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Enhancement of PV System Performance and Fault Detection Using Fuzzy Logic Control

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ABSTRACT

Population and economic growth in Karbala Governorate have significantly impacted various sectors, including tourism, scientific development, and politics. This growth has also led to an increased demand for electrical energy. Since 2003, challenges in power generation in Iraq have intensified due to continuous load growth, resulting in frequent daily power outages.

As agricultural, industrial, and residential expansions continue, reliance on solar energy sources has increased. In this study, a solar energy system installed to operate an agricultural motor at Fadak Farm in Karbala was investigated. A fuzzy logic control approach based on the Mamdani method was applied to enhance system performance and detect faults within a short time through continuous monitoring.

The results demonstrated significant economic benefits by increasing electrical power production from the system and reducing overall financial costs.

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1. INTRODUCTION

An Internet of Things (IoT) application is used as an effective method for monitoring and demonstrating the performance of a PV system. The system performance and power yield are displayed on a computer. System information is transmitted via Wi-Fi; this wireless communication improves system efficiency by enabling real-information is transmitted via Wi-Fi; this wireless communication improves system efficiency by enabling real-time visualization of system parameters at intervals of less than 30 seconds [1]. The monitoring system consists of three main parts: a sensing unit, a processing unit, and a display unit. The monitored data include PV panel temperature, current, humidity, voltage, and the amount of incident solar radiation. Solar irradiance is an important parameter that is taken into account when calculating the amount of power produced by the PV system [2]. The proper use of a photovoltaic system leads to optimal electricity production. This is achieved through continuous monitoring of PV parameters [3]. An increase or decrease in solar power production may occur, and sometimes power interruptions may happen in the PV system. Microcontroller-based circuits offer several advantages and contribute to effective PV monitoring applications. However, additional costs may be incurred. Many microcontroller-based circuits and sensors can be effectively implemented in residential and industrial zones. Solar PV systems can be divided into three categories based on their mode of operation off-grid (stand-alone) systems, on-grid (grid-tied) systems and hybrid PV systems. The stand-alone system is typically installed in rural areas where the electrical grid is not available. An off-grid system consists of PV panels, a charge controller, an inverter, an energy storage system (batteries), and other components that ensure energy delivery under various conditions such as cloudy weather or low solar irradiation [4]. This type of system is widely used in agricultural applications, irrigation systems, lighting, and communication sectors [5].Hybrid systems utilize multiple power sources, such as a solar PV system combined with a diesel generator, wind turbine (or small wind turbine), and distributed generation systems. These systems are designed to supply different types of loads and typically include a battery bank for energy storage. Hybrid systems are especially useful for enhancing system reliability during electrical grid failures or cloudy days [6,7].

In on-grid systems, both the electrical grid and the energy produced by the PV array operate synchronously. The generated PV power can either supply local loads or be exported to the utility grid. Examples of on-grid system applications include industrial factories, smart buildings, and solar electric vehicle charging systems. The structure of these systems optimizes energy utilization and increases overall system efficiency [8].

analysis in solar system. In FL, system characteristics are "fuzzified," allowing contributions to be quantified without strict limits, which makes it suitable for handling uncertainties and partial inputs [20,21]. A number of studies in the literature have been found an interesting idea in FLC. These are depending on analyzing of power. Bissey treated with the fuzzy logic of short-term load consumption, reducing the purchases of energy and minimizing the cost [23]. H. Mahamudal interested by the modeling technique of PV panels with FLC used Maximum Point Power Track MPPT to achieve more produced power [26]. F. Chekired presented the home energy management of photovoltaic system by fuzzy logic approach [22].

This work presents an effective strategy and a robust method for improving PV system performance based on the Mamdani Fuzzy Logic Control (FLC) approach. The proposed method enhances system efficiency, stabilizes power output, and optimizes energy extraction under changing environmental states [16,17]. The objectives of this study

• Integration of renewable energy and effective utilization of solar radiation to generate more electrical energy.
• Enhancement of grid reliability by reducing connected inductive electrical loads.
• Economic benefits through reducing electricity consumption from the national grid and minimizing electricity bills.
• Efficient energy management.

