RESEARCH ARTICLE

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# Optimum Siting of Wind Power Plant in a Distribution Network – A Case Study

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## ABSTRACT

Optimum site selection based on financial analysis can provide additional supplementary benefits, in terms of reduced power losses, if Wind Turbine Generator (WTG) installed at the site, is connected to an optimum node in the Distributed Network (DN). This article further optimizes the site selection with regard to the distribution network. In a large distribution network with a number of potential sites, the presented method proves very helpful in selecting an optimum site with regard to the distribution network.

**Keywords:** Wind power generation, Distribution network, Voltage profile.

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## INTRODUCTION

At present Indian power distribution system is facing the following major problems [1, 7, 9, 10, 32]:

- The voltage sags are common in the system, which are more especially in the rural side. The voltage sags result into the shortening of the equipment life and cause brownout problems.
- Unable to meet the Peak loads, which are 10–13% high. Forced power outages are common and many times results in power blackouts.

**Table 1:** State-wise Transmission and Distribution (T&D) losses

| *State* | *% T&D Losses* |
|---|---|
| Andhra Pradesh | 17 |
| Assam | 32 |
| Bihar | 41 |
| Chattisgarh | 26 |
| Gujarat | 23 |
| Haryana | 30 |
| Himachal Pradesh | 18 |
| Jammu & Kashmir | 50 |
| Jharkhand | 43 |
| Karnataka | 26 |
| Kerala | 20 |
| Madhya Pradesh | 38 |
| Maharashtra | 31 |
| Meghalaya | 30 |
| Punjab | 36 |
| Rajasthan | 33 |
| Tamil Nadu | 18 |
| Uttar Pradesh | 33 |

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- State electricity boards are suffering from transmission and distribution losses up to 18–20%. These higher losses result in higher rate of purchase for the customers. Indian selling rates are higher as compared to many countries in the world. The state-wise transmission and distribution losses are given in Table 1.

## DISTRIBUTED GENERATION

It is very relevant for a country like India, if electricity is generated near the consumer end, then a considerable reduction in distribution losses is possible. This can be achieved by introducing distributed generation (DG). DG is defined as the generation of power by small generators connected to the distribution system.

Assuming the topology does not change during the planning period, peak demand or the creation of new loads on the network will require investment in network upgrades. In such cases, DGs are an important option for planning engineers to delay or reduce investment in transmission upgrades

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because DGs are close to the load and don't need how much transmission and distribution is needed to serve load. The advantages of DG can be listed as follows [3,16,18,19,19,22]:

- Reduced power loss
- Improved voltage quality
- More reliable
- Better power quality (in some cases)
- Probably to exploit combined heat and power generation
- Reduce pollution (Compared to conventional power plants)
- Reduce construction hours

Since cost is a major factor in energy planning, the main goal of planners is to find the best solutions to reduce the total cost. In few cases, DG can offer lower costs (and greater reliability) than customers get from the main supply, and can deliver significant savings by adding DG to the right place in the system deployment.

Distributed power generation technologies in India include microturbines, wind turbines, biomass and biomass gasification, solar photovoltaics and hybrid systems. However, most decentralized power plants rely on wind power, hydropower, biomass, and biomass gasification. Solar photovoltaic technology is expensive and fuel cells are not yet commercially viable. The details of the renewable technologies available for the DG are in Table 2 below.

While India has taken steps to implement renewable energy technologies, these technologies are not yet ready for large-scale commercial use. However, DG plays an important role in present power systems. Advances in technology are so great that it is now possible to think of various solutions and find them useful. This opens up business opportunities for private investors to power projects and allows new capital to flow into business from traditionally un-commercialized projects in the energy industry.

## Factors leading to the acceptance of wind power plants as distributed generators

- Present wind turbine technology has matured to a point where turbine lifetimes exceed 20 years and operation and maintenance costs are reasonable when well estimated [4,11,25,26,29,30].
- National government incentives are encouraging and economically attractive.

Considering the new role of wind power plants as distributed generation sources, a new method of optimum siting of wind power plant in a distribution network is presented using a micro-genetic algorithm (MGA). Using MGA the minimum system losses are obtained simultaneously improving the voltage profile for distribution network. An actual radial distribution network is considered for case study. The results show that after placing wind power plants at optimally chosen nodes, the system losses gets minimized optimally and the voltage profile improves, which is quantified in terms of average voltage. This work helps the power system planners and for the better operation of the power system. [20,21,23,24,27,31,33,34]

**Table 2:** Renewable technologies available for DG

| *Renewable Technology* | *Typical available size per module* |
|---|---|
| Small hydro | 1-100 MW |
| Micro hydro | 25 kW-1 MW |
| Wind turbines | 200 W-3 MW |
| Photovoltaic arrays | 20 W – 100 kW |
| Solar receivers | 1- 10 MW |
| Biomass based | 100 kW-20 MW |

## Problem Formulation

In an existing power distribution network, optimum siting of distributed generation unit refers to the location or node in a network at which if DG unit is connected, the objective function gets optimally minimized.

## Objective function

The objective function is defined as

$$f(X) = \min(C_L) \tag{1}$$

where $C_L$ is system losses
and, $X$ is a power flow solution.
subjected to :

Voltage limits:

$$V_{\min} \le V_i \le V_{\max} \tag{2}$$

where $V_i$ is $i^{th}$ node voltage,
$V_{max}$ is maximum and $V_{min}$ is minimum voltage limits.

