Fuzzy logic-based approach for optimal allocation of distributed generation in a restructured power system

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Article Info

Article history:

Received Jul 25, 2023
Revised Aug 10, 2023
Accepted Aug 31, 2023

Keywords:

Distributed generation
Fuzzy logic
Power loss
Power system optimization
Restructured power system

ABSTRACT

Fuzzy logic emerges as a powerful tool for optimizing power flow solutions, particularly in the context of deregulated power systems. By employing fuzzy logic controls, the ideal placement of distribution generators (DGs) can be determined, ensuring the reliability indices are identified through optimal power flow solutions and fuzzy logic controllers to maintain system feasibility. In a deregulated power system, strategic placement of distribution generator units plays a crucial role in minimizing power loss and enhancing overall system performance by mitigating fluctuations. To identify areas of weakness, especially within transmission companies, accessing optimal power flow algorithms becomes essential in a deregulated power system. Both transmission and distribution networks should be appropriately adjusted to alleviate congestion within the respective companies. The aggregator must assess system performance, utilizing data obtained from distribution and transmission companies within the deregulated power system.

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1. INTRODUCTION

The conventional power system network has undergone a transformation into a deregulated power system, where regulations are decentralized and overseen by independent system operators (ISO). Various methods have been explored to address power system stability and transient stability in the restructured power system [1]. Aggregators within transmission and distribution companies play a key role in regulating tariff details in the electricity markets. The expansion of transmission and distribution companies in the deregulated power system includes the integration of solar parks and windmills. To ensure system reliability within the bulk power system network, the uncertainties, and impacts on the environment in the decentralized system are considered, emphasizing the proper placement of distribution generators [2].

To stabilize performance reliability in the test system, the nature and duration of uncertainty within the deregulated power network are classified, and corresponding recovery methods are proposed. Fuzzy logic is employed to address the flexibility in the expansion of the restructured power system and stabilize the failure rate at each node [3]. To mitigate the complexity of line flows and bus flows in the deregulated power system, stochastic or fuzzy logic controllers are utilized. Short-term and long-term uncertainties resulting from the presence of solar parks and wind energy in the deregulated power system network are addressed through strategic planning in power system planning [4].

When integrating wind energy and solar energy into distribution companies, a well-defined distribution generator allocation scheme is crucial [5]. The integration can be aligned with adaptive relay settings and system reliability. Intelligent electronic devices and relay settings help restore dynamic changes in fault current and network parameters [6]. Closed-loop integral controls are implemented to monitor primary and backup protection within the power system transmission and distribution network. Bulk storage of electricity within distribution companies in the restructured power industry is focused on wind energy and other renewable sources [7]. Ambiguities in bulk storage from renewable sources can lead to increased interruption rates and affect electricity markets.

Managing multiple distribution generators poses a significant challenge for distribution and transmission companies [8]. Increasing the number of distribution generators can result in transmission congestion, necessitating effective management of real power and reactive power fluctuations to minimize losses in the transmission network. Genetic algorithm and particle swarm optimization techniques are employed to determine the optimal size and location of distribution generators within the transmission network [9]. The demand tariff projected by the regulatory authority oversees congestion management in the transmission network and accounts for contingencies in the electricity markets. Investment and operating costs of distribution generators are considered in determining the final price, which is then communicated to independent system operators [10]. The congestion management in the transmission network is demonstrated using the IEEE test system, and subsequent improvements are justified.

2. THE IMPORTANCE OF DISTRIBUTED GENERATION INSTALLATION

Distribution generators (DGs) installed at distribution companies can be classified as passive when electrical power is supplied from centralized committed generating units to consumers. However, the addition of DG units transforms the system into an active distribution network, enabling bidirectional power flows [11]. The active distribution network brings numerous advantages, including reduced power losses, improved voltage profiles in the transmission network, emission reduction, and enhanced power quality. These benefits, such as voltage stability improvement and line loss reduction, are particularly crucial in areas where distribution generators are located.

The integration of distribution generators in restructured power systems has had a significant impact on improving system reliability [12]. It enhances system adequacy and security while enabling more economical dispatch of electrical energy. The placement of distribution generators in the deregulated power system has yielded noteworthy outcomes.

