Optimal Placement of Renewable Energy Power Generation Based on Sensitivity Analysis: Case of the IEEE 33 BUS Radial Distribution System

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https://doi.org/10.5109/7395500

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.72-78, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

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Abstract: *This research presents a sensitivity analysis method for the optimal placement of Renewable Energy Power Generation (REPG) units, based on the Loss Sensitivity Factor (LSF), with the aim of enhancing the voltage profile and minimizing active power losses in the power system. Compared to other methods,the proposed method is simple and analytically transparent and does not rely on complex iterations, thereby reducing execution time and computational burden. The method identifies three bus locations with the highest LSF and nominal voltages not exceeding 1.01 p.u. as suitable candidates for REPG integration. The method is applied to the IEEE-33 Bus Radial Distribution System (RDS), where Solar Photovoltaic (PV) and Wind Turbine Generators (WTGs) of different sizes are strategically placed at the selected bus locations to evaluate their effectiveness. Simulation results reveal that WTG-based REPG units outperform Solar PV-based REPG units in reducing active power losses, primarily due to their ability to provide reactive power support.*

Keywords: *Loss Sensitivity Factor;Voltage Profile Enhancement;Active Power Loss Minimization.*

1. INTRODUCTION

Over the past four decades, power systems around the world have undergone continuous reform. One of the major initiatives in this transformation is the decarbonization of the power system through the increased integration of Renewable Energy Power Generators, into the Distribution System (DS) [1], [2]. In addition to providing clean energy, they play a significant role in enhancing the voltage profile, minimizing losses, improving voltage control, and increasing overall system reliability when they are optimally sized and allocated within the DS[3].Conversely, improper sizing and placement of REPG units may lead to undesirable effects on the DS performance [4]. Solar and wind power are the most widely utilized REPG units due to their technological advancements, low operational and maintenance costs, and widespread resource availability [5].

To maximize the benefits of REPG units in DS, numerous studies over the past decade have focused on the optimal placement of REPG units with the aim of minimizing operational costs and greenhouse gas emissions, improving voltage profile, enhancing voltage stability, and reducing power losses. These studies have employed various methodologies, including conventional, metaheuristic, and sensitivity-based approaches.

References [5] to [11] present some of the recent studies that have employed metaheuristic approaches. Settoul et al. introduced a Whale optimization Algorithm for the optimal sizing and siting of WTGs and Solar PV, to reduce active power losses, improve voltage profile, and reduce operational costs [6]. In another study, Hari et al. applied the same algorithm to solve a multi-objective problem involving the optimal sizing and placement of DGs, with the objective of reducing economic losses and power losses, while enhancing the voltage profile [7].

Purlu and Turkay proposed the application of the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for optimal sizing and siting of REPG-based Distributed Generation (DG), with the objective of minimizing the voltage deviation index and annual energy losses [8]. Alizadeh et al. proposed the Evolutionary Algorithms for the optimal placement of solar PV-based REPG with the objective of minimizing power losses and enhancing the voltage profile [9].Yehia et al. presented a novel strategy based on the hybridization of fuzzy logic with the Equilibrium Optimizer (EO) for the optimal sizing and placement of DGs [10]. Malik et al. proposed the application of a multi-objective PSO for the optimal sizing and siting of various RERs, to improve the voltage profile and reduce power losses [11].

References [12] to [15] present some of the recent studies that have employed sensitivity analysis-based approaches. Kwangkaew et al. introduced the Load Disabling Nodal Analysis for Robust Voltage Stability to determine the optimal size and placement of REPG units, to improve voltage stability, and minimize power losses [12]. Viral and Khatod proposed an analytical approach for optimal placement and sizing of DGs in DS to reduce power losses [13]. Kayal et al. introduced a DG selection index for determining the optimal location and sizing of DGs, with the aim of enhancing voltage stability and minimizing power losses in DS [14]. Kashyap et al. proposed an analytical approach for the optimal allocation and sizing of REPG units in a DS, to enhance the voltage profile and reduce power losses [15].