The structure of the work is as follows. Section 2 details the selected system components that meet the appliance requirements in the smart home. Section 3 describes the proposed optimal energy management system. In section 4, The effectiveness and economic purpose of the model are demonstrated through a simulation of a smart home equipped with PV panels and a battery storage system. The simulation results are obtained using the MATLAB program. In section 5 presents the conclusions drawn from the study

2. Maximum Power Point Tracking (MPPT) and PV Energy Output

The application of photovoltaic systems combined with MPPT (Maximum Power Point Tracking) technology leads to optimal solar energy performance. The output of a PV module can be increased using power converters equipped with MPPT controllers. The main objective of MPPT technology is to extract the maximum available power from the PV array.

The relationship between the generated power and the terminal voltage of a PV array is represented by the P–V curve. The point on this curve at which the maximum power is produced is called the Maximum Power Point (MPP) [9].

Below is the general power–voltage relationship which can be calculated using the following formula (1):

$$P = V \times I \qquad (1)$$

The maximum power point occurs at the peak of the P–V curve, where the product of voltage and current is maximized. MPPT controllers continuously adjust the operating voltage of the PV module to ensure operation at this optimal point characteristics as shown in Figure .1.

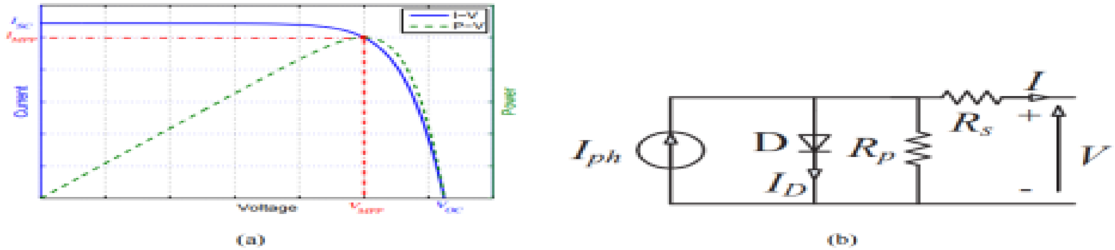

Figure .1 PV cell characteristics (a) current and power-voltage curves of solar cell and (b) Electrical equivalent circuit of PV cell [10].

The relationship between current and voltage at the Maximum Power Point (MPP) depends on continuous tracking of operating conditions. Since solar radiation changes throughout the day, MPPT techniques are used to extract the optimal amount of energy from the PV system and provide an effective solution for maximizing efficiency [11].

Several environmental factors affect the performance and efficiency of a PV system, including shading, clouds, dust, dirt, snow, trees, pollution, and nearby buildings. System efficiency is strongly influenced by sunlight exposure, which varies daily, monthly, and seasonally [9]. Solar irradiance incident on the panel surface is measured as energy per unit area over time and is expressed in kWh/m².

The electrical output of a PV module at any time can be calculated using equation (2) [12,13]:

$$E(pv) = A \times rpv \times Np \times H(t) \times (1 - 0.005\,(tc(t) - 25)) \quad \text{………………... ……} (2)$$

Where:

- rpv = PV module efficiency
- Np = Number of PV panels
- tc (t) = Ambient temperature (°C)
- A = Solar panel area (m²)
- H(t)= Solar radiation updated every 30 minutes (W/m²)

The energy output of PV panels can also be evaluated using Equation (3) [3,11]:

$$EPV=Pp\times rpv\times(H(t)/Hstc)\times(1-\alpha t(tc-tstc)) \quad \text{………………………………….} (3)$$

Where:

- Pp : Maximum power of the solar panel (kW)
- αt : Temperature coefficient of power (%/°C)
- tstc :Panel temperature under Standard Test Conditions (25°C)

Hstc: Solar irradiance under STC (1000 W/m²) as well air mass (1.5).

3. Solar Pump System Design for Fadak Farm

Harnessing solar energy in Iraq is a feasible option due to high solar radiation levels ranging from 2000 to 2600 kWh/m² per year. However, climate variations can affect PV system energy production. Therefore, future load estimates must be considered for effective energy planning [14].