Typically, distribution generators are situated close to the load side, resulting in negligible transmission losses, increased power transfer capability, and minimized power transfer costs from wind turbines. Fluctuations in real power and reactive power are reduced, thereby eliminating the need for power system stabilizers at each location [13]. As oscillations in power become negligible, the installation of capacitor banks and power system stabilizers can be minimized. The augmentation of power transfer capacity allows for the extension of operational domains to accommodate load enhancements or expansions within distributed power systems, such as those found in electric vehicles [14]. The delivery of power to consumers becomes more efficient with proper placement of distribution generators, reducing the need for load curtailment.

Selecting the appropriate location for different types of distribution generators is crucial, considering environmental conditions, geographical factors, temperature, wind velocity, and other relevant factors [15]. Typically, wind power or wind turbine-based distribution generation systems are established in areas with favorable wind conditions, while solar power generation systems are set up in shade-free areas with optimal sunlight coverage [16]. Distribution generators exhibit high flexibility, allowing their generated power to be easily integrated into the grid station of a restructured power system. Reliability indices in power systems oversee disruptions like flickers, leading to adjustments in operational domains. These adjustments are tailored to suit various applications, including the integration of electric vehicles, while also addressing associated power quality concerns within the context of the deregulated power industry [17].

3. EMPLOYMENT OF DISTRIBUTION GENERATORS

To determine the optimal placement of distribution generators, various optimization techniques are employed. Through power flow analysis using genetic algorithm or other optimization algorithms, the size and ratings of distribution generators can be selected to minimize power flow losses and identify the most suitable locations. The objective of the optimization algorithm is to identify the weaker areas within the reliability test system and install distribution generators accordingly. After installation, the cost of remedial actions and the estimated cost of energy not supplied are calculated. The size and associated costs of the distribution generator are evaluated and compared with the remedial action cost [18]. The optimized power flow solution takes into account constraints in real power and reactive power, enabling the calculation of the corresponding load flow solution. The capacity of distribution generators is regulated by independent system operators, and the installation locations are determined through power flow or load flow analysis using the iterative Newton-Raphson method.

4. DIMENSION AND RATING OF DGS

The ratings for distribution generators are determined based on the existing network analogy and the specific types of loads that need to be connected. However, certain technical dimensions and corresponding details must be considered. The capacity of a distribution generator is defined to be 20% higher than the demand posted to the feeder. When utilizing distribution generators such as solar power systems, the tolerance should exceed 30% of the feeder demand to account for uncertainties in the distribution system [19]. In deregulated power systems, if there are island loads connected to the distribution generators, the generator size should be twice that of the load attached to the feeder.

To design protective devices in the restructured power system, it is essential to take note of the short circuit or fault current in the connected network. The cost of the protective devices is also considered to accommodate any increase or decrease in the number of distribution generator units in the deregulated power system [20]. The estimation of unserved energy, evaluated through reliability indices, is taken into account when designing or modeling the distribution generator. Typically, the generating limit of the distribution generators is set to be 20% higher than the unavailability reliability index.

5. DG ALLOCATION USING FUZZY LOGIC

Fuzzy logic is a highly effective tool utilized for optimizing power flow solutions. In the restructured power system, identifying the ideal placement of distribution generators is a complex task, and this is where fuzzy logic controls come into play. Fuzzy logic controllers aid in determining the precise location for deploying distribution generators [21]. To identify the optimal location for placing distribution generators in the restructured power system, it is crucial to utilize optimal power flow solutions and employ fuzzy logic controllers. These tools help in evaluating reliability indices, which further contribute to the decision-making process.

5.1. Fuzzy logic controls

Fuzzy logic is a mathematical approach that characterizes data in an arithmetic progression, enabling the determination of acceptable parameters in power flow solutions [22]. By predefining the decision criteria as member functions, the inherent fuzziness within the system is effectively addressed. A key advantage of employing fuzzy logic controls is their ability to provide fuzzy values instead of binary outputs, allowing for clear identification of congestion levels. The predefined tolerance limits within fuzzy logic controllers facilitate decision-making in various scenarios [23]. The interactions between light and dark events are explicitly specified. The design complexity is reduced, making it easier and more reliable to modify system parameters during the design process. This flexibility enables the development of new systems with the necessary parameters. Furthermore, the computational complexity associated with multifaceted calculations is minimized when utilizing fuzzy logic controls.

