Application of Flower Pollination Algorithm for DG Units Allocation in an Indian Practical Distribution System

Sabarinath.G, T.Gowri Manohar

Abstract*: Indian practical rural distribution systems are very long and spread over a wide range of area. The nodes far away from the distribution substation are suffering from low voltage. In India, total distribution system losses are around 20% to 25%. From the past few years, penetration of distributed generation (DG) in to the distribution network/system is increasing expeditiously. DG allocation with appropriate location and size can provide numerous benefits to the distribution companies as well as to the society. In this regard, a new technique called combined sensitivity index (CSI), to find the optimal DG unit location, based on voltage sensitivity and network load magnitude is proposed. To assess the effectiveness of the proposed technique, it is tested on Indian practical 52-bus rural distribution system. Here, the optimal DG unit size is calculated using Flower Pollination Algorithm (FPA). The results show that the proposed CSI technique performs better in minimizing power losses and voltage profile augmentation when compared to existing technique in the literature.

Index Terms*: Combined sensitivity index, Distributed generation, Distribution system, Flower pollination algorithm, Power loss.

I. INTRODUCTION

Electrical energy distribution systems/networks are generally operated in radial configuration. Due to high resistance (R) / reactance (X) ratio [1], distribution networks cause a poor voltage regulation and considerable amount of power losses. And also as compared to transmission system, the distribution system (DS) is more complex in structure and is having more power loss due to low voltage and high current operating conditions. Major part of the load on DS is inductive in nature [2] and causes more power loss and poor voltage regulation. In the previous literature it is recorded that around 13% [3] of the total power production is lost in the DS as line losses. According to Indian records, distribution losses are around 21% [4]. From the past several years, power systems are transforming from centralized power generating state with power plants connected to the transmission system to the decentralized power generating state [5], with small power generating units directly connected to distribution systems. Minimization of such a high power loss and voltage regulation plays a vital role in distribution system planning, design and expansion [6]. Hence, it is essential to look towards the techniques that minimize the above drawbacks. Distributed / dispersed / decentralized generation [7] placement [1, 2, 4], network feeder re-configuration [3, 8-11], capacitor placement [12, 13] and load balancing [14] are the major techniques used for the power loss minimization and enhancement of system voltage. From the past couple of years, renewable energy based DG placement is being extensively used as it provides many technical, financial and ecological benefits [2].

DG technologies are broadly classified [15] into:

- ✓ Renewable energy based DGs comprise of small hydro, solar photovoltaic, wind, biomass, geothermal and so on.
- ✓ Fossil fuel/non-renewable energy based DGs comprise internal combustion engine, diesel engine, fuel cells and so on.

Another way of classifying DG technologies [16]:

- ➢ **Type-1 DG:** It can produce active power but not reactive power. (Solar PV)
- ➢ **Type-2 DG:** It can produce active as well as reactive power (Ex: Synchronous generator).
- ➢ **Type-3 DG:** It can produce active power and extracts reactive power (Ex: Induction generator).
- ➢ **Type-4 DG:** It can produce only reactive power (Ex: Capacitor).

The placement of DG has a significant effect on distribution network performance. Unsuitable position of DG may cause increased capital investment, decreased performance of system. On the other hand the appropriate placement helps in minimization of network loss and improvement of system voltage profile. There are numerous analytical and optimization approaches utilized in the literature. Majority of analytical and optimization approaches are employed to find the optimal location and size of DG respectively. Various scientists and researchers have been introduced several meta-heuristic based optimization algorithms for solving optimal DG allocation problem. In [17] authors were employed three meta-heuristic algorithms including imperialist competitive algorithm (ICA) , genetic algorithm (GA) and particle swarm optimization algorithm, to solve optimal DG allocation problem. In [17] authors reported that PSO performed better than ICA and GA. PSO is used [18] to solve multi-objective problem including maximization of network loss, minimization of initial investment on DG, voltage stability improvement and greenhouse emissions minimization considering time

Revised Manuscript Received on June 20, 2019
Sabarinath.G, Dept. of EEE, S.V.UniversityTirupathi,India.
Dr.T.Gowri Manohar,, Dept. EEE, S.V.University, tirupathi,India.

varying load. Multi objective chaotic symbiotic organisms search algorithm [19], whale optimization algorithm [20], flower pollination algorithm [21], improved multi-objective harmony search algorithm [22], grey wolf optimization algorithm [23] were employed.