## Genetic Algorithms

Genetic Algorithm (GA) is an evolutionary optimization method, an alternative to conventional optimization method. Genetic algorithm is one of the best methods for random complex models, Genetic Algorithms is a probabilistic search method based on the idea of evolutionary process. The Genetic Algorithm program is based on Darwin's principle of survival of the fittest. Create an initial population of several individuals, each represented by genetic string. All of them have an associated fitness measure. Then follow the idea that the fittest (or best) individuals in the population will produce more offspring to make up the next population. Each generation selects individuals for breeding (or crossbreeding) and uses the necessary mutations to change the individual's genes to create a new population. As a result, according to the solution, other groups of people make the subsequent populations more compatible, and those with lower compatibility are expelled from the population clan. The genetic algorithm has four main stages: evaluation, selection, crossover and mutation. The evaluation process evaluates fitness of each individual and assigns it a score. The random selection process selects individuals from the current population to create the next generation. The intersection operation takes two selected individuals and joins them around the crossover point, creating two new individuals. The mutation process changes the genes of affected individuals with minor changes, introducing more randomness to the population. This iterative process continues until one of the cutoff criteria is met [5,8,12,13,14,17]:

- when an acceptable or optimal solution level is attained
- when an extreme number of generations have been executed
- when an agreed number of generations without fitness improvement occur.

## Implementation of Micro Genetic Algorithm

Micro Genetic Algorithms (MGA) are fast converging algorithms [6,15,28]. Initially, a small population of six strings is generated randomly and operated through reproduction and crossover. Convergence is said to occur when the node number at which the DG is placed remains constant for at least 20 iterations. An elitist is chosen by the MGA, to ensure that the fittest of the best solution in the population, does not deteriorate as the generations advance. Elitist replaces the strings that do not satisfy the constraint equation. Elitist also saves the best solution found. In case of divergence, the program completes maximum iterations set by the operator and exits. The fitness value is computed by using decoupled load flow method. For this purpose, $V_{max}$ =1.1 p.u. and $V_{min}$ =0.9 are chosen. Reproduction is done using Roulette wheel process. Mutation operator is not used. The chromosome structure is shown in Figure 1. The crossover is designed between any randomly selected node of a random string and another string's randomly selected node. The flow chart is given in Figure 2. Parameters of MGA used in this chapter are shown in Table 3. The program is written using MATLAB 7.0.

## CASE STUDY AND RESULTS

A radial distribution network of Belgaum city, in north Karnataka, India is chosen for case study. The network has total of 46 nodes of which, all of them are connected to 11 kV supply. Karnataka Power and Transmission Corporation Ltd. (KPTCL) supplies power to the whole city. 11kV/440V distribution transformer at each node is connected from where the consumer draws the power. At present, the distribution losses are around 9%. Few nodes in the distribution network suffer from low voltage levels. The 46 node distribution network considered for case study is shown in Figure 3.

| Node No | Capacity of DG unit | Node No | Capacity of DG unit |
|---|---|---|---|

**Figure 1:** Chromosome structure

**Table 3:** Operational parameters of Micro Genetic Algorithm

| | |
|---|---|
| Population size | 6 |
| Probability of crossover | 0.8 |
| String size | 64 bits |
| Maximum number of iteration | 400 |