In deregulated power systems, optimal placement of distribution generator units is crucial for reducing power loss and improving stability by mitigating fluctuations. The reliability test system identifies oscillations based on relevant reliability and interruption indices. Conducting an optimized load flow analysis while considering specific constraints is essential for addressing power fluctuation and interruption indices throughout the entire system. In the context of power system networks, the fuzzy logic framework defines pre-existing minimization and maximization functions. Membership functions are employed to determine the size and rating of distribution generators, and the resulting evaluations are compared to reliability indices. During the formulation of optimization techniques or methodologies using fuzzy logic, indices obtained from different locations are equated with controller limits in power flow analysis [24].

The optimization functions are precisely defined to evaluate real power, reactive power, and all electrical parameters within a restructured or deregulated power system. The following represents the optimization function with the necessary constraints, minimize: P_{Loss}(x).

$$P_{Loss} = \sum_{k=1}^{NS} Gk \left(|V_i|^2 + |V_j|^2 - 2|V_i|\,|V_j| \cos(\delta\mathrm{i} - \delta\mathrm{j}) \right) \tag{1}$$

$$P_i = |V_i| \sum |V_k| \left[G_{ik}\, cos(\theta_i - \theta_k) + B_{ik}\, sin(\theta_i - \theta_k)\right] \tag{2}$$

$$Q_i = |V_i| \sum |V_k| \left[G_{ik}\, sin(\theta_i - \theta_k) + B_{ik}\, cos(\theta_i - \theta_k)\right] \tag{3}$$

Subject to constraints: i) power loss limits: $P_{Loss}^{With\ DG} < P_{Loss}^{Without\ DG}$, ii) DG power limits: $P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max}$, and iii) equality constraints: $\Sigma_{i=1}^{n} P_{Gi} \leq \Sigma_{i=1}^{n} (P_i + P_{Loss})$.

Minimizing power losses in the transmission system while ensuring compliance with power flow constraints is essential. In deregulated power systems, accessing optimal power flow algorithms is necessary to identify weak areas within the network, particularly in transmission companies. It is crucial to adjust the transmission and distribution networks to alleviate congestion issues in both sectors. The aggregator plays a key role in evaluating system performance, gathering data from distribution and transmission companies operating within the deregulated power system.

5.2. Employment of fuzzy logic controls

When incorporating multiple distribution generators into a restructured power system, numerous uncertainties arise due to the unpredictable nature of energy generated from renewable sources. Fuzzy logic controls employ various arithmetic operations and processes to effectively mitigate these uncertainties [25]. The inclusion of heuristic rules in fuzzy logic controls helps swiftly stabilize overshoot percentages and bring the operating points of the restructured power system within safer limits. By utilizing conditional logic sequences alongside heuristic rules, the optimal location for installing distribution generators can be determined, along with their corresponding ratings in the deregulated power system. The establishment of distribution generator locations is determined through power flow analysis in the reliability test system, which identifies weak points in the network. The rules of the fuzzy logic control system are outlined as: IF Foundation, THEN Supposition.

To determine the appropriate installation site for distribution generators, heuristic rules incorporating multiple foundations are formulated. These rules take into account input parameters such as indices for monitoring power loss and voltage magnitudes in the deregulated power system network. TensorFlow models were employed in conjunction with fuzzy logic to assess the network's severity within the restructured power system. This approach yields proportional functions for the deployment of distribution generators [26]. Depending on the severity level, the heuristic rules within the fuzzy logic system are formulated as:

- If the severity of the system is high, it prioritizes the installation of distribution generators in the deregulated power system.
- If the severity of the system is moderate, it assigns medium priority to the installation of distribution generators in the deregulated power system.
- If the severity of the system is low, it assigns lower priority to the installation of distribution generators in the deregulated power system.

