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OPTIMIZATION OF SOLAR PANEL USAGE IN GRID-CONNECTED HYBRID ENERGY SYSTEMS USING FUZZY METHOD

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ABSTRACT

The hybrid grid-connected power generation system combines solar power, wind power, and the PLN grid to meet the electricity demands of facilities such as schools, laboratories, mosques, and kindergartens at MTs Parmiyatu Wassa'adah School. Due to insufficient wind speed below the turbine's operational threshold, wind turbines cannot contribute to electricity generation, making solar power the primary energy source. Solar power capacity is crucial for meeting the electricity needs of these facilities. This study applies the Fuzzy method to analyze the optimal utilization of solar panels in a grid-connected hybrid system for electricity demand. Simulation results indicate three levels of solar panel utilization, with the most optimal performance achieved when school electricity usage is low, and additional loads are minimized.

Keywords: *electrical load, fuzzy method, hybrid grid-connected system, solar panel, wind turbine.*

I. INTRODUCTION

HYBRID energy systems for power generation often rely on renewable energy sources [1]–[3], such as wind, solar, geothermal, biomass, and water[4]–[6]. Among these, wind and solar energy are widely favored due to their ubiquitous availability [7]. Conversely, geothermal and water energy are location-specific [8], while biomass requires specific fuels [9] and is typically used in designated development areas [10], [11].

Wind energy conversion requires wind turbines, available in vertical and horizontal axis types [12]–[14]. This study employs horizontal axis wind turbines to harness wind energy. Similarly, solar panels are used to convert solar energy into electrical energy [15], [16]. However, the electrical output from wind and solar energy is highly dependent on weather conditions [17], [18]. Solar panel efficiency fluctuates during cloudy or sunny conditions, while wind speed variations impact electricity generation from turbines [19], [20]. To address these challenges and maximize electricity production, this study explores a combination of wind and solar power systems.

Research on the integration of solar power plants with the PLN electricity network to support electricity availability in school buildings has been conducted by several researchers [21], [22]. At MTs Parmiyatu Wassa'adah School, located in Percut Sei Tuan, Deli Serdang Regency, North Sumatra, the facilities include classrooms, a teacher's room, a principal's office, a laboratory, a prayer room (mosque), and a kindergarten. Currently, electricity needs are fully supplied by State Electricity Company (PLN). grid-connected power generation system, the electricity load for schools, laboratories, mosques, and kindergartens can be supported by solar panels and wind turbines, while still utilizing PLN electricity.

The feasibility analysis of solar panel usage in smart systems has been conducted using the Fuzzy grid simulation method [23]–[25]. This method is implemented through MATLAB [26]. Fuzzy logic, a rule-based approach, addresses uncertainty and ambiguity by utilizing degree-of-truth values between "true" and "false," making it suitable for complex systems that are challenging to model mathematically, such as temperature control or decision-making. Neural networks, inspired by the workings of the human brain, learn from data to recognize patterns, classify, and predict, making them ideal for applications such as image recognition and natural language processing [27], [28]. Optimization algorithms, on the other hand, identify the optimal solution by maximizing or minimizing an objective function, making them suitable for problems like scheduling or design [29]–[32]. Fuzzy logic is particularly effective in handling uncertainty, neural networks excel in pattern recognition with large datasets, and optimization algorithms are adept at solving problems with multiple variables or constraints [33], [34].

This study builds on prior research addressing the integration of renewable energy, such as solar and wind power, in grid-connected hybrid systems. By incorporating renewable energy into a hybrid electric system, it advances the field through a Fuzzy method-based approach to optimize solar energy utilization. The research makes a significant contribution by analyzing load variations across different facilities and demonstrating how solar power plants can effectively meet these demands. Furthermore, it underscores the importance of integrating renewable energy sources into grid systems to reduce dependency on PLN and enhance energy sustainability. By evaluating the performance of solar panels under varying operational conditions and applying smart control systems, this study enriches understanding of energy management strategies in hybrid systems, contributing to the adoption of clean and sustainable energy solutions for the future.

The purpose of this article is to evaluate the effectiveness of solar panel utilization in a grid-connected hybrid system using the Fuzzy method. Simulation results reveal the contribution of solar panels to electrical loads, including lighting, computers, fans, and air conditioners in kindergartens, laboratories, school buildings, and mosques.

II. RESEARCH METHOD

The primary electricity source for school buildings, laboratories, kindergartens, and mosques is PLN (the national power utility company), which meets the facilities' overall energy needs. However, a hybrid grid-connected power generation system supplements PLN's supply by integrating solar panels and wind turbines as alternative energy sources. This hybrid system aims to reduce reliance on PLN by utilizing renewable energy to power the buildings.