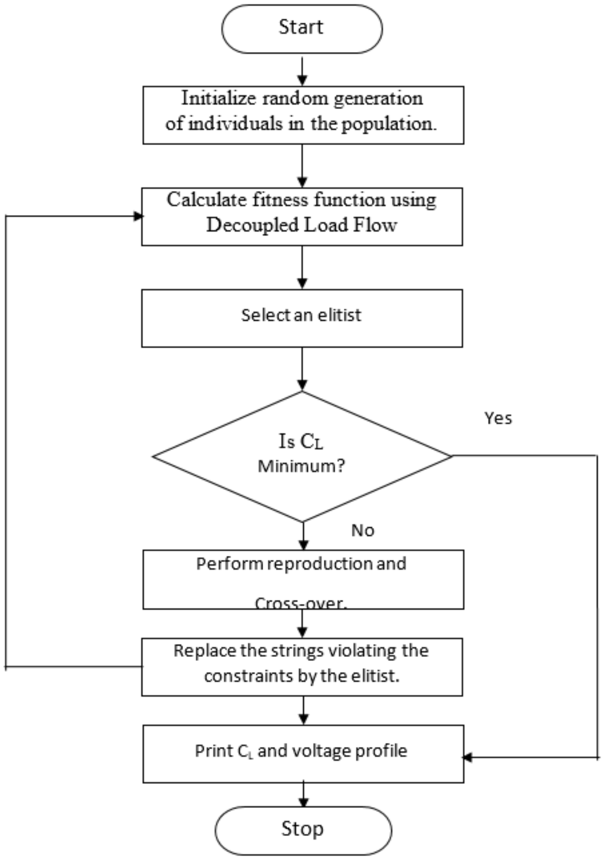

**Figure 2:** Flow chart of the method implemented

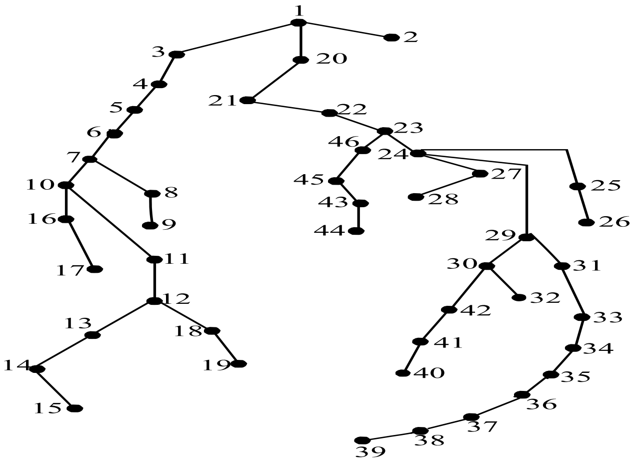

**Figure 3:** Radial distribution network of Belgaum city in north Karnataka, India

Developed MGA is applied in five different cases for the equal load of 19.458 MW. Slack bus voltage at node 1 is assumed to be equal to 1.06 p.u. Case A is conducted as a base case to bring out the Distribution Network (DN) status when no Wind Power Plant (WPP) is connected. In case B, an optimum node is determined for the connection of one WPP of capacity 225 kW. In case C, two optimum nodes are determined for the connection of two WPPs of same capacity each. Similarly, in case D and in case E, three and four optimum nodes are determined for the connection of three and four WPPs, respectively. The status of each case is compared with the base case.

***Case A.*** With no WPP included in the network, the voltage profile, power losses and average voltage are determined. The average voltage is 0.9603 p.u. and system losses are 1.699 MW, amounting to 8.73% of the load. The nodes from 33 to 41 suffer from low voltage having value below 0.9 p.u.