The fuzzy logic controllers accurately identify the installation sites for distribution generators using appropriate membership functions. The inference system of the fuzzy logic controls follows the widely used Mamdani fuzzy inference system, which employs the "most method" inference technique. In the Mamdani fuzzy inference system, the limits of the variable that determine priority are defined. The power loss in the system is denoted as PL, while the corresponding index is represented as power loss index (PLI).

The input parameters within the fuzzy inference system are logical variables, with one parameter representing voltage magnitude and the other parameter representing power losses in the system. Suitable reliability indices are equated with the fuzzy inference system, providing corresponding outcomes. Both voltage magnitude and power losses in the transmission and distribution networks are represented in per unit values. The tolerance for per unit values is set at 10%, allowing for a range from 0.9 to 1.1. Similarly, power loss variables must be defined in per unit values with the necessary tolerance based on the specific application.

$$PLI(i) = \frac{(Loss\ reduction\ (i) - Loss\ reduction(minimum))}{(Loss\ reduction\ (maximum) - Loss\ reduction(minimum))} \quad (4)$$

The fuzzy inference system regulates the membership functions using different parameters, ranging from acceptable low values to upper limit high values. These functions use letters to represent the severity of variables. The membership functions are denoted as: S: small, SM: small medium, M: medium, MH: medium high, and H: high. These variables are derived from optimal power flow solutions and are arranged in a sequence. Typically, trapezoidal functions are employed for the selection process. This allows for variations in power reliability indices within the restructured power system. The installation of distributed generators depends on these reliability indices, which are evaluated using heuristic functions in a logical sequence approach.

Table 1 presents the decision-making process in fuzzy logic controls. These rules are applied to determine suitable locations for establishing distribution generators in the distribution companies of a deregulated power system network. The voltage magnitude in the restructured power system, denoted as VM, is described in Table 1.

6. RESULTS AND DISCUSSION

The losses occurring in the transmission and distribution network are assessed using a loss index called the power loss index (PLI). The fuzzy pronouncement matrix represents the power loss index (PLI). The Table 1 displays the membership function that can be utilized to identify the appropriate location for establishing distribution generators.

Figure 1 illustrates the substantial reduction in losses within the test system. The presence of an adequate number of distribution generators and their strategic placement results in a significant improvement. This leads to the voltage magnitude approaching unity (per unit) and the losses becoming negligible.

The compilation of power loss variations for each case is depicted in Figure 2, showcasing the cumulative response and characteristics. The evaluation of power loss variations in the test system is dependent on the type and rating of the distribution generators. Each case exhibits a different level of reduction in power losses, highlighting the effectiveness of the optimization technique employed in the assessment of the test system.

Figure 2 presents the evaluation and compilation of voltage variations for each case within the fuzzy inference system. The observed improvement in voltage magnitude signifies the effectiveness of the optimization technique employed in the test system assessment. The voltages are found to be in close proximity to the one per unit value, indicating increased reliability within the deregulated power system network. However, it is crucial to exercise caution when placing distribution generators to minimize overshoot in the power system network. Figure 3 presents the variation of power loss with respect to the placement of DGs.

From the Table 2, it is evident that by adapting GA technique there is a better percentage loss reduction in IEEE 14 Bus. DG sizing is very optimal with the results derived from fuzzy logic technique where in there will be huge positive impact on cost savings in terms of loss reduction as well as DG size. Table 2 clearly proves there is almost 73.14% reduction in power losses on an average for the study conducted up to installation of three DGs.