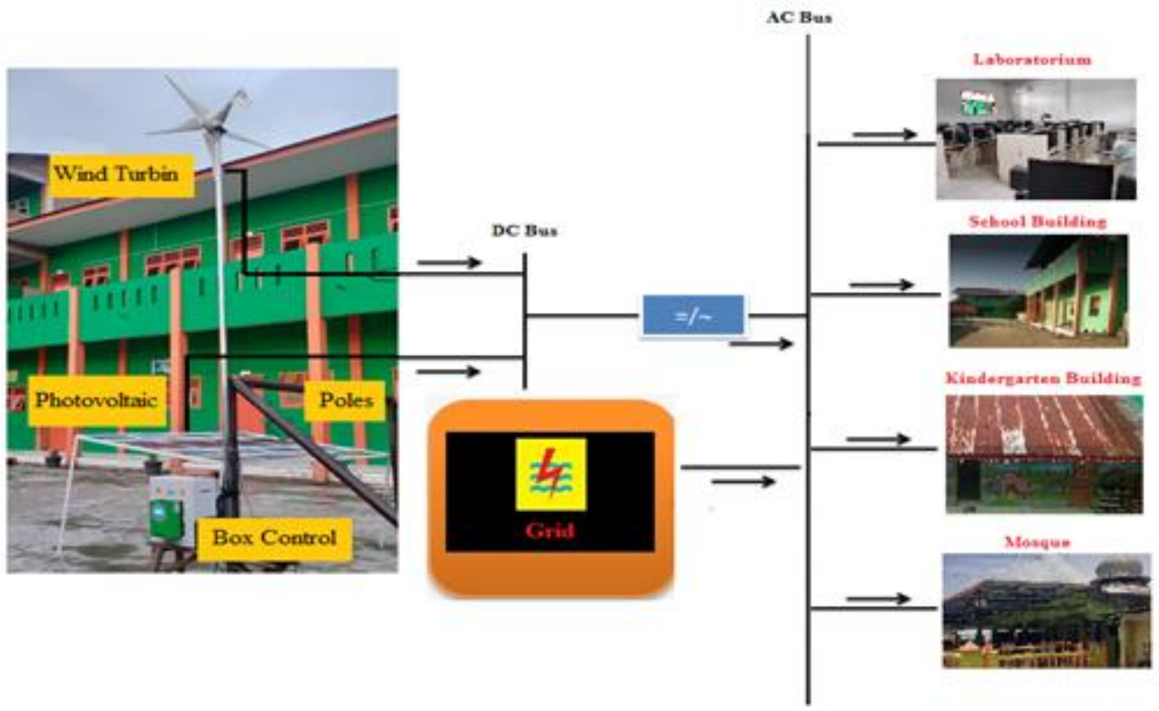


Figure 1. Power flow diagram of the hybrid grid-connected power generation system.

TABLE 1
SPECIFICATION DATA OF EQUIPMENT USED IN THE HYBRID GRID-CONNECTED POWER GENERATION SYSTEM.

Equipment name	Capacity	Quantity
Wind Turbine	500 Watt; 5 bilah;12 V; 1.1m/s; Model SH-D2	1
Solar Panel	Monocristalyne 30Wp; 12V	21
Battery	100AH/12V	2
Inverter Hybrid	1kW, 12Vdc/220Vac	1

TABLE 2
THE ELECTRIC LOAD CAPACITY

Load	Maximum capacity [kW]	Equipment
School building	10	Computer, Lamps, AC, Fan
Laboratory	5	Computers
Mosque	7	Lamps, AC
Kindergarten	3	Lamps, Computer, Fan

In this scenario, the average wind speed in the school area is insufficient to effectively drive the wind turbine blades. The wind speed falls below the threshold required for electricity generation, rendering the turbine inoperable under these conditions. The wind turbine's location within the school environment is suboptimal due to obstacles from classroom buildings that impede wind flow. The tall and dense structures surrounding the turbine further reduce wind speed, significantly diminishing its performance in generating electricity. This strategic limitation prevents effective utilization of available wind energy. Consequently, the hybrid system receives negligible or no contribution from wind energy, relying solely on solar panels as the renewable energy source supporting electricity demand in addition to PLN.

Figure 1 illustrates the system configuration, showing the integration of solar panels, wind turbines, and PLN in the hybrid grid-connected system. Solar panels are the primary renewable energy source in this setup, reducing dependency on PLN, particularly during daylight hours when solar energy availability is highest.

The specifications of the equipment used in the system, along with the load capacity for each facility (school buildings, laboratories, kindergartens, and mosques), are detailed in Tables 1 and 2. These tables provide crucial insights into energy consumption patterns and the capacity of renewable energy equipment, enabling an evaluation of the hybrid system's efficiency and its potential to meet energy demands. Despite the absence of wind energy support, the integration of solar panels offers a sustainable solution to reduce reliance on traditional power sources and encourages the use of renewable energy within the school environment.