From the studies presented in References [5] to [15] , it is evident that the maximum benefit of integrating REPG units into DSs is highly dependent on their optimal location and sizing within the system. This study presents the optimal placement of Solar Photovoltaic (PV) and Wind Turbine Generator (WTG) REPG units of known sizes, based on the Loss Sensitivity Factor (LSF). The proposed method is simple and analytically transparent compared to other methods reported in the literature, and it does not rely on complex iterative processes, thereby reducing both execution time and computational burden.

2. PROPOSED METHODOLOGY

To identify suitable buses for REPG integration, a sensitivity analysis is conducted using the Loss Sensitivity Factor (LSF), which quantifies the contribution of each bus to power losses. The formulation of the LSF, as presented in Equation (3), is derived from the single-line diagram of the distribution system shown in Figure 1. [16],[17],[18].

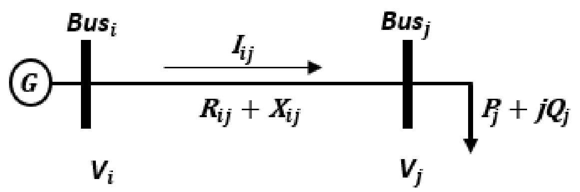

Figure 1: Distribution line

$$P_L = I_{ij}^2 \times R_{ij} \quad (1)$$

$$P_L = \left(\frac{P_j^2 + Q_j^2}{V_j^2}\right) \times R_{ij} \quad (2)$$

$$\frac{\partial P_L}{\partial P_{Li}} = \left(\frac{2 \times P_j}{V_j^2}\right) \times R_{ij} \quad (3)$$

$$V_N = V_i \,/\, 0.95 \quad (4)$$

Where P_L denotes the active power loss in the DS . I_{ij}, R_{ij} and X_{ij} denote the line current, line resistance and line reactance, respectively. P_j denotes the receiving end active power, and Q_j represents the receiving end reactive power. V_i denotes the sending end voltage, and V_j is the receiving end voltage, while V_N denotes the normalized voltage.

The Loss Sensitivity Factor (LSF), presented in Equation (1), is used to evaluate the power loss sensitivity of each bus within the DS. Firstly, the base load power flow analysis is conducted without the inclusion of solar PV and WTG REPG units. The power flow results are used to compute the normalized voltage at each bus, as defined by Equation (4). Additionally, the power flow results are used to determine the LSF for each bus.

The calculated LSF values are then arranged in descending order and paired with their respective normalized voltages. Buses with normalized voltages exceeding 1.01 are excluded from consideration as locations for REPG integration. Only buses with high LSF values and normalized voltages not exceeding 1.01 are considered for REPG placement.

Subsequently, power flow analysis is carried out with REPG units installed at the identified candidate buses.These results are compared with those of the base load case to evaluate how REPG integration affects voltage profile and minimizes power losses.

The proposed algorithms for identifying candidate buses for REPG placement and for comparing base load results with various REPG deployment scenarios are outlined in **Algorithm 1** and **Algorithm 2**, respectively.

Algorithm 1: Algorithm to select the candidate bus for REPG placement

1: Run baseload power flow analysis using MATPOWER
2: **For** each bus i in the DS **do**
3: Calculate LSF at each bus using Equation (3)
4: Calculate V_N at each bus, using Equation (4)
5:**end for**
6: Create a list of (Bus(i), LSF(i), V_N(i)) for all buses
7: Sort the list in step 6 in descending order based on LSF(i)
8: **For** each bus (i) in step 7 **do**
9: **If** $V_N < 1.01$ **then**
10: Include the bus for REPG placement;
11: **Else**
12: Exclude the bus for REPG placement;
13: **end if**
14: **end for**

Algorithm 2: Algorithm to compare base load results from different REPG scenarios

1: **For** each REPG unit size and type **do**
2: **For** each scenario **do**
3: Place the REPG units at the locations identified in Algorithm 1
4: Run power flow analysis using MATPOWER
5: Store the load flow results from Step 4
6: **End for**
7: **End for**
8: Compare the base case load flow results from Algorithm 1 with the results obtained in Step 5

3. RESULTS AND DISCUSSIONS

3.1 Test system

The proposed LSF-based approach for optimal REPG placement is evaluated using the IEEE-33 Bus Radial Distribution System (RDS), as illustrated in Figure 2. The RDS consists of 33 buses and 32 distribution branches. Bus 1 serves as the slack bus, while buses 2 through 33 supply a total active and reactive power demand of 3.72 MW and 2.3 MVAr, respectively. The simulation model is developed and adapted using MATPOWER version 7.1 within the MATLAB R2023b environment. The Newton-

Raphson technique is utilized to carry out the power flow analysis [19], [20].