II. PROBLEM FORMULATION & CONSTRAINTS

A. Problem Formulation

The main motive of this problem is to diminish the network power loss. The sum of total network loss is considered as fitness function and is calculated as

$$P_{total\,loss} = \min \sum_{m=1}^{nb} P_{loss}(m, m+1) \quad (1)$$

Where nb=total no. of nodes and
$P_{loss}(m,m+1)$ =Real loss between m^{th}, $(m+1)^{th}$ nodes

B. Power Flow Constraints

The Real power eq. (2) and reactive power eq. (3) flow in each branch and end bus voltage eq. (4) are determined as follows [24]:

$$P_{m+1} = P_m + P_{DG} - P_{L,m+1} - R_{m,m+1} \times \frac{(P_m^2 + Q_m^2)}{|V_m|^2} \quad (2)$$

$$Q_{m+1} = Q_m + Q_{DG} - Q_{L,m+1} - X_{m,m+1} \times \frac{(P_m^2 + Q_m^2)}{|V_m|^2} \quad (3)$$

$$|V_{m+1}|^2 = |V_m|^2 - 2(R_{m,m+1} \times P_m + X_{m,m+1} \times Q_m) + (R_{m,m+1}^2 + X_{m,m+1}^2) \times \frac{(P_m^2 + Q_m^2)}{|V_m|^2} \quad (4)$$

C. Voltage Limits

The magnitude of voltages of all buses should lie within the pre-specified range and is represented as

$$V_j^{\min} \le V_j \le V_j^{\max} \quad (5)$$

Where $V_j^{\min} = 0.9$ p.u and $V_j^{\max} = 1.05$ p.u

III. OPTIMAL POWER FACTOR

A fast approach [25] is considered to select the optimal power factor (P.F). Consider a simple two bus radial DS in Fig.1. The conceivable least power loss can be accomplished when the P.F of DG (PF_{DG}) is selected to be equal to that of total system connected load power factor (PF_{load}). That can be represented by

$$PF_{DG} = PF_{load} \quad (6)$$

The connected load P.F of the system (PF_{load}) is given by

$$PF_{load} = \frac{P_L}{\sqrt{P_L^2 + Q_L^2}} \quad (7)$$

$$PF_{DG} = \frac{P_{DG}}{\sqrt{P_{DG}^2 + Q_{DG}^2}} \quad (8)$$

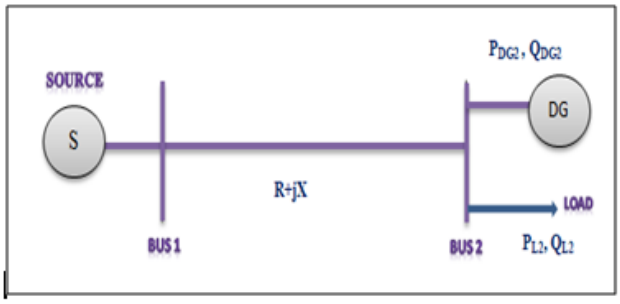

Fig.1.Simple two bus system

Where,

P_L and P_{DG} are active power of load and DG.

Q_L and Q_{DG} are reactive power of load and DG.

IV. COMBINED SENSITIVITY INDEX

Proposed CSI [26] is employed to locate the most suitable nodes/buses to incorporate the DG units on an Indian practical 52-bus RDN. It mainly depends on

- Voltage sensitivity
- Apparent power of a connected load

CSI (S_b) is mathematically modeled as follows

$$S_b = \sum_{k=2}^{nb} V_{k,b} * KVA_k + \Delta V_b^{\max} \quad (9)$$

for b=2,3,4,……nb

Note: Node '1' is not considered because it is sub-station node or reference node and *nb*= maximum number of nodes or buses.

The maximum change in voltage magnitude ($\Delta V_b^{\max}$) after the placement of DG unit is given as follows:

$$\Delta V_b^{\max} = \max |V_{k,b}^{act} - V_{k,b}^{base}| \quad (10)$$

Here, variables V_{kb}^{act} and V_{kb}^{base} are voltages at node '*b*' after and before placement of DG at node *'k'*, respectively

The KVA magnitude of connected load at bus '*k*' is calculated as follows:

$$KVA_k = \sqrt{(PL_k)^2 + (QL_k)^2} \quad (11)$$

Here, PL_k and QL_k are active power magnitude and reactive power magnitude of connected load at node '*k*'. Ranking of buses in each feeder is obtained using eq. (9). The value of Sb is calculated at each bus (except reference bus) by injecting active power of 10%, 20% and 30% of total active power. Bus with highest Sb value should be selected as candidate bus to place DG unit.