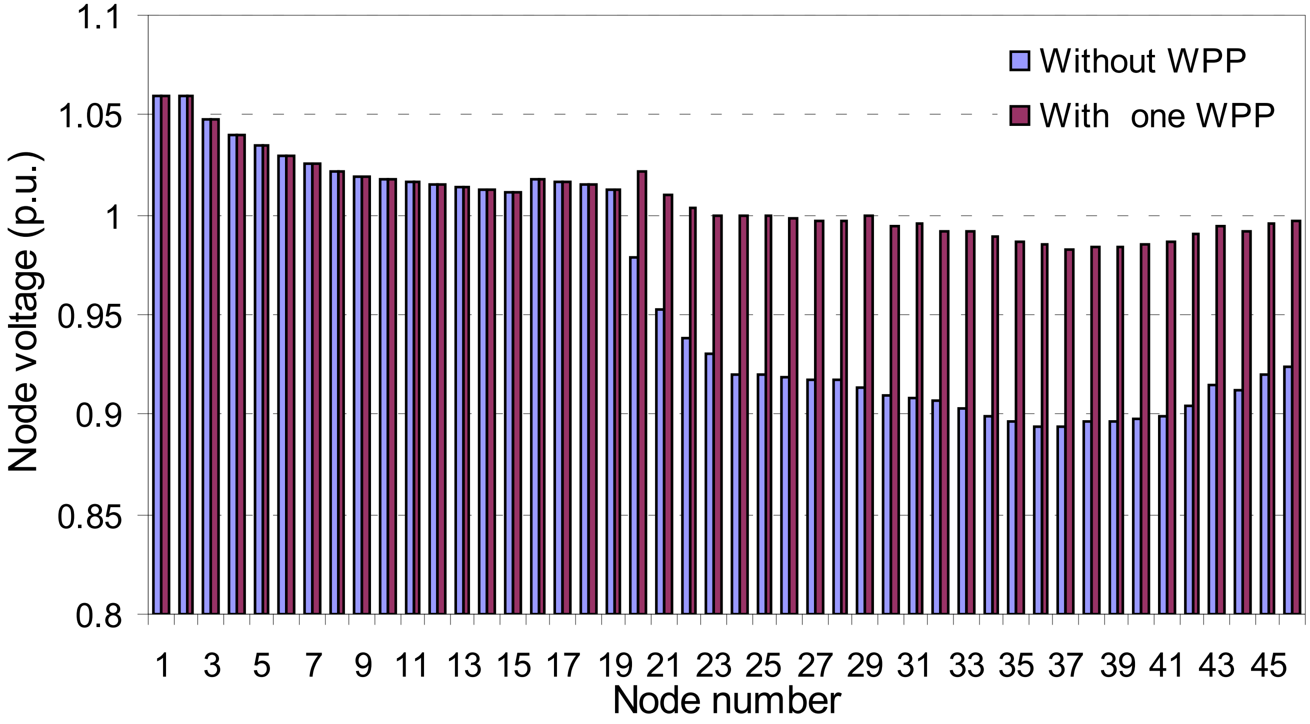

**Figure 4:** Voltage profile before and after including WPP

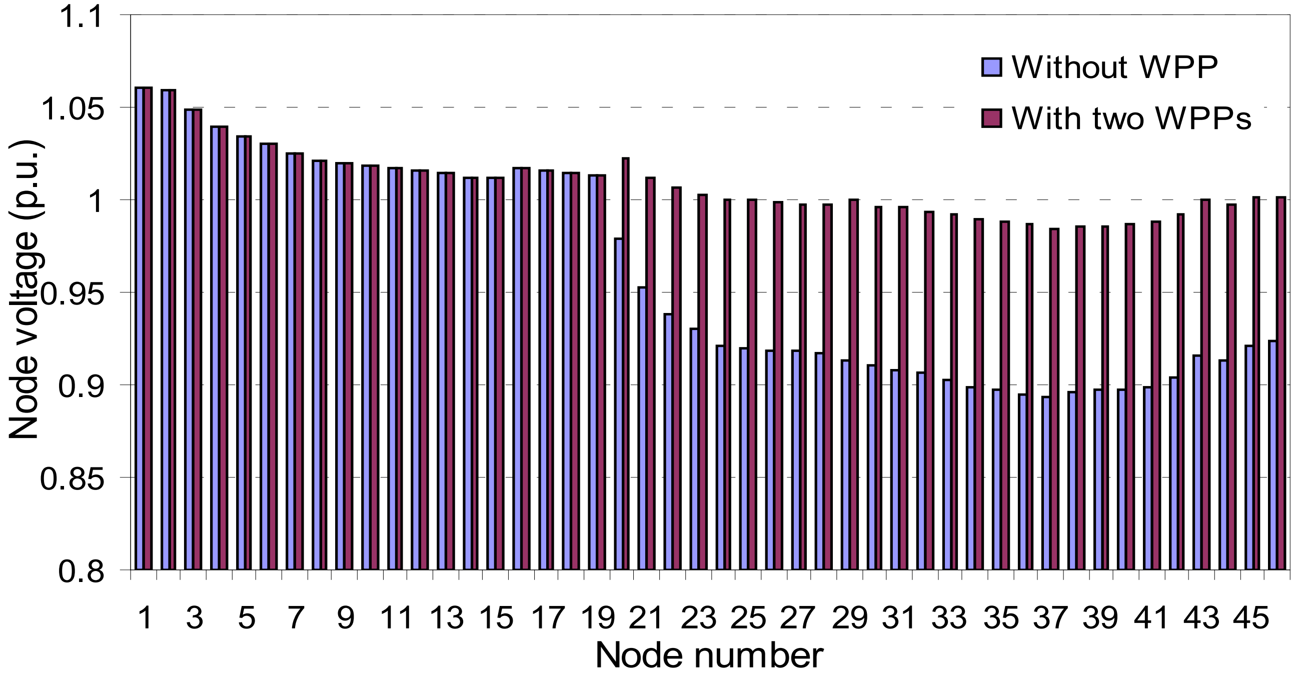

**Figure 5:** Voltage profile before and after including two WPPs

***Case B.*** With a provision to include one WPP in the network the optimum node at which WPP can be connected is determined. In this case, the optimum node for the WPP connection in the network is 29. The average voltage is found to improve to 1.0074 p.u. distribution loss is reduced to 0.99 MW amounting to 5.08% of the load. All the node voltages are more than the lower limit of 0.9 p.u. Voltage profile before and after connecting one WPP of capacity 225 kW at the optimum node is shown in Figure 4.

***Case C.*** With a provision to include two WPP in the network the optimum nodes at which WPPs can be connected is determined. In this case, optimum nodes for the connection of WPPs in the network are found to be 29 and 43. The average voltage is found to be 1.0085 p.u. Distribution loss is reduced to 0.9704 MW amounting to 4.98% of the load. All the node voltages are more than the lower limit. Voltage profile before and after connecting two WPP of capacity 225 kW at the optimum nodes is shown in Figure 5.