The case study in this paper focuses on the Fadak Farm region in Karbala Province. The geographical location of Karbala lies between longitudes 43.1°E and 44.19°E and latitudes 32.5°N to 32.8°N, placing it within a sun-rich region. The total annual sunshine duration exceeds 2,800 hours per year.

Climate data recorded in Karbala City between 1989 and 2019 show that:

- The average daytime temperature is 37.9°C
- The average solar radiation is 702.63 W/m² , These values confirm the suitability of the region for solar energy applications [15].

PV system is designed to supply electrical power to a submersible water pump for approximately 7 hours The per day, based on the average daily sunshine duration. Therefore, the solar power system provides around 7 hours of electricity during daytime operation.

The pumped water is stored as backup in the fourth reservoir, which has:

- A capacity of approximately 20,000 cubic meters
- Dimensions of 75 m × 75 m
- A depth of 3.75 m

Frequent power outages from the national grid negatively affect the farm by causing water shortages and irregular irrigation schedules. The implementation of the solar PV system ensures continuous water pumping and improves irrigation reliability.

This project contributes to reducing carbon emissions and maintaining a clean environment. The implementation involves installing a solar PV system at Fadak Farm in Karbala Province, with the farm covering the system installation costs. The proposed system improves energy reliability, reduces dependence on the national grid, lowers operational costs, and promotes sustainable agricultural development. The enhancement of PV system performance and efficiency, energy conversion, and solar power generation must be carried out according to varying environmental conditions.

Figure 2. Fadk water pump project

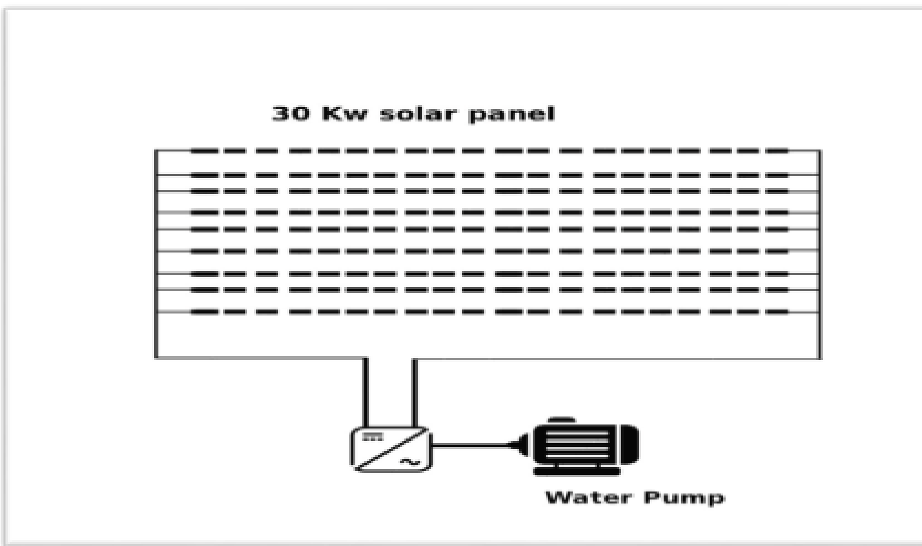

Figure 3. Solar pump system design

The Fadak Farm office has determined that installing a solar-powered water pump system is the optimal solution to overcome power outages from the national grid. To supply the existing 30 kW water pump:

- The system includes 150 PV panels, each rated at 250 W, providing a total peak output of 37.5 kW.
- A 37 kW hybrid solar pump driver is used to convert the DC power from the PV array to three-phase AC power for the motor.
- The average daily solar irradiance allows approximately 9 hours of effective solar power generation, which ensures the water pump receives electricity according to operational needs.

System losses are estimated at approximately 30%, accounting for internal resistance of batteries, wiring type and quality and photovoltaic panel efficiency. These losses are included in the energy consumption calculation. To ensure reliable operation, PV power generation is designed to exceed the pump's required energy by a factor of

1.3–1.5, based on the load demand. Therefore, the total PV system capacity is designed to supply 45 kW to reliably meet the 30 kW demand of the existing water pump. The number of PV panels is determined based on the calculated energy production, considering the capacity of each solar panel [18,19]. For high reliability and efficiency, 180 panels are structured in the PV array of the system as shown in Figures 2-3. Tables 1-2 are presented the electrical characteristics of the PV panels used in the project Ferrania Solis type (manufactured in Italy) and water pump inverter.