V. FLOWER POLLINATION ALGORITHM

Flower pollination algorithm (FPA) [27] inspired by the natural biological phenomenon of flowering plants was developed and introduced in by Yang. Flower pollination (FP) is the process moving pollen to female flower from male flower through biotic or abiotic pollination. Almost around 90% of the pollination process is caused by animals

and insects and the left over 10% is due to natural causes. In cross pollination pollen moves from one flower to another flower where as in self-pollination pollen moves in the same flower itself. Biotic and cross pollination process generally takes place between flowers which are furthest from each other and hence they are considered as global optimization. Abiotic and self-pollination takes place in the same flower hence they are considered as local optimization.

The characteristics of FPA

1. Biotic and cross pollination are thought of global pollination because pollen follows Levy flight movement.
2. Abiotic and self-pollination are thought of local pollination.
3. Flower constancy can be developed by pollinators which is considered as production probability.
4. The interaction between local and global pollination process is managed by a switch probability p$\in$ [0, 1].

First rule can be represented as

$$X_i^{t+1} = X_i^t + L(X_i^t - g_*) \quad (12)$$

Where X_i^t is the ith pollen, t is the iteration number g_* current best solution obtained and L is strength of pollination Because insects may travel over a long distance with different distance steps we can use a levy flight.

$$L = \frac{\lambda\Gamma \sin(\frac{\prod \lambda}{2})}{\prod} \frac{1}{S^{1+\lambda}} \quad (13)$$

Here $\lambda\Gamma$ is standard gamma function. This is valid for large steps S>0. In this λ =1.5.

Rule 2, 3 and local pollination can be represented as

$$X_i^{t+1} = X_i^t + \varepsilon(X_j^t - X_k^t) \quad (14)$$

Here X_i^t and X_k^t are pollen from separate flowers of the same plant species. X_i^t and X_k^t comes from same species for local random walk, then ε drawn from uniform distribution as [0,1]. In principle, FP activities can take place at all scales, both global and local. However neighbour flower patches are pollinated by local flower pollen.

VI. EXPERIMENTAL RESULTS

The Indian practical radial distribution system portrayed in [28] is considered for evaluation of proposed technique. The line and load information [29] about this considered test system is presented in appendix. This test system consists of 3 main feeders, 52 buses and 51 branches feeding a total network load of (4184+j2025) KVA. The power factor of connected load of this test system is 0.9 lagging. The base KV and KVA for this considered test system are considered as 11 and 1000, respectively. The maximum and minimum bus voltage magnitude limits for the given test system are 1.05per unit and 0.9 per unit., respectively. For Indian 52-bus practical distribution system without integration of DG unit, total active and reactive losses are (887.19+j381.69) KVA. Total active and reactive power injection from the substation is (5071.19+j2406.69) KVA. The vital objective of this work is minimization of network loss and total load voltage deviation. The maximum number of DG units installed for this system is considered to be equal to 3.

Table 1. Specifications of Indian practical 52-bus RDN

Base KVA	Base KV	Connected load		Power loss	
		KW	KVAr	KW	KVAr
1000	11	4184	2025	887.19	381.69

In simulation the following four case studies are analyzed.

- ✓ Case-1: Three DGs injecting active power only i.e. operating at Unity power factor.
- ✓ Case-2: Three DGs injecting both active and reactive power and operating at 0.9 power factor (optimal power factor).
- ✓ Case-3: Three DGs injecting active power and consuming reactive power at 0.9 power factor (optimal power factor).
- ✓ Case-4: Three DG units injecting reactive power only.

The locations of DGs are first finalized using the proposed CSI. The CSI values are graphically presented in Fig.3 for DG 10%, 20% and 30% of total active power injection at load buses. The top 3 ranked buses i.e 19, 44 and 50 are selected to incorporate DG units.

Case-1: In case-1, three type-1 DGs delivering active power at unity P.F are installed at nodes 19, 44 and 50. The optimized numerical results attained in this case are provided in Table 2. After placing three DG units of capacities 696.75 KVA (at bus 19), 536.91KVA (at bus 44) and 695.34 KVA (at bus 50), active power losses (ΣKW loss) are reduced from 887.19 KW to 261.88 KW and reactive power losses (ΣKVAr loss) from 381.69KVAr to 112.67 KVAr. Fig. 3 shows the voltage profile of test system. From Fig. 3, it is very clear that there is a considerable improvement in voltage profile from base case to case-1. In this case the minimum voltage level (|Vmin|) is improved from 0.6844p.u to 0.91094 p.u and total load voltage deviation (Σ|Vdevi|) is reduced from 8.5796 to 2.8143.