The implementation of a hybrid grid-connected power generation system can be applied in various scenarios, such as:

1) school and kindergarten buildings: Daily load usage is at a medium level between 8:00 AM and 2:00 PM and reaches maximum levels from 2:00 PM to 4:00 PM;
2) laboratory: Load levels vary from medium to maximum depending on the scheduled use and the number of computers in operation; and
3) mosque: Load usage ranges from minimum to maximum between 8:00 AM and 4:00 PM, influenced by the availability of natural light entering the mosque.

The mathematical model for the system is expressed as (1). When wind speeds are insufficient to drive wind turbine blades, the wind turbine contribution can be neglected, simplifying the equation to (2).

$$P_{pln} + P_{pV} + P_{wt} = P_{Sch} + P_{Lab} + P_{KG} + P_{Mo} \quad (1)$$

$$P_{pln} + P_{pV} = P_{Sch} + P_{Lab} + P_{KG} + P_{Mo} \quad (2)$$

To evaluate the contribution of solar panels in meeting various loads, the electricity supply from PLN is initially disregarded. In this case, the required power is assumed to be supplied solely by solar panels, with the output categorized into minimum, medium, and maximum levels, as illustrated in Figures 2(a), 2(b), 2(c), and 2(d).

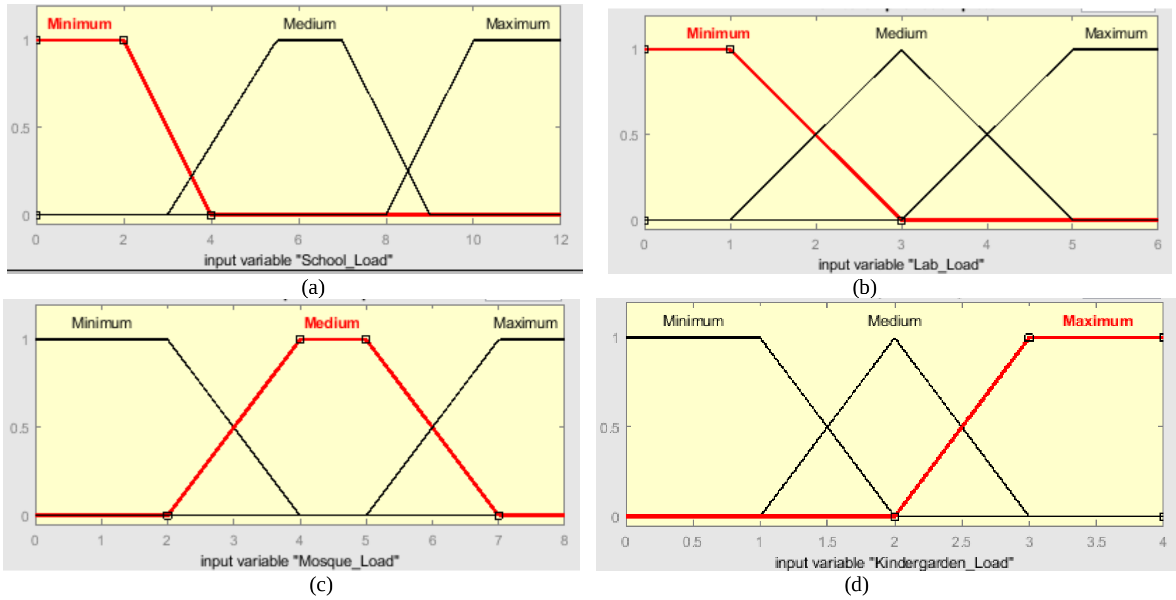


Figure 2 (a) Input variable for school building load
(b) Input variable for laboratory load
(c) Input variable for mosque load
(d) Input variable for kindergarten building load

The achievement of solar panel utilization in the hybrid grid-connected system is assessed by modeling four input load variables: school load, lab load, mosque load, and kindergarten load, with the output variable being the solar panel (PV). Each variable is characterized by minimum, medium, and maximum power levels, with fuzzy membership functions applied to each category. The membership functions used include linear, triangular, and trapezoidal fuzzy membership functions, as illustrated in Figures 2(a), 2(b), 2(c), and 2(d).

Figure 2 provides a detailed overview of the load variables for different facilities, utilizing fuzzy logic. Each sub-figure represents the load conditions for a specific facility.

Figure 2(a) illustrates the load variable for a school building with three distinct levels of power consumption. The minimum level is represented by a downward-sloping trapezoidal fuzzy membership function, ranging from 0 to 4 kW, indicating low energy demand. The medium level is modeled with a trapezoidal fuzzy membership function spanning 3 to 9 kW, reflecting moderate energy consumption. The maximum level uses an upward-sloping trapezoidal fuzzy membership function, ranging from 8 to 12 kW, representing the highest possible load for the school building.