Table 1. Fuzzy pronouncement matrix

AND		VM				
		S	SM	M	MH	H
	S	SM	SM	S	S	S
PLI	SM	M	SM	SM	S	S
	M	MH	M	SM	S	S
	MH	MH	MH	M	SM	S
	H	H	MH	M	SM	SM

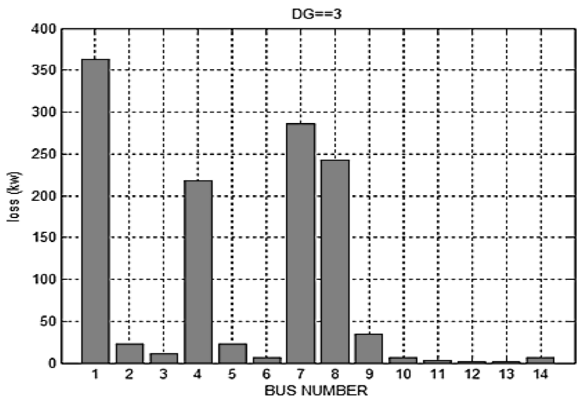

Figure 1. Variation of power losses after the establishment of three DGs

Table 2. Comparison of results of test system

Cases with DGs		DG Bus setting	Prime DG size (KW)	Power loss with DG (MW)	Power loss without DG (MW)	Percentage lessening in loss
Case 1	Base case	--	--	--	53.5	--
Case 2	DG one	11	1060	51.5	----	5.5%
Case 3	DG one	4	798	26.54	----	50.39%
	DG two	7	759			
Case 4	DG one	6	239	14.37	----	73.14%
	DG two	4	273			
	DG three	2	665			

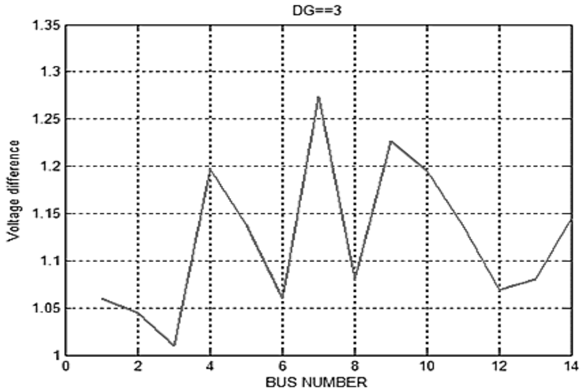

Figure 2. Variation of voltage magnitude after the inclusion of 3 DGs

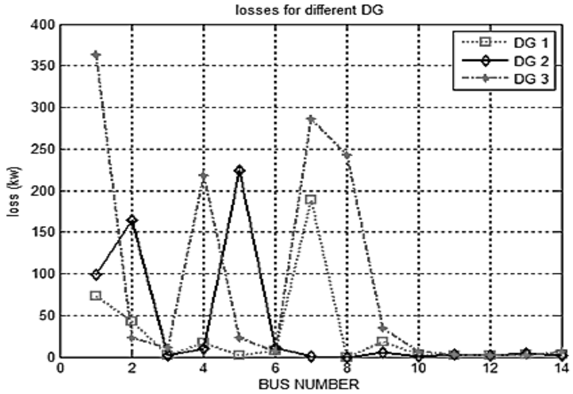

Figure 3. Power loss variation with respect to the DG placement

7. CONCLUSION

The utilization of fuzzy logic algorithm for the allocation of DGs yields superior outcomes in the given sample system, considering the optimal size and location. This research study demonstrates the reduction in loss percentage achieved through the integration of multiple distribution generators at the optimal size and location, as determined by fuzzy logic. The results of the research study unequivocally display an average decrease of around 73% power loss, when incorporating multiple distribution generators at their most suitable sizes and positions. Based on the results, the installation of either a single DG or two DGs resulted a reduction in power loss, which amounts to approximately 50%. However, the installation of three DGs led to an increase in the system power loss, and the percentage reduction in loss in the distribution network dropped to 73%. Therefore, it can be concluded that incorporating multiple DGs at suitable location significantly contributes to the reduction of power loss when compared to the base case results (without DG). Additionally, after incorporating DGs at their optimal locations, there is a reduction in power loss, and the voltage magnitude is very close to one per unit. The scope of this endeavor can be expanded to specific renewable sources of distributed generation, allowing for an evaluation of installation costs and the integration of DG with the power grid to ensure system stability.

ACKNOWLEDGEMENTS

Authors thank the Hindustan Institute of Technology and Science, Chennai for the sponsor and financial support.