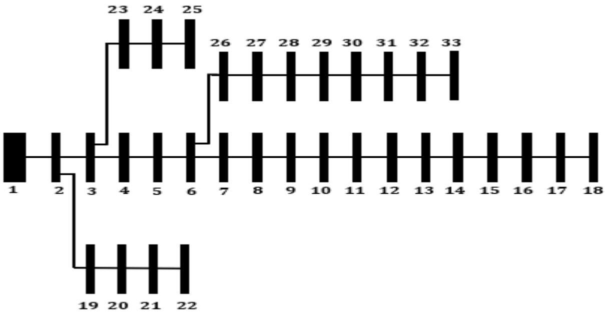

Figure 2: The IEEE 33-RDS

Table 1: Descending order of LSFs with corresponding bus numbers and normalized voltage magnitudes in the IEEE-33 RDS.

LSF	Bus No.	Base voltage	Normalized voltage
0.23866	**6**	**0.94966**	**0.99964**
0.21601	3	0.98294	1.03467
0.12331	**28**	**0.93373**	**0.98287**
0.11246	4	0.97546	1.02680
0.11186	5	0.96806	1.01901
0.10060	**9**	**0.93506**	**0.98427**
0.09964	24	0.97268	1.02387
0.09759	13	0.92077	0.96923
0.09366	10	0.92924	0.97815
0.08901	8	0.94133	0.99087
0.08737	29	0.92551	0.97422
0.06066	31	0.91779	0.96609
0.05497	23	0.97935	1.03090
0.05143	20	0.99293	1.04519
0.04998	25	0.96936	1.02037
0.04633	30	0.92195	0.97047
0.04520	2	0.99703	1.04951
0.03513	27	0.94517	0.99491
0.03132	14	0.91850	0.96685
0.02891	17	0.91370	0.96179
0.02853	7	0.94617	0.99597
0.02797	12	0.92688	0.97567
0.02674	26	0.94773	0.99761
0.02373	15	0.91709	0.96536
0.02336	16	0.91572	0.96392
0.01595	11	0.92838	0.97725
0.01244	32	0.91687	0.96513
0.00986	18	0.91309	0.96115
0.00934	21	0.99222	1.04444
0.00810	22	0.99158	1.04377
0.00744	19	0.99650	1.04895
0.00304	33	0.91659	0.96483

3.2 Base load

Table 1 presents the simulation results of the active power LSF, arranged in descending order according to their respective bus numbers and normalized voltage magnitudes. The three buses with the highest LSFs and normalized voltage magnitudes not exceeding 1.01 are considered for REPG placement. Accordingly, buses 6, 28, and 9 with LSF values of 0.23866, 0.12332, and 0.10060 and corresponding normalized voltage magnitudes of 0.99964, 0.98287, and 0.98427, respectively, are selected as the optimal locations for REPG placement.

3.3 Scenario analysis

The proposed LSF-based approach for optimal REPG placement is analysed under three distinct scenarios to evaluate the impact of REPG unit type, size, and placement location. Tables 2 and 3 present the different types and sizes of REPG units used in the study across different scenarios. In Scenario 1, one REPG unit is placed at the most sensitive bus, i.e., bus 6, as identified by the proposed LSF-based approach. In Scenario 2, two REPG units of different sizes are installed at the two most sensitive buses, i.e., buses 6 and 28. Additionally, in Scenario 3, three REPG units, each with a distinct size, are placed at the three most sensitive buses, i.e., buses 6, 28, and 9, as determined by the proposed approach.