Figure 2(b) depicts the load variable for a laboratory, similarly defined by three levels of power consumption. The minimum level is modeled with a downward-sloping trapezoidal fuzzy membership function ranging from 0 to 3 kW, representing the lowest energy usage. The medium level, defined by a triangular fuzzy membership function, spans 1 to 5 kW, indicating moderate energy demand. The maximum level uses an upward-sloping trapezoidal fuzzy membership function, covering a range from 3 to 6 kW, representing peak energy usage in the laboratory.

Figure 2(c) shows the load variable for a mosque, also characterized by three power consumption levels. The minimum level is represented by a downward-sloping trapezoidal fuzzy membership function with a range from 0 to 4 kW. The medium level, modeled using a trapezoidal fuzzy membership function, spans 2 to 7 kW, indicating moderate energy consumption. Finally, the maximum level is defined by an upward-sloping trapezoidal fuzzy membership function ranging from 5 to 8 kW, representing the mosque's highest potential load.

Figure 2(d) represents the load variable for a kindergarten building. The minimum level is modeled with a downward-sloping trapezoidal fuzzy membership function ranging from 0 to 2 kW, reflecting the building's lowest energy demand. The medium level, defined by a triangular fuzzy membership function, spans 1 to 3 kW, indicating moderate energy consumption. The maximum level uses an upward-sloping trapezoidal fuzzy membership function, ranging from 2 to 4 kW, representing the peak energy usage of the kindergarten.

TABLE 3
THE 10 (TEN) RULES USED IN THE SIMULATION PROCESS

Rule	Load_School building	Load_Lab	Load_ Mosque	Load_ Kindergarten building	PV
1	*Minimum*	*Minimum*	*Minimum*	*Minimum*	*Minimum*
2	Maximum	Maximum	Maximum	Maximum	Maximum
3	Maximum	Medium	Maximum	Maximum	Maximum
4	Maximum	*Minimum*	Maximum	Maximum	Medium
5	Medium	Maximum	*Minimum*	Maximum	Medium
6	Medium	Medium	*Minimum*	Maximum	Medium
7	Maximum	*Minimum*	*Minimum*	Maximum	Medium
8	Medium	Maximum	*Minimum*	*Minimum*	Medium
9	Medium	Medium	*Minimum*	*Minimum*	Medium
10	Medium	*Minimum*	*Minimum*	*Minimum*	*Minimum*

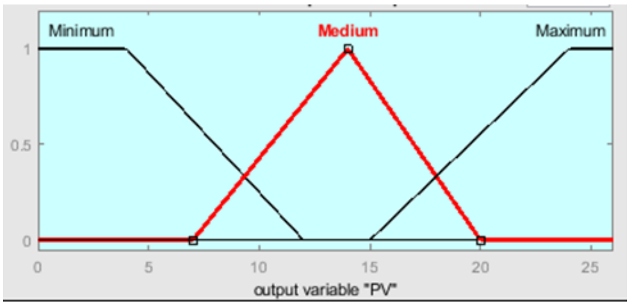


Figure 3. The output variable of the solar panel system.

Together, these figures utilize fuzzy logic to represent varying levels of power consumption for each facility, offering a flexible and adaptable approach to modeling real-world energy demands. Fuzzy membership functions enable smooth transitions between low, medium, and high consumption levels, ensuring accurate control and optimization of energy distribution under different operational states. This method is particularly critical for systems such as solar panels, where efficient load management is essential for maintaining energy balance and optimizing resource utilization.

