
[24] M. E. Baran and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Power Engineering Review*, vol. 9, no. 4, pp. 101–102, 1989, doi: 10.1109/MPER.1989.4310642.
[25] M. T. Kenari, M. S. Sepasian, and M. S. Nazar, "Probabilistic assessment of static voltage stability in distribution systems considering wind generation using catastrophe theory," *IET Generation, Transmission & Distribution*, vol. 13, no. 13, pp. 2856–2865, Jul. 2019, doi: 10.1049/iet-gtd.2018.5497.

BIOGRAPHIES OF AUTHORS

Manjunatha Babu Pattabhi received B.E degree in Electrical and Electronics Engineering from Golden Valley Institute of Technology, Kolar Gold Fields in 2004. M.E Degree in Power and Energy System from University Visveshwaraiah College of Engineering in 2010. He is currently working as Assistant Professor in BMS institute of Technology and Management, Bengaluru also he is currently working toward the Ph.D. degree at the Department of Electrical Engineering, Visveshwaraiah Technological University, Belagavi, India. His research interests include voltage stability and reliability in power system and FACTs. He can be contacted at email: manjubabup@gmail.com.

Krishna Shanmukha Sundar has obtained Ph.D in Electrical and Electronics Engineering Sciences during the year 2010 from Visvesvaraya Technological University, Belgaum, Karnataka, India. He is presently working as Professor, Department of Electrical and Electronics Engineering, DayanandaSagar Academy of Technology and Management, Bangalore. Technical papers were published in various international, National Journals and Conferences. His area of research includes FACTS controllers, power system operations & controls, voltage stability, renewable energy sources, control systems and optimization of power systems, power electronics and drives. He can be contacted at email: bonniekhs@gmail.com.

Bengaluru Rangappa Lakshmikantha received B.E degree in Electrical and Electronics Engineering from M S Ramaiah, in 1979. M.E Degree in Power and Energy System from University Visveshwaraiah College of Engineering in 1981. He completed his Ph.D. degree at the Department of Electrical Engineering, Visveshwaraiah Technological University, Belagavi, India in 2009. Served as a principal and Director at DayanandaSagar Academy of Technology and Management more than a decade. Technical papers were published in various international, National Journals and Conferences. His research interest is in power systems and FACTs. He can be contacted at email: brlakshmikantha@gmail.com.