Table 2: Different solar PV REPG sizes and placement locations considered in each scenario

Scenario	Size MW	MVar	Bus No.
1	2.5896	-----------	6
2	1.8987	-----------	6
	0.6499	-----------	28
3	1.2773	-----------	6
	0.9861	-----------	28
	0.6911	-----------	9

Table 3: Different WTG REPG sizes and placement locations considered in each scenario

Scenario	Size MW	MVar	Bus No.
1	2.5582	1.7611	6
2	1.1712	0.1881	6
	1.0954	1.6670	28
3	1.0589	0.8329	6
	0.9861	0.8326	28
	0.6911	0.5973	9

Scenario 1

In this scenario, as stated earlier, only one REPG unit is considered for placement at bus number 6, which has the highest LSF. The simulation results show a significant improvement in the voltage profile when REPG unit is incorporated, compared to the base case without REPG unit. This improvement is clearly illustrated in Figure 3. The minimum voltage magnitude for the base load at bus number 18 is increased from 0.913 p.u to 0.950 p.u with the Solar PV REPG unit, and to 0.964 p.u with the WTG

REPG unit. Meanwhile, active power losses are significantly reduced when REPG unit is incorporated, compared to the base case without REPG unit , as illustrated in Figure 4. The total active power losses in the base case were found to be 0.203 MW. With the integration of Solar PV REPG unit, the losses were reduced to 0.110 MW, while the inclusion of WTG REPG unit further decreased the losses to 0.064 MW.

Scenario 2

In this scenario, two REPG units are considered for placement as shown in Tables 2 and 3. Similar to Scenario 1, the simulation results show a significant improvement in the voltage profile when REPG unit is incorporated, compared to the base case without REPG unit. This improvement is clearly depicted in Figure 5. The minimum voltage magnitude at bus number 18 increases from 0.913 p.u to 0.951 p.u with the 2 Solar PV REPG units and to 0.967 p.u with the 2 WTG REPG units. Additionally, active power losses are significantly reduced when REPG unit is incorporated, compared to the base case without REPG unit , as illustrated in Figure 6. With the integration of 2 Solar PV REPG units, the losses reduced to 0.094 MW, while with the inclusion of 2 WTG REPG units, the losses further decreased to 0.05 MW.

Scenario 3

In this scenario, three REPG units are considered for placement. The first and the second units are placed as in Scenario 2, while the third unit is placed at bus number 9, which has the third-highest LSF. Similar to previous scenarios, the simulation results show a significant improvement in the voltage profile when REPG unit is incorporated, compared to the base case without REPG unit. This improvement is clearly depicted in Figure 7. The minimum voltage magnitude at bus number 18 increased from 0.913 p.u to 0.965 p.u with the 3 Solar PV REPG units, and to 0.985 p.u with the 3 WTG REPG units. Similar to previous scenarios, active power losses are significantly reduced when REPG unit is incorporated, compared to the base case without REPG unit, as illustrated in Figure 8. With the integration of 3 Solar PV REPG units, the losses decrease to 0.089 MW, while with the inclusion of 3 WTG REPG units, the losses further decrease to 0.04 MW.