Table 1.The electrical characteristic of PV panel

Parameter	Symbol	Value
Max. power	P_{MP}	250W
Open circuit voltage	Voc	38.03V
Short circuit current	I_{SC}	8.87A
Voltage at max. power	V_{MP}	30.52V
Current at max. power	I_{MP}	8.2A

Table 2. The specifications of water pump inverter

Variable	Value
V DC	850V
V AC	415V
Hz	50-60
Power	38kw
current	70 amp

4. Solar Energy Potential in Iraq

Harnessing solar energy in Iraq is a feasible and effective option due to the country's high solar radiation, which ranges from 2000 kWh/m² per year to 2600 kWh/m² per year. However, variations in climate can affect the energy production of PV systems. Therefore, it is crucial to consider future load estimates and demand projections for effective energy planning [14]. Figure 4 displays the daily characteristics of temperature and solar radiation on August 1st & 2nd ,2021 in Karbala city according to data recorded in the weather forecast office in Karbala province [27].

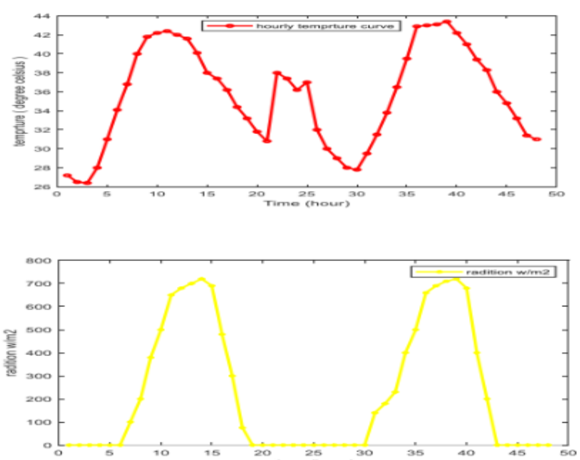

Figure 4. Shows the hourly temperature and hourly solar radiation curves on August 1st & 2nd, 2021 in Karbala city

4. Fuzzy Logic-Based Energy Management and Fault Detection

The most commonly used fuzzy inference method is the Mamdani method, one of the earliest regulatory frameworks developed using fuzzy set theory. Ebrahim Mamdani extended this technique to control the operation of steam engines by using a set of control rules derived from operational experience. In this approach, fuzzy sets are used to predict output variables. A single-output membership function is often more effective than distributed fuzzy sets, and this method has been shown to provide practical and reliable results [20]- [26].

A suitable result is acting the comparison between normal state in PV system's operation and occurring the fault.

Additionally, the predictions process operation throughout fuzzy logic method and the calculations of output produced power are depending on section 2,3 & 4 information and data of climate at 1st and 2nd August ,2021[27].

5. Method of The Study

This work is primarily based on the Internet of Things (IoT), where the study proposes transmitting data to a monitoring computer through cloud computing using two methods:

First, real-time electrical power supplied to the water pump from photovoltaic (PV) panels is measured. This is achieved through the water pump inverter and transmitted to a smart meter equipped with a Wi-Fi modem. The smart meter sends multiple readings to the cloud, which are then accessed by the monitoring computer for data processing and analysis.

Second, environmental data is collected using sensors that measure solar irradiance and ambient temperature. A microcontroller-based electronic control system processes these measurements and transmits the climate-related data to the cloud, and then to the computer. These inputs are used in mathematical models to estimate the optimal power generation from the solar panels.

Using MATLAB software, a comparison is performed between:

Po1: the actual measured power transmitted from the smart meter, and

Po: the calculated PV power based on irradiance and temperature conditions.

The difference between these two values is defined as:

$$DP = Po - Po1$$

The system applies Mamdani's Fuzzy Logic Control (FLC) method, which includes three main stages: fuzzification, inference, and defuzzification. The model uses two input variables (Po and DP) and produces one output.