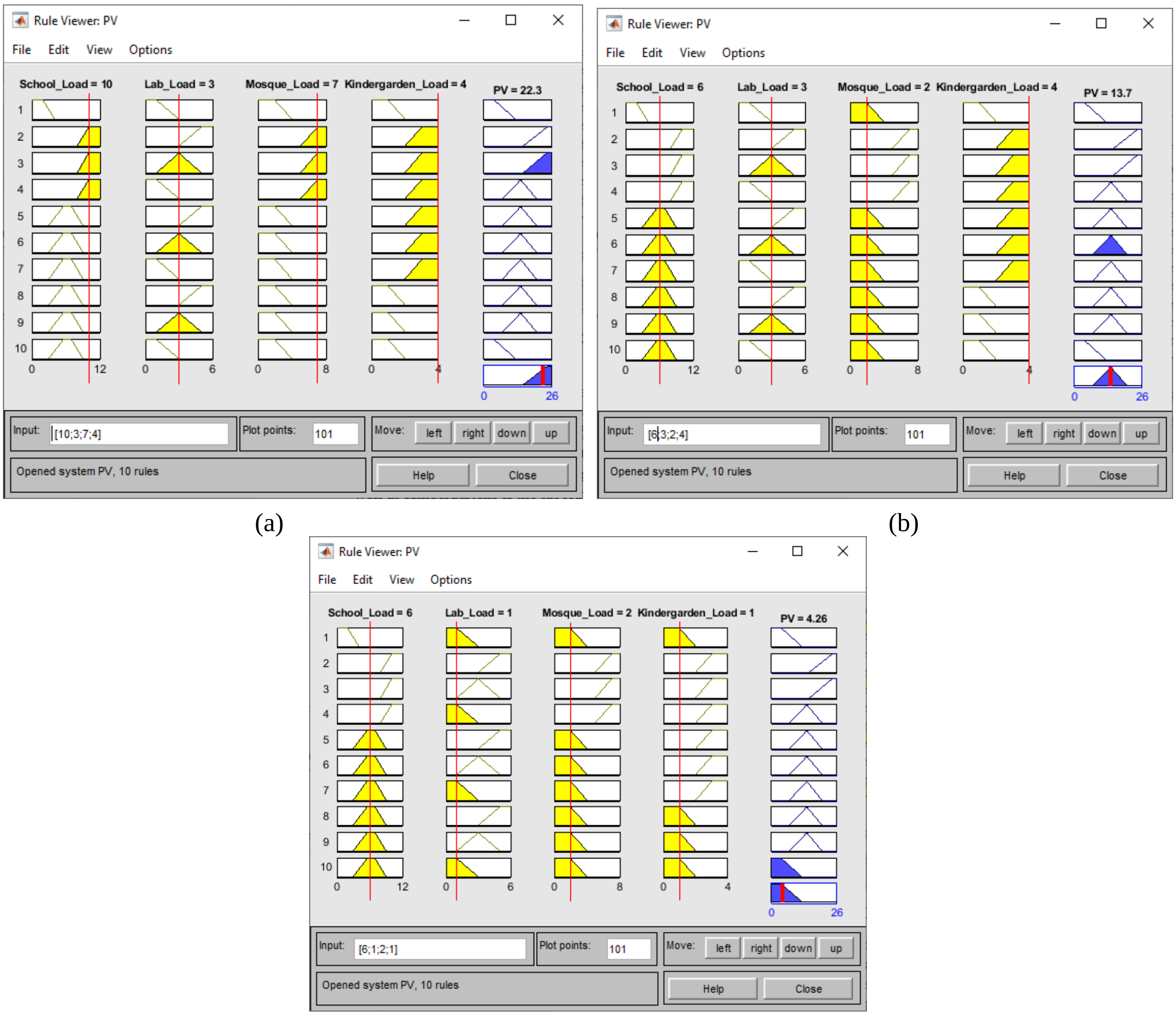
Figure 3 illustrates the output variables of the solar panel system under three distinct conditions, represented by fuzzy logic membership functions. The first condition, representing the minimum limit, is modeled using a downward-sloping trapezoidal fuzzy membership function with a value range from 0 to 12 kW, indicating the system's lowest possible power output. The second condition, the medium limit, employs a triangular fuzzy membership function spanning 7 to 20 kW, reflecting a moderate or balanced output. Finally, the maximum limit is defined by an upward-sloping trapezoidal fuzzy membership function, with values ranging from 15 to 26 kW, representing the system's highest potential output.

Before running the simulation, several rules must be defined to guide and constrain the system's behavior under various load scenarios. These rules, outlined in Table 3, are essential for determining transitions between different levels of solar panel output and ensuring effective operation under varying conditions. By setting these parameters, the simulation can more accurately model real-world performance and variability, predicting how the solar panel system will respond in different operational states.

The combination of fuzzy membership functions and predefined rules provides a flexible framework for modeling the system's behavior. This approach enables smooth transitions between minimum, medium, and maximum solar panel outputs, ensuring effective management and optimization. As a result, the system can adapt to varying load conditions while maintaining efficiency and stability.

III. RESULT AND DISCUSSION

The simulation results yield intersection graphs as shown in Figures 4(a), 4(b), and 4(c). Figure 4(a) illustrates the scenario where loads of 10 kW for schools, 3 kW for laboratories, 7 kW for mosques, and 4 kW for kindergartens result in a photovoltaic (PV) system output of 22.3 kW. Based on the ten predefined rules, the achievement of PV utilization is indicated by the blue shading, which satisfies rule 3. In



(a) (b)

(c)

Figure 4. (a) Conditions with maximum solar panel output
(b) Conditions with medium solar panel output
(c) Conditions with minimum solar panel output

this condition, the system operates optimally, unlike other rules where not all loads are shaded, resulting in the system being off [23]. Rule 3 states: If the school building load is Maximum, the laboratory load is Medium, the mosque load is Maximum, and the kindergarten load is Maximum, then the solar panel output is Maximum. This corresponds to daily load usage from 2:00 PM to 4:00 PM, where schools and kindergartens operate at full load, while the laboratory and mosque are also in high-demand states, necessitating total electricity supply from solar panels.