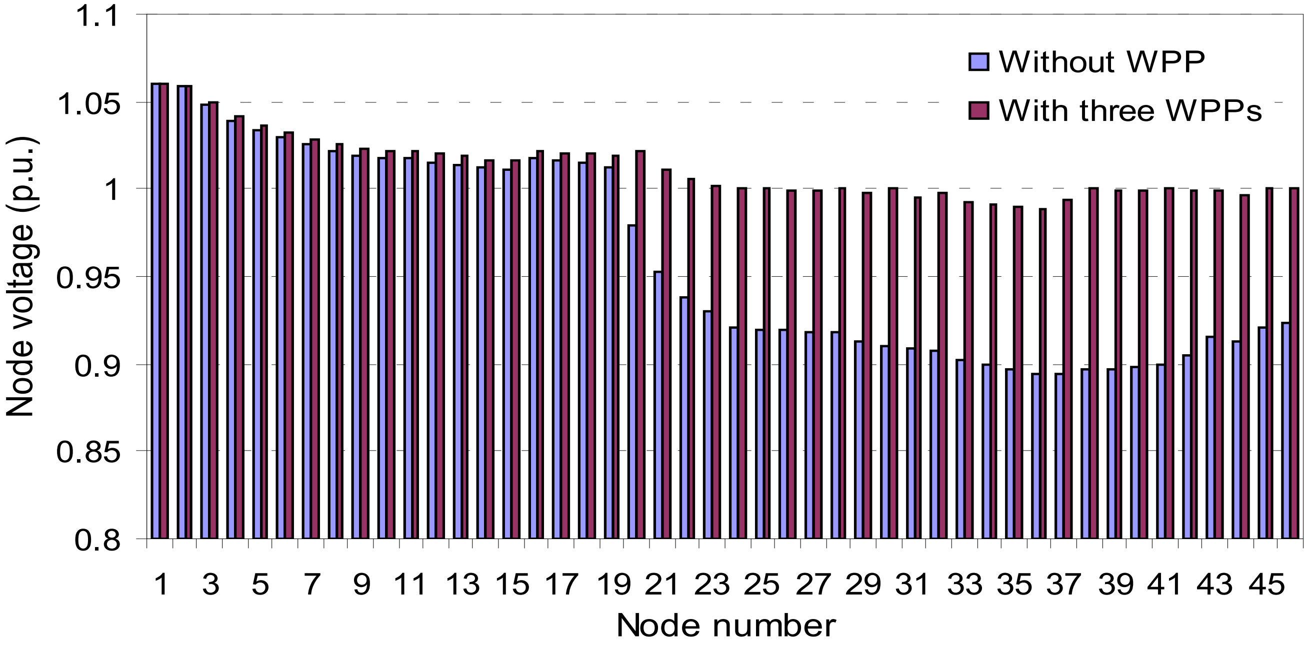

**Figure 6:** Voltage profile before and after including three WPPs

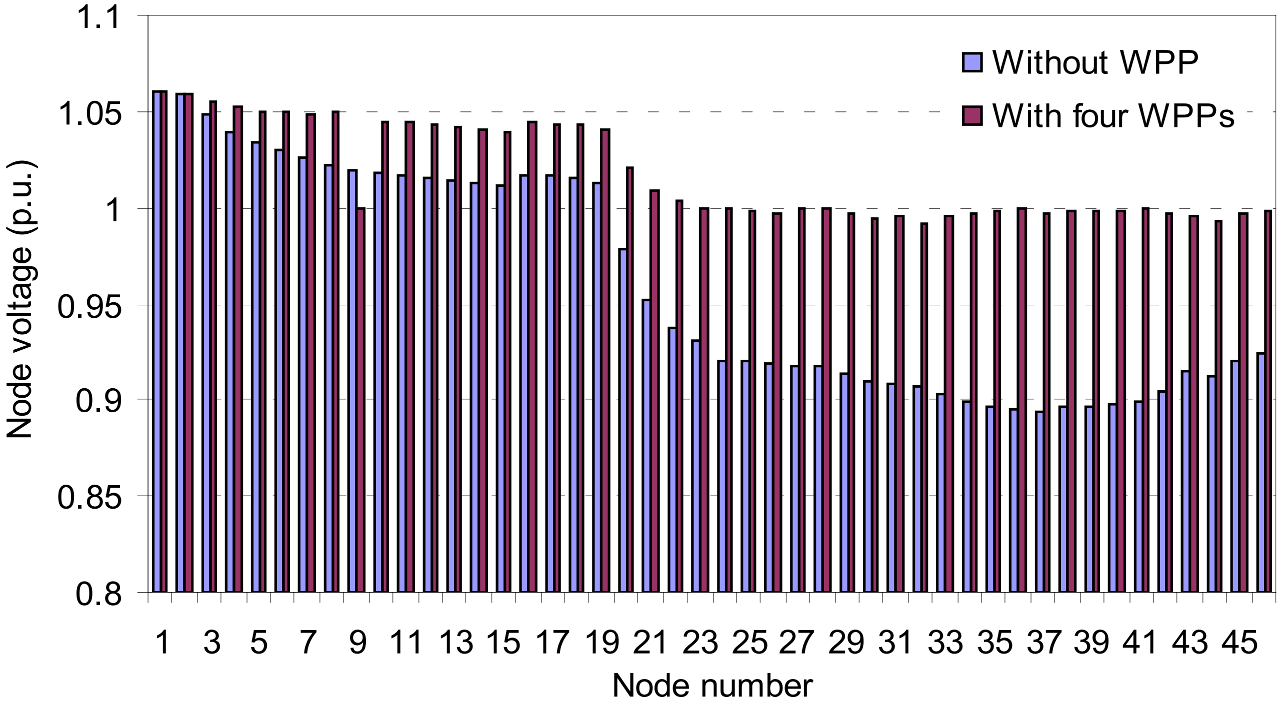

**Figure 7:** Voltage profile before and after including four WPPs

**Table 4:** Voltage profile under different cases

| *Node voltage (p.u.)* | | | | | |
|---|---|---|---|---|---|
| *Node number* | *Without WPP* | *With one WPP* | *With two WPP* | *With three WPP* | *With four WPP* |
| 1 | 1.0600 | 1.0600 | 1.0600 | 1.0600 | 1.0600 |
| 2 | 1.0592 | 1.0592 | 1.0592 | 1.0592 | 1.0592 |
| 3 | 1.0484 | 1.0484 | 1.0484 | 1.0494 | 1.0551 |
| 4 | 1.0395 | 1.0395 | 1.0395 | 1.0413 | 1.0519 |
| 5 | 1.0342 | 1.0342 | 1.0343 | 1.0365 | 1.0501 |
| 6 | 1.0300 | 1.0300 | 1.0300 | 1.0327 | 1.0492 |
| 7 | 1.0255 | 1.0255 | 1.0255 | 1.0287 | 1.0485 |
| 8 | 1.0214 | 1.0214 | 1.0214 | 1.0251 | 1.0494 |
| 9 | 1.0195 | 1.0195 | 1.0195 | 1.0234 | 1.0000 |
| 10 | 1.0181 | 1.0181 | 1.0181 | 1.0223 | 1.0451 |
| 11 | 1.0171 | 1.0171 | 1.0171 | 1.0214 | 1.0450 |
| 12 | 1.0156 | 1.0156 | 1.0156 | 1.0201 | 1.0434 |
| 13 | 1.0143 | 1.0143 | 1.0143 | 1.0189 | 1.0422 |
| 14 | 1.0123 | 1.0123 | 1.0123 | 1.0168 | 1.0402 |
| 15 | 1.0116 | 1.0116 | 1.0116 | 1.0161 | 1.0395 |
| 16 | 1.0174 | 1.0174 | 1.0174 | 1.0217 | 1.0445 |
| 17 | 1.0161 | 1.0161 | 1.0161 | 1.0207 | 1.0435 |
| 18 | 1.0149 | 1.0149 | 1.0149 | 1.0199 | 1.0426 |
| 19 | 1.0129 | 1.0129 | 1.0129 | 1.0190 | 1.0407 |
| 20 | 0.9786 | 1.0211 | 1.0230 | 1.0220 | 1.0210 |
| 21 | 0.9524 | 1.0096 | 1.0122 | 1.0108 | 1.0094 |
| 22 | 0.9381 | 1.0041 | 1.0064 | 1.0054 | 1.0038 |
| 23 | 0.9303 | 0.9998 | 1.0029 | 1.0020 | 0.9998 |
| 24 | 0.9206 | 0.9997 | 1.0006 | 1.0001 | 0.9989 |
| 25 | 0.9201 | 0.9993 | 1.0002 | 0.9999 | 0.9985 |
| 26 | 0.9189 | 0.9982 | 0.9991 | 0.9994 | 0.9974 |
| 27 | 0.9178 | 0.9971 | 0.9980 | 0.9993 | 1.0000 |
| 28 | 0.9176 | 0.9969 | 0.9978 | 1.0000 | 0.9998 |
| 29 | 0.9131 | 1.0000 | 1.0000 | 0.9982 | 0.9966 |
| 30 | 0.9101 | 0.9940 | 0.9965 | 1.0000 | 0.9946 |