Case-2: In case-2, three type-2 DG units injecting both active and reactive powers at 0.9 P.F are installed at nodes 19, 44 and 50. The optimal numerical results obtained with this case are recorded in Table 2. By installing three DG units with its optimal capacities of 781.90 KVA (at bus 19), 585.89 KVA (at bus 44) and 763.15 KVA (at bus 50), the active losses are minimized to 165.56 KW and reactive losses to 112.67 KVAr. The voltage profile of this case is portrayed in Fig.3. From Fig.3 it is clear that the voltage profile is significantly improved when compared to case-1. In this case, |Vmin| is improved from 0.6844p.u to 0.93452 p.u and Σ|Vdevi| is reduced from 8.5796 to 1.7833. From Fig.3, it is also noticed that all nodes of test system are within the acceptable voltage limit i.e. in between 0.9p.u and 1.05p.u.

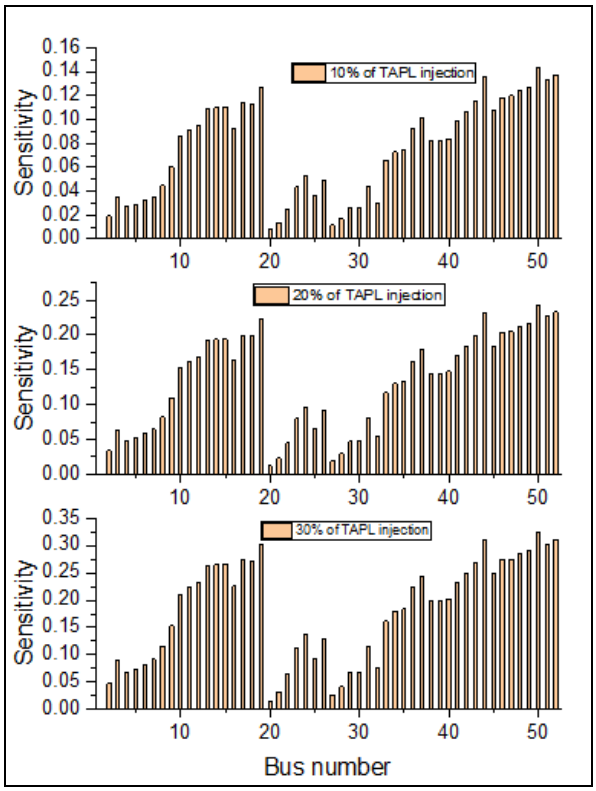

Fig.2. Combined sensitivity index of test system

Table 2. Optimization results

Particulars	Base case	Case-1	Case-2	Case-3	Case-4
ΣKW loss	887.194	261.88	165.56	530.96	702.85
ΣKVAr loss	381.69	112.67	71.23	228..43	302.39
DG location and size (KVA)	-----	696.75	781.90	461.06	304.09
		536.91	585.89	388.22	264.70
		695.34	763.15	481.01	322.03
|Vmin| (p.u)	0.6844	0.9109 4	0.9345 2	0.8258	0.7482 3
Σ|Vdevi|	8.5796	2.8143	1.7833	5.619	7.2823

Case-3: Three type-3 DG units injecting active power and consuming reactive powers at 0.9 P.F (optimal P.F) are installed at nodes 19, 44 and 50 of Indian practical 52-bus rural distribution system. The obtained optimal numerical results are inserted in Table 2. The optimal size of DG units at nodes 19, 44 and 50 are found to be 461.06 KVA (at bus 19), 388.22KVA (at bus 44) and 481.01KVA (at bus 50), respectively. Case-3 yields reduced active and reactive power loss of 530.96KW and 228.43KVAr, respectively. The value of |Vmin| is improved from 0.6844p.u to 0.8258p.u. Total load voltage deviation is reduced to 8.5796 to 5.619

Case-4: Three type-4 DG units injecting only reactive powers at are installed at nodes 19, 44 and 50 of Indian practical 52-bus rural distribution system. The obtained optimal numerical results are inserted in Table 2. The optimal size of DG units at nodes 19, 24 and 50 are found to be 304.09 KVA (19), 264.70 KVA (44) and 322.03KVA (50), respectively. Case-4 yields reduced active and reactive power loss of 702.85KW and 302.39KVAr, respectively. The value of |Vmin| is improved from 0.6844p.u to 0.74823p.u. Total load voltage deviation is reduced to 8.5796 to 7.2823.