The average daily PV power output fluctuates due to weather changes, including sunny, cloudy, and rainy conditions. These variations directly impact the intensity of sunlight absorbed by the solar panels, affecting energy production [23]. When weather conditions are insufficient for full electricity generation, the deficit is supplemented by PLN. Despite these fluctuations, the solar panel utilization level remains high.

Figure 4(b) represents a scenario where different loads are distributed as follows: 6 kW for schools, 3 kW for laboratories, 2 kW for mosques, and 4 kW for kindergartens, resulting in a PV system output of 13.7 kW. Based on the predefined rules, this condition satisfies rule 6, as indicated by the blue shading in the figure. This suggests the system is functioning in a balanced state, in contrast to other scenarios where insufficient shading results in the system being off.

According to rule 6, the condition is defined as follows: when the school building load is medium, the laboratory load is medium, the mosque load is at a minimum, and the kindergarten load is at a maximum, the solar panel output is categorized as medium. In this scenario, while electricity demand in the school building is reduced and the laboratory remains operational, the kindergarten experiences high energy consumption, and the mosque's energy usage stays low. Despite these varying load demands, the solar panel system effectively supports the overall energy needs, albeit not at full capacity.

Under these conditions, the solar panels perform moderately, reflecting balanced but not fully optimized usage. The distribution of loads across different facilities results in a medium level of solar energy achievement, demonstrating effective but limited utilization of the photovoltaic system.

Figure 4(c) depicts a scenario where electrical loads are distributed as follows: 6 kW for schools, 1 kW for laboratories, 2 kW for mosques, and 1 kW for kindergartens, resulting in a solar panel output of 4.26 kW. Based on the system's 10 predefined rules, the blue shading in the figure indicates that rule 10 is met, signifying the system is in optimal working condition. This contrasts with other rules, where incomplete shading results in the system being off.

Rule 10 applies when the school building load is medium, and the loads on the laboratory, mosque, and kindergarten are at a minimum. In this scenario, with reduced electricity demand in the school building, no laboratory usage, low energy consumption in the mosque, and the kindergarten closed, the solar panel system operates at its maximum efficiency to support the remaining loads. Consequently, under these conditions, the solar panel utilization level is exceptionally high, enabling efficient energy distribution and optimal performance of the photovoltaic system.

Figure 5 illustrates the variation in solar panel output based on the electricity loads of a kindergarten and a mosque, as modeled using a fuzzy decision system [23], [24]. The kindergarten's electricity load ranges from 0 to 4 kW, while the mosque's load ranges from 0 to 8 kW. The figure shows a steep increase in solar panel output when the kindergarten operates at a load of 2 kW and the mosque's load varies between 0 and 4 kW. This increase highlights the sensitivity of the system to simultaneous load variations from both facilities, with solar panels becoming more actively engaged as the mosque's load increases within this range.

For kindergarten loads above or below 2 kW, when the mosque's load varies between 0 and 3 kW, the solar panel output stabilizes at a higher level of approximately 13.6 kW. This indicates that, within this range, the solar panels consistently deliver high energy output, maintaining stable performance regardless of fluctuations in the mosque's load. The system effectively meets the combined demand without significant variations in energy output.

When the mosque's load exceeds 4 kW, the figure reveals a substantial drop in solar panel contribution, indicating that the panels no longer support the system. This threshold suggests that the combined loads of the kindergarten and the mosque surpass the solar panels' capacity, leading to a cessation of their contribution. This condition underscores the limitations of the photovoltaic system when faced with high energy demands, particularly when multiple facilities require substantial power simultaneously.

The analysis in Figure 5 provides valuable insights into how solar panel output varies with load demands from different facilities. It emphasizes the need for efficient energy distribution management. By understanding these load variations, it is possible to optimize solar panel usage, ensuring effective operation under varying conditions and avoiding energy shortages when demands exceed system capacity.

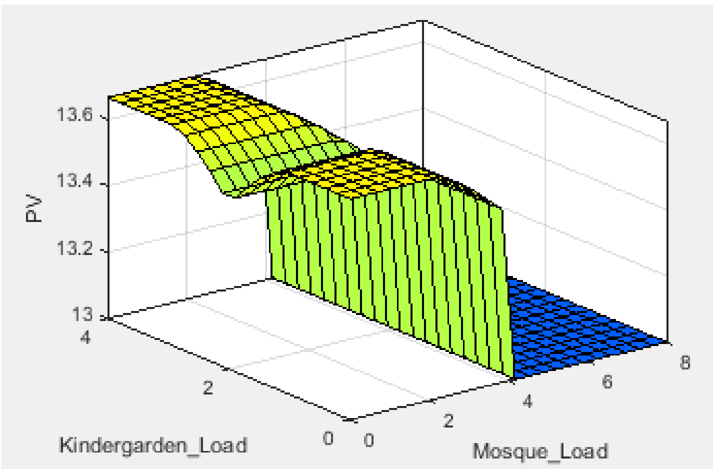


Figure 5. Solar panel performance surface against the load given to a kindergarten and a mosque.