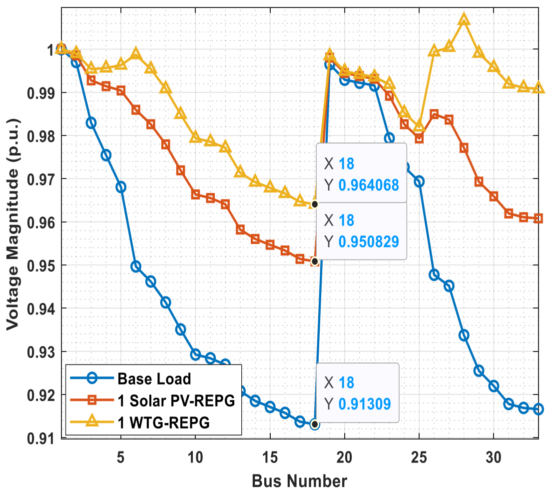

Figure 3:Voltage profile improvement in Scenario 1

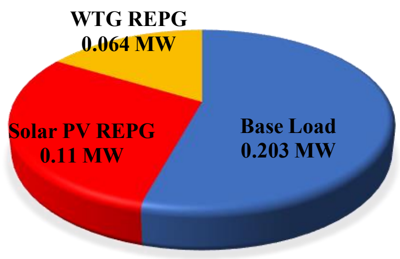

Figure 4: Active power loss contribution in Scenario 1

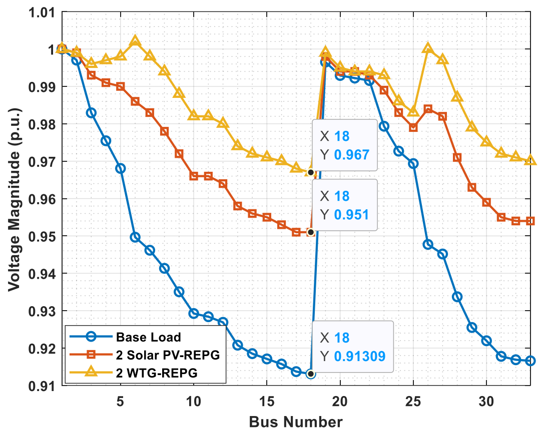

Figure 5: Voltage profile improvement in Scenario 2

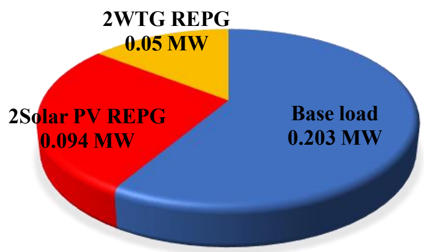

Figure 6: Active power loss contribution in Scenario 2

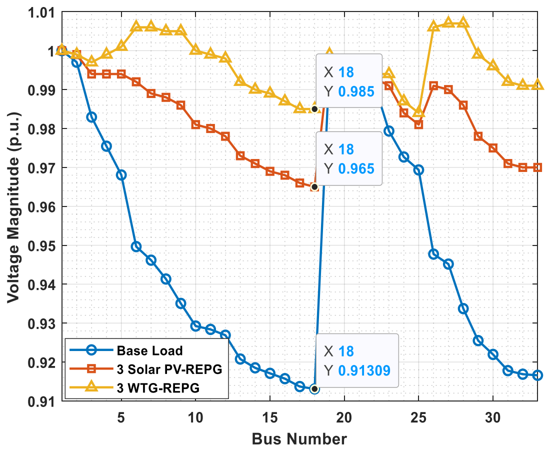

Figure7:Voltage profile improvement in Scenario 3

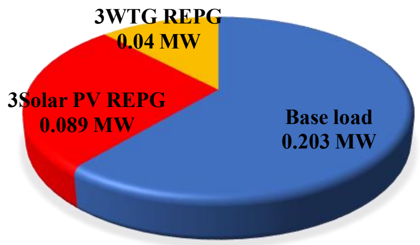

Figure 8: Active power loss contribution in Scenario 3

Scenarios Comparisons

Figure 9-11 shows the percentage voltage profile improvement at each bus of the IEEE-33 RDS in each scenario. In Figure 9, the highest voltage profile improvement is observed when the WTG REPG unit is used, with a maximum percentage voltage profile improvement of approximately 6%, compared to the Solar PV REPG, which achieves a maximum improvement of about 4%. Furthermore, Figure 10 presents the percentage voltage profile improvement at each bus of the RDS in scenario 2. The highest voltage profile improvement is observed when 2 WTG REPG units are used, with a maximum percentage voltage profile improvement of approximately 8%, compared to about 4.8% with 2 Solar PV REPG units. Additionally, Figure 11 presents the percentage voltage profile improvement at each bus of the RDS in scenario 3. The highest voltage profile improvement is observed when 3 WTG REPG units are used, with a maximum voltage profile improvement of approximately 8%, compared to about 5.9 % with 3 Solar PV REPG units.