Output (Po1): representing the probability of supplying electrical power to the water pump load.

During the fuzzification process:

The membership function of Po defines the level of PV power generation.

The membership function of DP represents the deviation between expected and actual power output.

Next, a set of IF–THEN inference rules is applied to evaluate the system's operating condition (normal or faulty). For example:

If Po is Medium (M) AND DP is Low (L), THEN the probability of supplying the pump motor with electricity is Very Low (VL).

The fuzzy inference results for the inputs (Po and DP) and the output (Po1) are summarized in tables, which also present the predicted operational states of the pump motor load.

Finally, the defuzzification process is performed using the Center of Gravity (COG) method to obtain a precise output value. The resulting output represents the probability of successfully supplying electrical power to the pump motor and helps in load management.

This approach provides clear results for assessing the likelihood of powering the water pump and enables fault detection in the solar system through continuous monitoring and fault signaling for timely maintenance as shown in Figures 5-6.

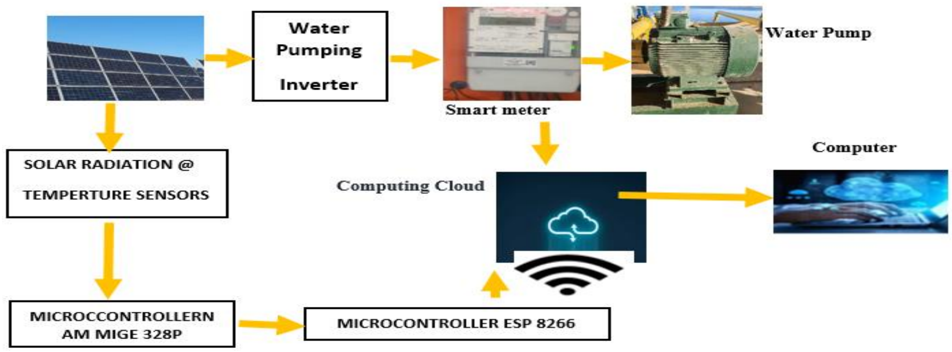

Figure 4. Schematic diagram comprises of comparison measuring PV in fadak project.

Figure 5 presents flow chart of three following important cases energy generation, energy management and fault detection in PV system.

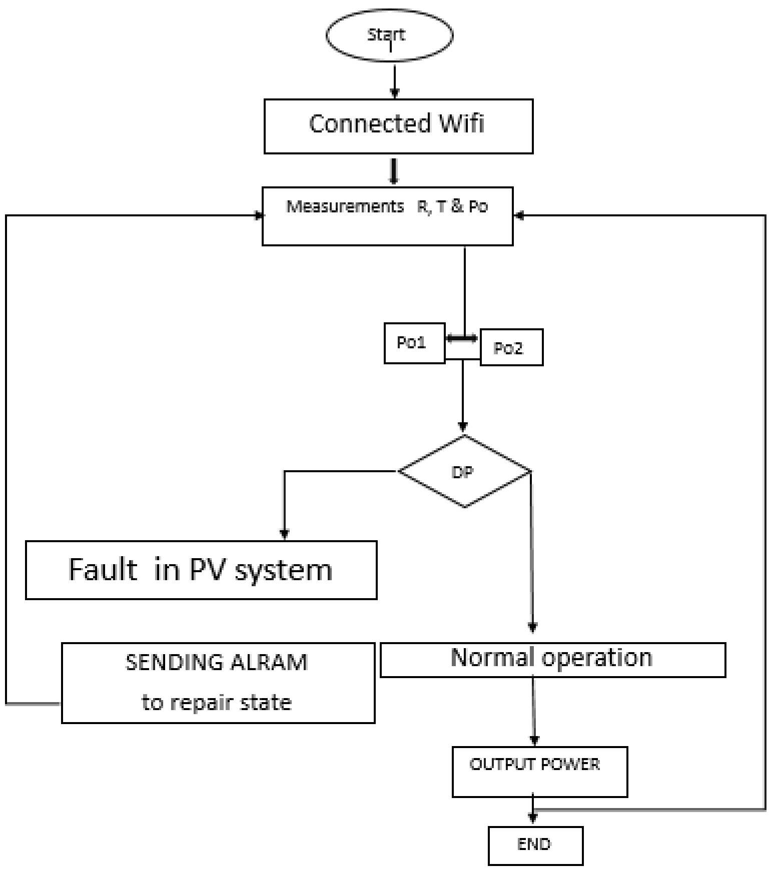

Figure 6. The process of produced power, energy management and detection of fault in solar system.