One effective strategy is the dynamic regulation of energy distribution based on load priority, where facilities with critical needs, such as laboratories or classrooms, are given higher priority during peak operating hours. Additionally, integrating energy storage technologies, such as batteries, enables surplus energy generated during the day to be stored for use at night or during periods of high demand exceeding production capacity.

IV. CONCLUSION

The effectiveness of solar panels varies based on the electrical loads of different facilities, including schools, laboratories, mosques, and kindergartens. Under typical conditions, solar panel performance decreases when the electrical loads in school buildings and kindergartens are at their maximum, as weather conditions directly impact energy generation. However, solar panel performance improves significantly when electricity usage in schools is reduced, and other expenses are minimized.

Future research will examine in greater depth how variations in electrical loads across facilities affect solar panel efficiency. This includes further exploring the relationship between weather conditions and solar panel performance under peak load conditions.

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REFERENCES

[1] H. Azoug, H. Belmili, and F. Bouazza, "Grid-connected control of pv-wind hybrid energy system," International Journal of Power Electronics and Drive Systems, vol. 12, no. 2, pp. 1228–1238, Jun. 2021, doi: 10.11591/ijpeds.v12.i2.pp1228-1238.

[2] M. Amir, A. K. Prajapati, and S. S. Refaat, "Dynamic Performance Evaluation of Grid-Connected Hybrid Renewable Energy-Based Power Generation for Stability and Power Quality Enhancement in Smart Grid," Front Energy Res, vol. 10, Mar. 2022, doi: 10.3389/fenrg.2022.861282.

[3] M. Ur Rashid, I. Ullah, M. Mehran, M. ~N. ~R. Baharom, and F. Khan, "Techno-Economic Analysis of Grid-Connected Hybrid Renewable Energy System for Remote Areas Electrification Using Homer Pro," Journal of Electrical Engineering & Technology, vol. 17, no. 2, pp. 981–997, Mar. 2022, doi: 10.1007/s42835-021-00984-2.

[4] D. Maizana, S. Muthia Putri, and Z. Bahri, "The influence of alternative sources on the efficiency of smart grid systems on campus buildings," in IOP Conference Series: Earth and Environmental Science, Jun. 2021, vol. 753, no. 1. doi: 10.1088/1755-1315/753/1/012006.

[5] M. D. R. Donode, R. G. Shrivastava, M. K. N. Sawalakhe, and M. R. M. Akare, "Grid connected hybrid renewable energy system for vehicles charging station and street lightning system," International Research Journal of Engineering and Technology, 2018, [Online]. Available: www.irjet.net

[6] H. O. Guelleh, R. Patel, C. Kara-Zaitri, and I. M. Mujtaba, "Grid connected hybrid renewable energy systems for urban households in Djibouti: An economic evaluation," S Afr J Chem Eng, Nov. 2022, doi: 10.1016/j.sajce.2022.11.001.

[7] V. K. Tatikayala and S. Dixit, "DC Side Controllers for Grid Connected Hybrid Renewable Energy Sources," in 2021 IEEE 2nd International Conference On Electrical Power and Energy Systems (ICEPES), 2021, pp. 1–7. doi: 10.1109/ICEPES52894.2021.9699605.

[8] M. Lukawski, K. Vilaetis, L. Gkogka, K. Beckers, B. Anderson, and J. Tester, "A Proposed Hybrid Geothermal - Natural Gas - Biomass Energy System for Cornell University. Technical and Economic Assessment of Retrofitting a Low - Temperature Geothermal District Heating System and Heat Cascading Solutions," Nov. 2013.

[9] A. Amiri and C. Brewer, "Biomass as a renewable energy source for water desalination: a review," Desalination Water Treat, vol. 181, pp. 113–122, Nov. 2020, doi: 10.5004/dwt.2020.25130.

[10] I. Thain and R. Dipippo, "Hybrid Geothermal-Biomass Power Plants: Applications, Designs and Performance Analysis," 2015.

[11] H. Cui and R. Wu, "Feasibility Analysis of Biomass Power Generation in China," in Energy Procedia, 2012, vol. 16, pp. 45–52. doi: 10.1016/j.egypro.2012.01.009.

[12] A. Kumar, M. Z. U. Khan, and B. Pandey, "Wind Energy: A Review Paper," Gyancity Journal of Engineering and Technology, vol. 4, no. 2, pp. 29–37, Jul. 2018, doi: 10.21058/gjet.2018.42004.