Figure 12 shows a comparison of active power losses across the three scenarios. The results clearly depict that active power losses decrease significantly as the number of RER units increases. Furthermore, the WTG REPG units contribute more substantially to the reduction of active power losses in each scenario compared to the Solar PV REPG units.

Overall, the integration of WTG REPG units provides better performance in terms of both voltage profile enhancement and power loss reduction when compared to Solar PV REPG units.This is attributed to the reactive power support provided by the WTG REPG units.

3.4 Simulation results validation

Tables 4 and 5 provide a comparative assessment of different types, locations, and sizes of REPG units applied across the three proposed scenarios, alongside corresponding results from related research work presented in [21]. The results highlight that the selection and positioning of REPG units highly influence the effectiveness of active power loss reduction in the RDS. Enhanced power loss reduction is achieved when appropriate units of REPG are incorporated into the RDS. Additionally, the placement of REPG units proves critical, as demonstrated by the performance differences in Scenarios 2 and 3 and supported by findings in earlier research. Moreover, the type of REPG unit also plays a critical role. As previously discussed, WTG REPG units contribute more significantly to active power loss reduction compared to Solar PV-REPG units, primarily due to their ability to supply reactive power to the system.

4 CONCLUSION

This research work proposed optimal allocation of REPG units in RDS based on the Loss Sensitivity Factor to enhance the voltage profile and minimize power losses. Simulation outcomes demonstrated that WTG REPG units outperformed Solar PV REPG units due to their ability to supply reactive power. The findings validate the effectiveness of the proposed approach and highlight its improved performance compared to similar methods reported in the literature.

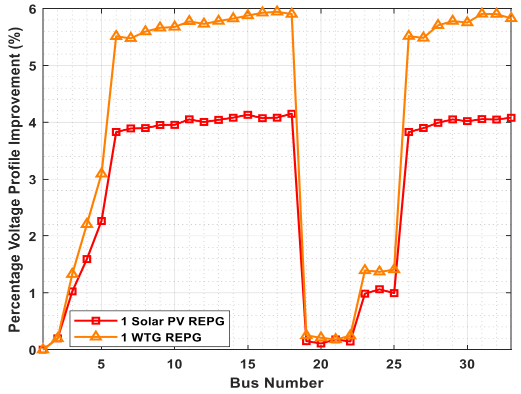

Figure 9: Comparison of percentage voltage profile improvement using different REPG units in Scenario1

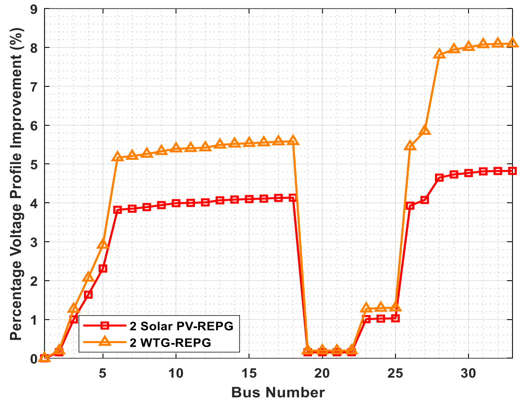

Figure 10: Comparison of percentage voltage profile improvement using different REPG units in Scenario 2

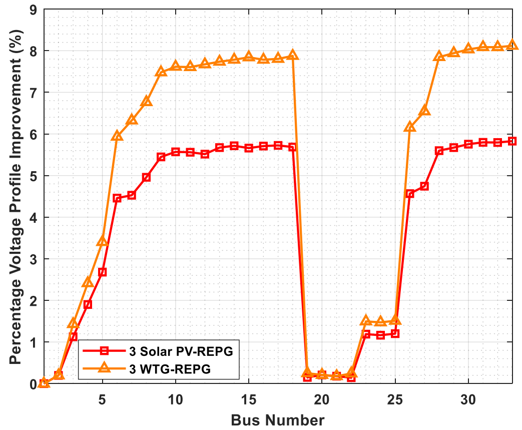

Figure 11: Comparison of percentage voltage profile improvement using different REPG units in Scenario 3