REFERENCES

[1] H. B. Puttgen, D. R. Volzka, and M. I. Olken, "Restructuring and Reregulation of the U.S. Electric Utility Industry," *IEEE Power Engineering Review*, vol. 21, no. 2, pp. 8–10, 2001, doi: 10.1109/39.896819.

[2] S. S. Reddy, "Optimal Placement of FACTS Controllers for Congestion Management in the Deregulated Power System," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 3, pp. 1336–1334, Jun. 2018, doi: 10.11591/ijece.v8i3.pp1336-1344.

[3] N. M. Lindsay and A. K. Parvathy, "Power System Reliability Assessment in a Complex Restructured Power System," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 4, pp. 2296–2302, Aug. 2019, doi: 10.11591/ijece.v9i4.pp2296-2302.

[4] E. L. Draper, "Assessment of Deregulation and Competition," *IEEE Power Engineering Review*, vol. 18, no. 7, pp. 17–18, Jul. 1998, doi: 10.1109/MPER.1998.686949.

[5] F. M. Rodrigues, L. R. Araujo, and D. R. R. Penido, "A Method to Improve Distribution System Reliability Using Available Mobile Generators," *IEEE Systems Journal*, vol. 15, no. 3, pp. 4635–4643, Sep. 2021, doi: 10.1109/JSYST.2020.3015154.

[6] R. Kizito, X. Li, K. Sun, and S. Li, "Optimal Distributed Generator Placement in Utility-Based Microgrids During a Large-Scale Grid Disturbance," *IEEE Access*, vol. 8, pp. 21333–21344, 2020, doi: 10.1109/ACCESS.2020.2968871.

[7] C. Thrampoulidis, S. Bose, and B. Hassibi, "Optimal Placement of Distributed Energy Storage in Power Networks," *IEEE Transactions on Automatic Control*, vol. 61, no. 2, pp. 416–429, Feb. 2016, doi: 10.1109/TAC.2015.2437527.

[8] D. S. Kumar, D. Srinivasan, and T. Reindl, "A Fast and Scalable Protection Scheme for Distribution Networks with Distributed Generation," *IEEE Transactions on Power Delivery*, vol. 31, no. 1, pp. 67–75, Feb. 2016, doi: 10.1109/TPWRD.2015.2464107.

[9] M. Bazrafshan, N. Gatsis, and E. Dall'Anese, "Placement and Sizing of Inverter-Based Renewable Systems in Multi-Phase Distribution Networks," *IEEE Transactions on Power Systems*, vol. 34, no. 2, pp. 918–930, Mar. 2019, doi: 10.1109/TPWRS.2018.2871377.

[10] P. Dehghanian, M. Fotuhi-Firuzabad, S. Bagheri-Shouraki, and A. A. Razi Kazemi, "Critical Component Identification in Reliability Centered Asset Management of Power Distribution Systems Via Fuzzy AHP," *IEEE Systems Journal*, vol. 6, no. 4, pp. 593–602, Dec. 2012, doi: 10.1109/JSYST.2011.2177134.

[11] N. K. Rayaguru, N. M. Lindsay, R. G. Crespo, and S. P. Raja, "Hybrid bat–grasshopper and bat–modified multiverse optimization for solar photovoltaics maximum power generation," *Computers and Electrical Engineering*, vol. 106, p. 108596, Mar. 2023, doi: 10.1016/j.compeleceng.2023.108596.