The fuzzification step is implemented by applying the rules as shown in Figures 7-8 which presented membership functions of inputs variable. Next, the center of gravity method is used for defuzzification. Figure 9 illustrates the output membership functions for the probability of supplying electricity to the pump motor as an example of load management.

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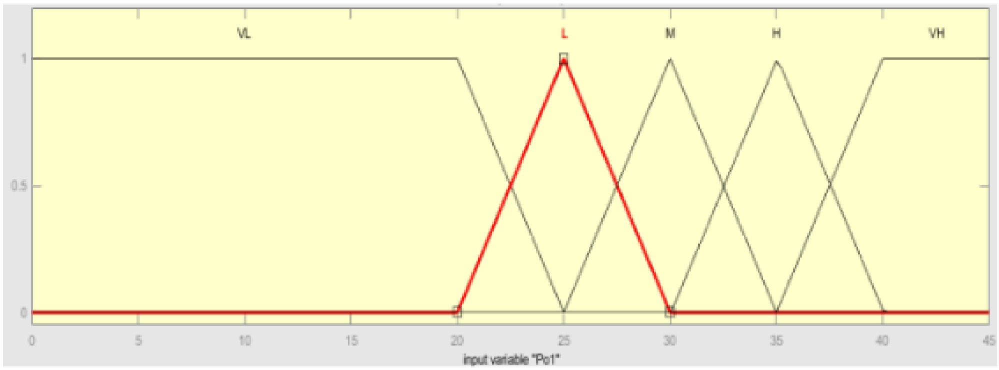