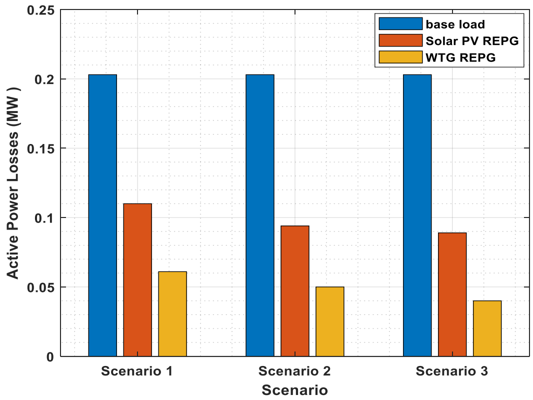

Figure 12: Comparison of active power losses across the three scenarios

Table 4: Solar PV REPG comparison with other methods

Unit	Size of Solar PV-REPG		Optimal location		Active Power losses	
	MW	MVar	This study	[21]	This study	[21]
1	2.5896	--------	6	6	0.11	0.11
2	1.8987 0.6499	-------	6 28	6 3	0.094	0.104
3	1.2773 0.9861 0.6911	-------	6 28 9	6 3 28	0.089	0.093

Table 5: WTG REPG comparison with other method

Unit	Size of WTG - REPG		Optimal location		Active Power losses	
	MW	MVar	This study	[21]	This study	[21]
1	2.5582	1.7611	6	6	0.064	0.064
2	1.1712 1.0954	0.1881 1.6670	6 28	6 3	0.05	0.053
3	1.0589 0.9861 0.6911	0.8329 0.8326 0.5973	6 28 9	6 3 28	0.04	0.049

REFERENCES

[1] M. H. Rehmani, M. Reisslein, A. Rachedi, M. Erol-Kantarci, and M. Radenkovic, "Integrating Renewable Energy Resources into the Smart Grid: Recent Developments in Information and Communication Technologies," *IEEE Trans Industr Inform*, vol. 14, no. 7, pp. 2814–2825, Jul. 2018, doi: 10.1109/TII.2018.2819169.

[2] A. N. Mulumba and F. Hooman, "Economic Contributions and Green Job Implications of Japan's Energy Transition:An Integrated Assessment of Decarbonization Scenarios in Kyushu Region," in *International Exchange and Innovation Conference on Engineering and Sciences*, Kyushu University, 2024, pp. 1246–1254. doi: 10.5109/7323416.

[3] A. K. Singh and S. K. Parida, "A novel hybrid approach to allocate renewable energy sources in distribution system," *Sustainable Energy Technologies and Assessments*, vol. 10, pp. 1–11, Jun. 2015, doi: 10.1016/j.seta.2015.01.003.

[4] V. Vita, T. Alimardan, and L. Ekonomou, "The impact of distributed generation in the distribution networks' voltage profile and energy losses," in *Proceedings - EMS 2015: UKSim-AMSS 9th IEEE European Modelling Symposium on Computer Modelling and Simulation*, Institute of Electrical and Electronics Engineers Inc., Sep. 2016, pp. 260–265. doi: 10.1109/EMS.2015.46.

[5] A. Y. Abdelaziz, Y. G. Hegazy, W. El-Khattam, and M. M. Othman, "Optimal allocation of stochastically dependent renewable energy based distributed generators in unbalanced distribution networks," *Electric Power Systems Research*, vol. 119, pp. 34–44, 2015, doi: 10.1016/j.epsr.2014.09.005.

[6] S. Settoul, R. Chenni, M. Zellagui, and H. Nouri, "Optimal Integration of Renewable Distributed Generation Using the Whale Optimization Algorithm for Techno-Economic Analysis," in *Lecture Notes in Electrical Engineering*, Springer Science and Business Media Deutschland GmbH, 2021, pp. 513–532. doi: 10.1007/978-981-15-6403-1_35.

[7] P. C. Hari, K. Subbaramaiah, and P. Sujatha, "Optimal DG unit placement in distribution networks by multi-objective whale optimization algorithm & its techno-economic analysis," *Electric Power Systems Research*, vol. 214, Jan. 2023, doi: 10.1016/j.epsr.2022.108869.