[12] X. Bi, S. Cao, and D. Zhang, "A Variety of Engine Faults Detection Based on Optimized Variational Mode Decomposition-Robust Independent Component Analysis and Fuzzy C-Mean Clustering," *IEEE Access*, vol. 7, pp. 27756–27768, 2019, doi: 10.1109/ACCESS.2019.2901680.
[13] H. U. R. Habib *et al.*, "Analysis of Optimal Integration of EVs and DGs Into CIGRE's MV Benchmark Model," *IEEE Access*, vol. 10, pp. 95949–95969, 2022, doi: 10.1109/ACCESS.2022.3204311.
[14] A. T. Jacob and N. M. Lindsay, "Designing EV Harness Using Autocad Electrical," in *2022 8th International Conference on Smart Structures and Systems (ICSSS)*, Apr. 2022, pp. 1–4, doi: 10.1109/ICSSS54381.2022.9782226.
[15] Y. Wang, G. Wei, H. Yang, H. Chen, and Z. Ouyang, "Novel Protection Scheme of Single-Phase Earth Fault for Radial Distribution Systems With Distributed Generators," *IEEE Transactions on Power Delivery*, vol. 33, no. 2, pp. 541–548, Apr. 2018, doi: 10.1109/TPWRD.2016.2585380.
[16] A. K. Singh and S. K. Parida, "Optimal placement of DGs using MINLP in deregulated electricity market," in *Proceedings of the International Conference on Energy and Sustainable Development: Issues and Strategies (ESD 2010)*, Jun. 2010, pp. 1–7, doi: 10.1109/ESD.2010.5598876.
[17] D. V. K. Sarma and N. M. Lindsay, "Structural Design and Harnessing for Electric vehicle Review," in *2023 9th International Conference on Electrical Energy Systems (ICEES)*, Mar. 2023, pp. 107–111, doi: 10.1109/ICEES57979.2023.10110190.
[18] A. M. Yasin and M. F. Alsayed, "Fuzzy logic power management for a PV/Wind microgrid with backup and storage systems," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 4, pp. 2876–2888, Aug. 2021, doi: 10.11591/ijece.v11i4.pp2876-2888.
[19] M. Ghofrani, A. Arabali, M. Etezadi-Amoli, and M. S. Fadali, "A Framework for Optimal Placement of Energy Storage Units Within a Power System with High Wind Penetration," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 2, pp. 434–442, Apr. 2013, doi: 10.1109/TSTE.2012.2227343.
[20] A. O. Aluko, R. P. Carpanen, D. G. Dorrell, and E. E. Ojo, "Robust State Estimation Method for Adaptive Load Frequency Control of Interconnected Power System in a Restructured Environment," *IEEE Systems Journal*, vol. 15, no. 4, pp. 5046–5056, Dec. 2021, doi: 10.1109/JSYST.2020.3005979.
[21] S. S. Rachakonda, G. Jaya Prakash, and N. M. Lindsay, "Modeling and Simulation of Hybrid Energy Generation for Stand Alone Application," in *2022 8th International Conference on Smart Structures and Systems (ICSSS)*, Apr. 2022, pp. 1–6, doi: 10.1109/ICSSS54381.2022.9782301.
[22] Y. Mi, H. Zhang, Y. Fu, C. Wang, P. C. Loh, and P. Wang, "Intelligent Power Sharing of DC Isolated Microgrid Based on Fuzzy Sliding Mode Droop Control," *IEEE Transactions on Smart Grid*, vol. 10, no. 3, pp. 2396–2406, May 2019, doi: 10.1109/TSG.2018.2797127.
[23] S. R. Ghatak and P. Acharjee, "Optimal Allocation of DG Using Exponentential PSO with Reduced Search Space," in *2016 Second International Conference on Computational Intelligence & Communication Technology (CICT)*, Feb. 2016, pp. 489–494, doi: 10.1109/CICT.2016.103.
[24] V. S. Sree and C. S. Rao, "Distributed power flow controller based on fuzzy-logic controller for solar-wind energy hybrid system," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 4, pp. 2148–2158, Dec. 2022, doi: 10.11591/ijpeds.v13.i4.pp2148-2158.
[25] K.-H. Tan, F.-J. Lin, C.-M. Shih, and C.-N. Kuo, "Intelligent Control of Microgrid with Virtual Inertia Using Recurrent Probabilistic Wavelet Fuzzy Neural Network," *IEEE Transactions on Power Electronics*, vol. 35, no. 7, pp. 7451–7464, Jul. 2020, doi: 10.1109/TPEL.2019.2954740.
[26] M. L. Nesaian, A. E. Rao, and M. P. Kalyan, "Real-Time Object Detection with Tensorflow Model Using Edge Computing Architecture," in *2022 8th International Conference on Smart Structures and Systems (ICSSS)*, Apr. 2022, pp. 01–04, doi: 10.1109/ICSSS54381.2022.9782169.

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