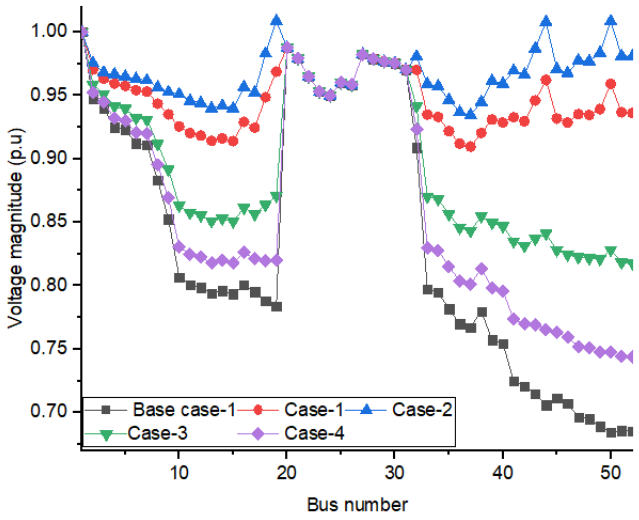

Fig.3. Voltage profile of test system

VII. CONCLUSIONS

In this work, an optimal DG allocation problem on Indian practical 52-bus radial distribution system was solved. Here, CSI is used to determine the DG locations. A new algorithm called flower pollination algorithm was used to calculate the optimal DG size. From the results it is observed/concluded that, the least values of power loss and total voltage deviation are achieved with minimum DG size in scenario-2. The results achieved with case-2.

REFERENCES

1. D. B. Prakash and C. Lakshminarayana, "Multiple DG placements in radial distribution system for multi objectives using Whale Optimization Algorithm," *Alexandria Eng. J.*, vol. 57, no. 4, pp. 2797–2806, 2018.
2. R. Viral and D. K. Khatod, "Optimal planning of distributed generation systems in distribution system: A review," *Renew. Sustain. Energy Rev.*, vol. 16, no. 7, pp. 5146–5165, 2012.
3. Y. H. Song,G.S.Wang,A.T.Johns and P.Y.Wang, "Distribution network reconfiguration for loss reduction using fuzzy controlled evolutionary programming," no. 1, pp. 345–350, 1997.
4. S. Nawaz and A. Tandon, "Power loss minimisation of rural feeder of Jaipur city by renewable-based DG technologies," *Aust. J. Electr. Electron. Eng.*, vol. 00, no. 00, pp. 1–8, 2018.
5. F. Blaabjerg, Y. Yang, D. Yang, and X. Wang, "Distributed Power-Generation Systems and Protection," *Proc. IEEE*, vol. 105, no. 7, pp. 1311–1331, 2017.
6. K. Seethalekshmi, U. C. Trivedi, and M. Ramamoorty, "Technical Loss Evaluation in Distribution Feeders," no. 760, pp. 673–675, 2002.
7. M. Geidl, "Protection of Power Systems with Distributed Generation : State of the Art," *Technology*, no. July, p. 353, 2005.
8. C. F. Chang, "Reconfiguration and capacitor placement for loss reduction of distribution systems by ant colony search algorithm," *IEEE Trans. Power Syst.*, vol. 23, no. 4, pp. 1747–1755, 2008.
9. E. O. Santos and J. S. B. Martins, "Distribution Power Network Reconfiguration in the Smart Grid."
10. M. T. M. Emmerich, K. Yang, J. Wang, T. Bäck, and R. Li, "Power Distribution Network Reconfiguration by Evolutionary Integer Programming," pp. 11–23, 2014.
11. M. S. Mazliham, B. Abu Bakar, M. J. Tahir, and M. Alam, "Distribution System Power Losses Minimization Using Network Reconfiguration," *Int. J. Integr. Eng.*, vol. 10, no. 7, pp. 1–9, 2018.
12. K. R. Devabalaji, A. M. Imran, T. Yuvaraj, and K. Ravi, *Power Loss Minimization in Radial Distribution System*, vol. 79. Elsevier B.V., 2015.
13. D. B. Prakash and C. Lakshminarayana, "Optimal siting of capacitors in radial distribution network using Whale Optimization