[8] M. Purlu and B. E. Turkay, "Optimal Allocation of Renewable Distributed Generations Using Heuristic Methods to Minimize Annual Energy Losses and Voltage Deviation Index," *IEEE Access*, vol. 10, pp. 21455–21474, 2022, doi: 10.1109/ACCESS.2022.3153042.

[9] S. Alizadeh, M. Mahdavian, and E. Ganji, "Optimal placement and sizing of photovoltaic power plants in power grid considering multi-objective optimization using evolutionary algorithms," *Journal of Electrical Systems and Information Technology*, vol. 10, no. 1, Jan. 2023, doi: 10.1186/s43067-023-00073-6.

[10] M. Yehia, D. Allam, and A. F. Zobaa, "A Novel Hybrid Fuzzy-Metaheuristic Strategy for Estimation of Optimal Size and Location of the Distributed Generators," *Energy Reports*, vol. 8, pp. 12408–12425, Nov. 2022, doi: 10.1016/j.egyr.2022.09.019.

[11] M. Z. Malik *et al.*, "Strategic planning of renewable distributed generation in radial distribution system using advanced MOPSO method," *Energy Reports*, vol. 6, pp. 2872–2886, Nov. 2020, doi: 10.1016/j.egyr.2020.10.002.

[12] A. Kwangkaew, S. Skolthanarat, C. Charoenlarpnopparut, and M. Kaneko, "Optimal Location and Sizing of Renewable Distributed Generators for Improving Robust Voltage Stability Against Uncontrollable Reactive Compensation," *IEEE Access*, vol. 11, pp. 52260–52274, 2023, doi: 10.1109/ACCESS.2023.3279716.

[13] R. Viral and D. K. Khatod, "An analytical approach for sizing and siting of DGs in balanced radial distribution networks for loss minimization," *International Journal of Electrical Power and Energy Systems*, vol. 67, pp. 191–201, 2015, doi: 10.1016/j.ijepes.2014.11.017.

[14] P. Kayal, S. Chanda, and C. K. Chanda, "An analytical approach for allocation and sizing of distributed generations in radial distribution network," *International Transactions on Electrical Energy Systems*, vol. 27, no. 7, Jul. 2017, doi: 10.1002/etep.2322.

[15] M. Kashyap, S. Kansal, and R. Verma, "Sizing and Allocation of DGs in A Passive Distribution Network Under Various Loading Scenarios," *Electric Power Systems Research*, vol. 209, Aug. 2022, doi: 10.1016/j.epsr.2022.108046.

[16] R. S. Rao, K. Ravindra, K. Satish, and S. V. L. Narasimham, "Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation," *IEEE Transactions on Power Systems*, vol. 28, no. 1, pp. 317–325, 2013, doi: 10.1109/TPWRS.2012.2197227.

[17] Kamisetti, Prakash, Maheswarapu, and Sydulu, "Particle Swarm Optimization Based Capacitor Placement on Radial Distribution Systems."

[18] V. V. S. N. Murthy and A. Kumar, "Comparison of optimal DG allocation methods in radial distribution systems based on sensitivity approaches," *International Journal of Electrical Power and Energy Systems*, vol. 53, no. 1, pp. 450–467, 2013, doi: 10.1016/j.ijepes.2013.05.018.

[19] H. R. E H Bouchekara, "Comprehensive Review of Radial Distribution Test Systems", doi: 10.36227/techrxiv.12578648.v1.

[20] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "MATPOWER: Steady-state operations, planning, and analysis tools for power systems research and education," *IEEE Transactions on Power Systems*, vol. 26, no. 1, pp. 12–19, Feb. 2011, doi: 10.1109/TPWRS.2010.2051168.

[21] E. O. Okendo and H. Farzaneh, "Optimal Allocation of Renewable Energy Resources to Improve Voltage Profile and Minimize Power Losses on the Most Critical Buses Prone to Voltage Instability," in *International Exchange and Innovation Conference on Engineering and Sciences*, Kyushu University, 2024, pp. 68–73. doi: 10.5109/7323244.