| 31 | 0.9083 | 0.9960 | 0.9961 | 0.9953 | 0.9959 |
| 32 | 0.9070 | 0.9912 | 0.9937 | 0.9972 | 0.9918 |
| 33 | 0.9026 | 0.9915 | 0.9918 | 0.9922 | 0.9959 |
| 34 | 0.8992 | 0.9888 | 0.9892 | 0.9906 | 0.9967 |
| 35 | 0.8968 | 0.9871 | 0.9876 | 0.9898 | 0.9979 |
| 36 | 0.8945 | 0.9856 | 0.9862 | 0.9891 | 1.0000 |
| 37 | 0.8937 | 0.9829 | 0.9842 | 0.9935 | 0.9971 |
| 38 | 0.8966 | 0.9842 | 0.9859 | 1.0000 | 0.9982 |
| 39 | 0.8970 | 0.9843 | 0.9861 | 0.9994 | 0.9983 |
| 40 | 0.8977 | 0.9848 | 0.9866 | 0.9995 | 0.9988 |
| 41 | 0.8993 | 0.9861 | 0.9879 | 0.9998 | 1.0000 |
| 42 | 0.9045 | 0.9899 | 0.9920 | 0.9997 | 0.9971 |
| 43 | 0.9153 | 0.9947 | 1.0000 | 0.9995 | 0.9952 |
| 44 | 0.9127 | 0.9923 | 0.9976 | 0.9971 | 0.9928 |
| 45 | 0.9206 | 0.9963 | 1.0007 | 1.0001 | 0.9966 |
| 46 | 0.9239 | 0.9974 | 1.0014 | 1.0007 | 0.9977 |

**Table 5:** Power loss, average voltage and optimum node numbers for different cases

| | *With out WPP* | *With one WPP* | *With two WPPs* | *With three WPPs* | *With four WPPs* |
|---|---|---|---|---|---|
| Distribution loss (MW) | 1.6990 | 0.9900 | 0.9704 | 0.9566 | 0.9373 |
| Average voltage (p.u.) | 0.9603 | 1.0074 | 1.0085 | 1.0116 | 1.0189 |
| Optimum nodes | - | 29 | 29, 43 | 28, 30, 38 | 9, 27, 41, 36 |

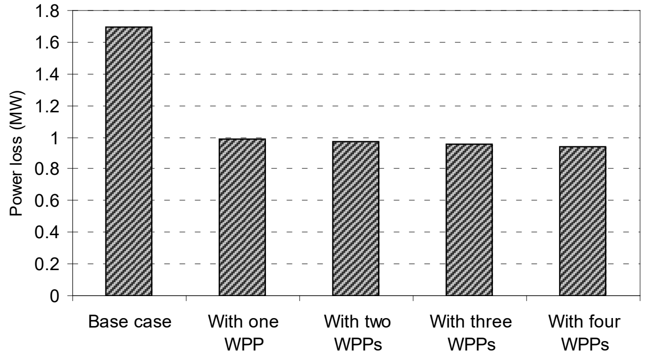

**Figure 8:** Distribution loss (MW) under different cases

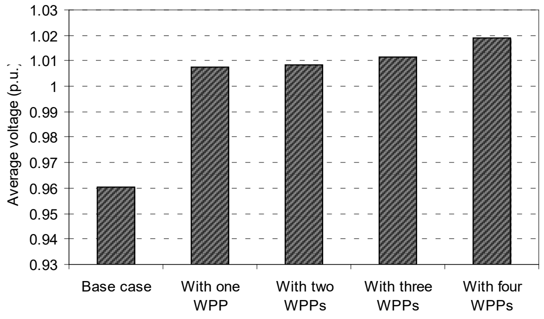

**Figure 9:** Average voltage (p.u.) under different cases

***Case D.*** With a provision to include three WPP in the network the optimum nodes at which WPPs can be connected is determined. In this case, optimum nodes for the connection of WPPs in the network is found to be 28, 30 and 38. The average voltage is found to be 1.0116 p.u. System losses are further reduced to 0.9566 MW amounting to 4.92%. All The node voltages are more than the lower limit. Voltage profile before and after connecting three WPP of capacity 225 kW at the optimum nodes is shown in Figure 6.