Algorithm," *Alexandria Eng. J.*, vol. 56, no. 4, pp. 499–509, 2017.
14. P. Taylor, P. V Prasad, S. Sivanagaraju, and N. Sreenivasulu, "Electric Power Components and Systems Network Reconfiguration for Load Balancing in Radial Distribution Systems Using Genetic Algorithm Network Reconfiguration for Load Balancing in Radial Distribution Systems Using Genetic Algorithm," no. August 2013, pp. 37–41.
15. G. Sabarinath, T.G,Manohar,"Optimal Sitting And Sizing Of Renewable Energy Resources For Power Loss Reduction In Radial Distribution Systems Using Whale Optimization Algorithm," *2018 Int. Conf. Emerg. Trends Innov. Eng. Technol. Res.*, pp. 1–5, 2018.
16. H. Hassanzadehfard and A. Jalilian, "A novel objective function for optimal DG allocation in distribution systems using meta- heuristic algorithms," *Int. J. Green Energy*, vol. 13, no. 15, pp. 1624–1634, 2016.
17. H. Hassanzadehfard and A. Jalilian, "Optimal sizing and siting of renewable energy resources in distribution systems considering time varying electrical / heating / cooling loads using PSO algorithm," *Int. J. Green Energy*, vol. 00, no. 00, pp. 1–16, 2018.
18. S. Saha, "A novel multiobjective chaotic symbiotic organisms search algorithm to solve optimal DG allocation problem in radial distribution system," no. January, pp. 1–25, 2019.
19. M. N. Morshidi, I. Musirin, S. R. A. Rahim, M. R. Adzman, and M. H. Hussain, "Whale optimization algorithm based technique for distributed generation installation in distribution system," *Bull. Electr. Eng. Informatics*, vol. 7, no. 3, pp. 442–449, 2018.
20. E. S. Oda, A. A. Abdelsalam, M. N. Abdel-Wahab, and M. M. El-Saadawi, "Distributed generations planning using flower pollination algorithm for enhancing distribution system voltage stability," *Ain Shams Eng. J.*, vol. 8, no. 4, pp. 593–603, 2017.
21. W. Sheng, K. Liu, Y. Li, Y. Liu, and X. Meng, "Improved Multiobjective Harmony Search Algorithm with Application to Placement and Sizing of Distributed Generation," vol. 2014, 2014.
22. U. Sultana, A. B. Khairuddin, A. S. Mokhtar, N. Zareen, and B. Sultana, "Grey wolf optimizer based placement and sizing of multiple distributed generation in the distribution system," *Energy*, vol. 111, pp. 525–536, 2016.
23. M. H. Haque, "Efficient load flow method for distribution systems with radial or mesh configuration," *IEE Proc. - Gener. Transm. Distrib.*, vol. 143, no. 1, p. 33, 2002.
24. D. Q. Hung, N. Mithulananthan, and R. C. Bansal, "Analytical expressions for DG allocation in primary distribution networks," *IEEE Trans. Energy Convers.*, vol. 25, no. 3, pp. 814–820, 2010.
25. S. R. Gampa and D. Das, "Electrical Power and Energy Systems Optimum placement and sizing of DGs considering average hourly variations of load," *Int. J. Electr. POWER ENERGY Syst.*, vol. 66, pp. 25–40, 2015.
26. X.S.Yang,M.Karamanoglu,and X.He, "Flower pollination algorithm: A novel approach for multiobjective optimization"Talor & Francis.
27. S. Chanda, "Determination of Voltage Stabilityin Distribution Network Using ANN Technique," no. October, 2015.
28. D. Thukaram, S. Member, H. P. Khincha, S. Member, H. P. Vijaynarasimha, and S. Member, "Artificial Neural Network and Support Vector Machine Approach for Locating Faults in Radial Distribution Systems," vol. 20, no. 2, pp. 710–721, 2005.

AUTHORS' PROFILES

Sabarinath.G received his B.Tech and M.Tech degrees in Electrical and Electronics Engineering from JNT University Anantapuramu, India, in 2009 and 2013, respectively. Currently, he is pursuing his Ph.D. in the Department of Electrical and Electronics Engineering at the S.V. University, Tirupati.

Dr. T. Gowri Manohar pursuied his B.Tech (EEE), M.Tech (Power Systems) and Ph.D. (Power systems) degrees from S.V. University, Tirupati, India, in 1996, 1998 and 2007 respectively. At present, he is serving as a professor in the department of EEE, SV University, Tirupati.