[13] I. Daut, A. R. N. Razliana, Y. M. Irwan, and Z. Farhana, "A study on the wind as renewable energy in perlis, northern Malaysia," in Energy Procedia, 2012, vol. 18, pp. 1428–1433. doi: 10.1016/j.egypro.2012.05.159.

[14] Y. Charabi, S. Abdul-Wahab, and H. Ziaiefar, "Correction to: Wind turbine performance analysis for energy cost minimization," Renew Wind Water Sol, vol. 8, no. 1, Dec. 2021, doi: 10.1186/s40807-020-00065-4.

[15] U. Arachchige and S. R. G. Weliwaththage, "Solar Energy Technology," Nov. 2020.

[16] R. Ahmed, V. Sreeram, Y. Mishra, and M. D. Arif, "A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization," Renewable and Sustainable Energy Reviews, vol. 124, p. 109792, 2020, doi: https://doi.org/10.1016/j.rser.2020.109792.

[17] J. K. Kaldellis, M. Kapsali, and K. A. Kavadias, "Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece," Renew Energy, vol. 66, pp. 612–624, 2014, doi: https://doi.org/10.1016/j.renene.2013.12.041.

[18] P. E. Bett and H. E. Thornton, "The climatological relationships between wind and solar energy supply in Britain," Renew Energy, vol. 87, pp. 96–110, 2016, doi: https://doi.org/10.1016/j.renene.2015.10.006.

[19] J. Chen, J. Chen, and C. Gong, "New Overall Power Control Strategy for Variable-Speed Fixed-Pitch Wind Turbines Within the Whole Wind Velocity Range," IEEE Transactions on Industrial Electronics, vol. 60, no. 7, pp. 2652–2660, 2013, doi: 10.1109/TIE.2012.2196901.

[20] P. J. Schubel and R. J. Crossley, “Wind Turbine Blade Design,” Energies (Basel), vol. 5, no. 9, pp. 3425–3449, 2012, doi: 10.3390/en5093425.
[21] E. Tarigan, “Simulation and Feasibility Studies of Rooftop PV System for University Campus Buildings in Surabaya, Indonesia,” 2018.
[22] F. Toja-Silva, C. Peralta, O. Lopez-Garcia, J. Navarro, and I. Cruz, “Effect of roof-mounted solar panels on the wind energy exploitation on high-rise buildings,” Journal of Wind Engineering and Industrial Aerodynamics, vol. 145, pp. 123–138, 2015, doi: https://doi.org/10.1016/j.jweia.2015.06.010.
[23] D. Maizana and S. M. Putri, “Appropriateness analysis of implementing a smart grid system in campus buildings using the fuzzy method,” International Journal of Power Electronics and Drive Systems, vol. 13, no. 2, pp. 873–882, Jun. 2022, doi: 10.11591/ijpeds.v13.i2.pp873-882.
[24] L. Suganthi, S. Iniyan, and A. A. Samuel, “Applications of fuzzy logic in renewable energy systems – A review,” Renewable and Sustainable Energy Reviews, vol. 48, pp. 585–607, 2015, doi: https://doi.org/10.1016/j.rser.2015.04.037.
[25] Ahmed, O.K., Daoud, R.W., Bawa, S.M., Ahmed, A.H. (2020),”Optimization of PV/T Solar Water Collector based on Fuzzy Logic Control. Int. Journal of Renewable Energy Development”, 9(2),303-310,doi: 10.14710/ijred.9.2.303-310
[26] I.H. Altas and A.M. Sharaf, “A Generalized Direct Approach for Designing Fuzzy Logic Controllers in Matlab/Simulink GUI Environment”, ”, International Journal of Information Technology and Intelligent Computing, Int. J. IT&IC no.4 vol.1, 2007.
[27] Zadeh, L. A.. Fuzzy sets. Information and Control, 8(3), 338-353. 1965.
[28] Kosko, B. Fuzziness vs. probability. International Journal of General Systems, 17(2-3), 211-240, 1990.
[29] Haykin, S. A comprehensive foundation for neural networks. IEEE Signal Processing Magazine, 15(5), 84-85, 1998.
[30] Lecun, Y., Bengio, Y., & Hinton, G. Deep learning. Nature, 521(7553), 436-444, 2015.
[31] Holland, J. H. Adaptation in natural and artificial systems. University of Michigan Press, 1, 183-189, 1975.
[32] Goldberg, D. E., & Holland, J. H. Genetic algorithms and machine learning. Machine Learning, 3(2), 95-99, 1988.
[33] Kennedy, J., & Eberhart, R. Particle swarm optimization. Proceedings of ICNN'95 - International Conference on Neural Networks, 4, 1942-1948, 1995
[34] Jang, J. S. R. ANFIS: Adaptive-network-based fuzzy inference system. IEEE Transactions on Systems, Man, and Cybernetics, 23(3), 665-685. 1993.