Case E. With a provision to include four WPP in the network the optimum nodes at which WPPs can be connected is determined. In this case, optimum nodes for the connection of WPPs in the network is found to be 9, 27, 41 and 36. The average voltage is found to be 1.0189 p.u. System losses are 0.9373 MW amounting to 4.81%. All The node voltages are more than the lower limit. Voltage profile before and after connecting four WPP of capacity 225 kW at the optimum nodes is shown in Figure 7. Detailed voltage profiles under different cases are shown in Table 4

Power losses, average voltage and optimum nodes under different cases and the corresponding optimum nodes found for connection of WPPs are shown in Table 5. As the number of WPPs increase in number, it seen that the distribution loss decreases as shown in Figure 8. Corresponding improvement in the average voltage is shown in Figure 9.

## CONCLUSIONS

Optimum siting of wind power plant is determined for a distribution network. It shown that after connecting wind power plant at found optimum node, the system losses are reduced by 3.65% (0.709 MW) for load of 19.458 MW. It is also seen that, the average voltage improves from 0.9603 p.u. to 1.0074 p.u. It is shown that, the node numbers 34 to 41 which were having low voltage below voltage minimum of 0.9 p.u., after the inclusion of wind power plant have improved the voltage above the minimum limit of 0.9 p.u. The results of subsequent increase in number of WPPs have been presented.

In a large distribution network with a number of potential sites, the presented method proves very helpful in selecting an optimum site with regard to distribution network.

## REFERENCES

[1] “Central Electricity Authority”, [Online] Available: http://cea.nic. In /god/special_reports/AT&C-%20LOSSES_PFC_2003-04%20to%202006-07.pdf

[2] “The Energy & Resources Institute (TERI)”, [Online] Available: http://www.teriin. org/

[3] “The Role of Distributed Generation in Power Quality and Reliability”, Report - New York State Energy Research and development Authority, 17 Columbia Circle, Albany, New York 12203-6399.

[4] Henry G. du Pont, (2003). Wind Turbine Generators Gain Acceptance in Distributed Generation Applications. *Power Engineering Society General Meeting, 2003, IEEE,* Vol. 4, 13-17 Page(s):2318-2319.

[5] D. E. Goldberg, (1989). Genetic Algorithms in Search, Optimization and Machine Learning, Addison Wesley, MA.

[6] G. A. Bakare, U. O. Aliyu, G. K. Venayagamoorthy and Y. K. Shu’aibu, (2003). Computational Enhancement of Genetic Algorithm Via Control Device Pre-Selection Mechanism for Power System Reactive Power/Voltage Control. Proceedings of the IEEE Power Engineering Society General Meeting, 2003, Institute of Electrical and Electronics Engineers (IEEE). (https://doi.org/10.1109/PES.2003.1267411)

[7] Justus C. G., Hargraves, W. R., and Ali Yakin, (1976). Nationwide Assessment of Potential Output from Wind Powered Generators. Journal of Applied Meteorology, Vol.15, pp.673-678.(https://doi.org/10.1175/1520-0450(1976)015%3C0673:NAOPOF%3E2.0.CO;2)

[8] L. S. Srinath, (1991). Reliability Engineering. Third Ed, Affiliated East-West Press Pvt. Ltd. ISBN: 8185336393, 9788185336398

[9] Thomas Bellarmine and Joe Urquhart, (1996). Wind Energy for the 1990s and Beyond. Energy Conversion and Management (Elsevier), Vol.37, No.12, pp.1741-1752. (https://doi.org/10.1016/0196-8904(96)00009-X)

[10] Anna Mani and Ranagarajan,S., (1996). Wind Energy-Resource Survey in India. Vol.I-IV, Allied Publishers, New Delhi, India. ISBN: 8170235731, 9788170235736

[11] Jangamshetti, S. H., and Rau, V. G., (1999). “Site Matching of Wind Turbine Generators: A Case Study,” IEEE Transactions on Energy Conversion, vol. 14, No 4, pp 1537-1543. (https://doi.org/10.1109/60.815102)

[12] Charles. E. Ebeling, (2000). An introduction to Reliability and Maintainability Engineering, Tata McGraw-Hill Publishing Company Ltd. ISBN 9780070421387

[13] Peng Wang and R. Billinton, (2001). Reliability benefit analysis of adding WTG to a distribution system. in IEEE Transactions on Energy Conversion, vol. 16, no. 2, pp. 134-139. (https://doi.org/10.1109/60.921464).

[14] Michos D, Dialynas E, Vionis P. (2002). Reliability and Safety Assessment of Wind Turbines Control and Protection Systems. Wind Engineering. Vol 26, No. 6, pp: 359-369.(https://doi.org/10.1260/030952402765173358).

[15] Herman, S.A., (2003). DOWEC Cost Model – Implementation. DOWEC-F1W2-SH-01-068/01-C. ECN report number ECN-CX-02-048. Petten.

[16] R. Karki and R. Billinton, (2004). Cost-effective wind energy utilization for reliable power supply. *IEEE Transactions on Energy Conversion*, vol. 19, no. 2, pp. 435-440. (https://doi.org/10.1109/TEC.2003.822293).

[17] M. M. Khan, M. T. Iqbal and F. Khan, (2005). Reliability and condition monitoring of a wind turbine. Canadian Conference on Electrical and Computer Engineering, 2005., Saskatoon, SK, Canada, pp. 1978-1981. (https://doi.org/10.1109/CCECE.2005.1557371).

[18] Peter Tavner, Clare Adwards, Andy Brinkman and Fibio Spinato, (2006). Influence of Wind Speed on Wind Turbine Reliability. Wind Engineering, Vol. 30, No 1, pp 55-72. ( https://doi.org/10.1260/030952406777641441)

[19] A. P. Leite, C. L. T. Borges and D. M. Falcao, (2006). Probabilistic Wind Farms Generation Model for Reliability Studies Applied to Brazilian Sites. IEEE Transactions on Power Systems, vol. 21, no. 4, pp. 1493-1501. (https://doi.org/10.1109/TPWRS.2006.881160).

[20] X. Liu and S. Islam, (2006). Wind-diesel-battery hybrid generation system reliability analysis on site and size factors,” in Proc. 2006 4th Int. Conf. Elect. Comput. Eng. (ICECE 2006), Dhaka, Bangladesh, pp. 229–232. (https://doi.org/10.1109/ICECE.2006.355332)

[21] Tavner P, Edwards C, Brinkman A, Spinato F. (2006). Influence of Wind Speed on Wind Turbine Reliability. Wind Engineering. vol. 30, no.1, pp. 55-72.(https://doi.org/10.1260/030952406777641441)

[22] J. Ribrant and L. M. Bertling, (2007). Survey of Failures in Wind Power Systems With Focus on Swedish Wind Power Plants During 1997–2005,” in IEEE Transactions on Energy Conversion, vol. 22, no. 1, pp. 167-173. (https://doi.org/10.1109/TEC.2006.889614).

[23] Simone Kaiser and Michael Fröhlingsdorf, WUTHERING HEIGHTS- (2007). The Dangers of Wind Power. [Online] Available: https://www.spiegel.de/international/germany/wuthering-heights-the-dangers-of-wind-power-a-500902.html

[24] H. Yang, W. Zhou and C. Lou, (2009). Optimal Design And Techno-economic Analysis Of A Hybrid Solar-Wind Power Generation System”, Applied Energy, vol. 86, pp. 163-169, ( https://doi.org/10.1016/j.apenergy.2008.03.008)

[25] Diwakar. R. Joshi and S. H. Jangamshetti, (2010). A Novel Method to Estimate the O&M Costs for the Financial Planning of the

Wind Power Projects Based on Wind Speed—A Case Study," in IEEE Transactions on Energy Conversion, vol. 25, no. 1, pp. 161-167. (https://doi.org/10.1109/TEC.2009.2032591).

[26] C. J. Sudhakar, A. V. Deshpande and D. R. Joshi, (2017). Charge controller for hybrid VAWT and solar PV cells. 2017 2nd International Conference for Convergence in Technology (I2CT), Mumbai, India, pp. 343-347, (https://doi.org/10.1109/I2CT.2017.8226148).

[27] S. Paul and Z. H. Rather, (2018). A Pragmatic Approach for Selecting a Suitable Wind Turbine for a Wind Farm Considering Different Metrics. *IEEE Transactions on Sustainable Energy*, vol. 9, no. 4, pp. 1648-1658. (https://doi.org/10.1109/TSTE.2018.2805262).

[28] Anastasia Ioannou, Andrew Angus, Feargal Brennan, (2018). A lifecycle techno-economic model of offshore wind energy for different entry and exit instances, Applied Energy, Vol 221. pp 406-424, ISSN 0306-2619, (https://doi.org/10.1016/j.apenergy.2018.03.143).

[29] C. J. Sudhakar and D. R. Joshi, (2019). Design of DC-DC converter for wind power application, 2019 Fifth International Conference on Electrical Energy Systems (ICEES), Chennai, India, pp. 1-4, (https://doi.org/10.1109/ICEES.2019.8719235).

[30] C. J. Sudhakar, D. R. Joshi and N. R. Chitragar, (2019). A review on design of low wind speed wind turbines", International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, Vol. 7, Issue 12, page no. 23–28. (doi: 10.17148/IJIREEICE.2019.71203)

[31] K. Zou, G. Mohy-ud-din, A. P. Agalgaonkar, K. M. Muttaqi and S. Perera, (2020). Distribution System Restoration With Renewable Resources for Reliability Improvement Under System Uncertainties," in *IEEE Transactions on Industrial Electronics*, vol. 67, no. 10, pp. 8438-8449. ( https://doi.org/10.1109/TIE.2019.2947807).

[32] "Global Wind Report 2022", [Online] Available https://gwec.net/globalwindreport2022/

[33] "Wind Energy In India". [Online] Available: http://www.inwea.org/wind-energy-in-india/wind-power-installation/

[34] "Renewable Energy Information System on Internet (REISI)", the database from which WMEP reports are prepared, [Online] Available: https://www.osti.gov/etdeweb/biblio/673038