Figure 7. Membership function of input variable Po1

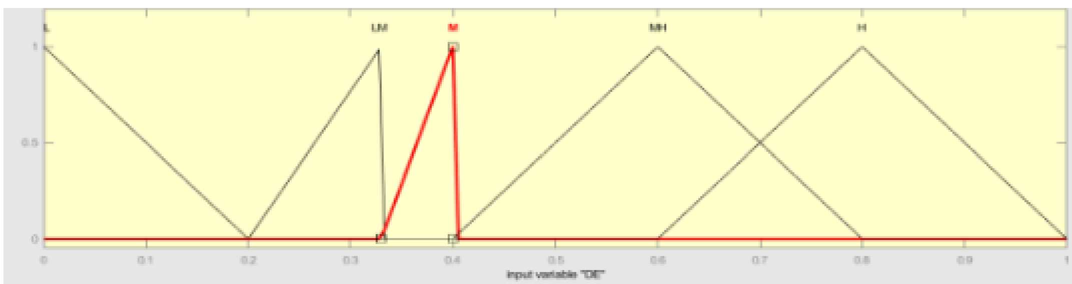

Figure 8. Membership functions of input variable DP

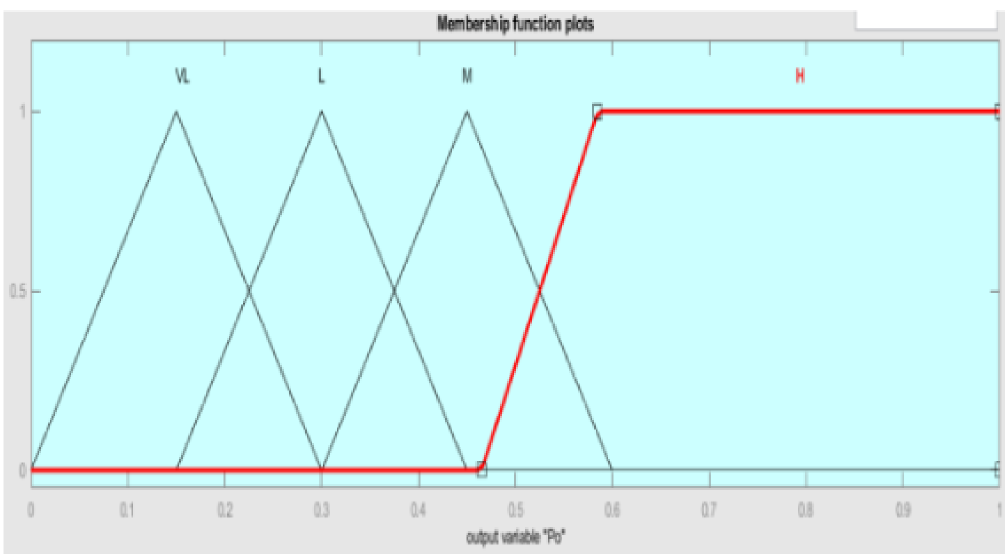

Figure 9. presents the output membership functions for the probability of supplying electricity to the pump motor**.**

Table 3 shows the fuzzy inference results for the two inputs, DP and Po, with the output Po1 (probability of supplying the pump motor load) also Figure 10 shows generated surface of fuzzy probability in meeting water pump motor :

Table 3. shows the predict states of supplying the pump motor load

DP / Po	L	LM	M	MH	H
VL	No	No	No	No	No
L	No	No	No	No	No
M	VL	No	No	No	No
H	M	L	No	No	No
VH	H	M	VL	No	No

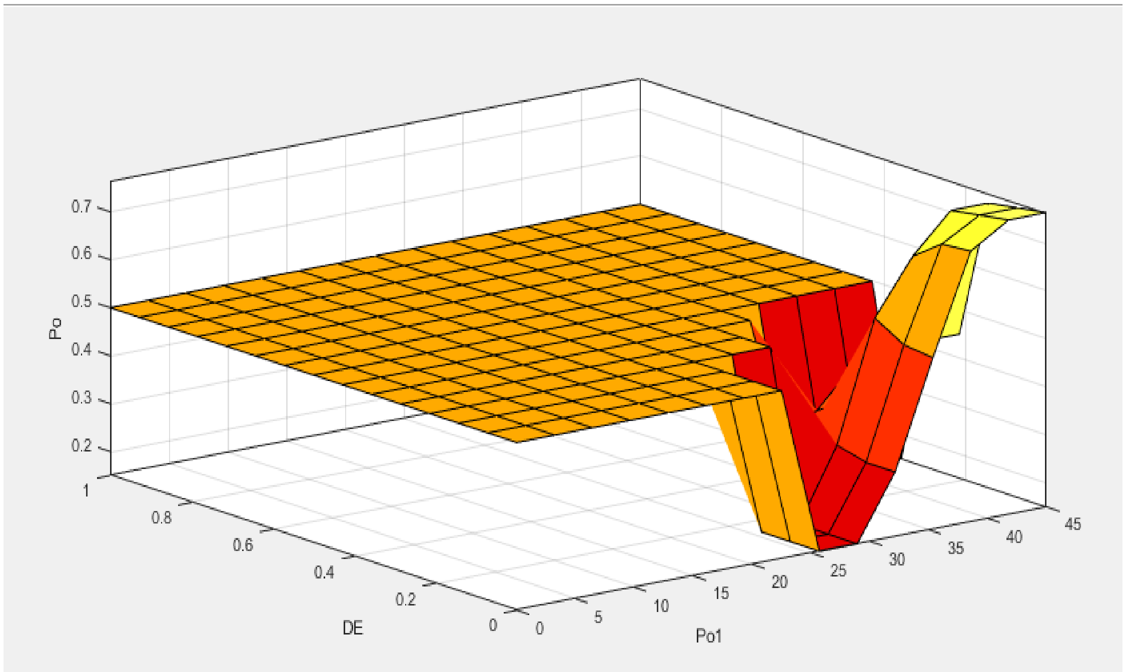

Figure 10. Generated surface of fuzzy probability in supplying water pump motor

6. RESULTS AND DISCUSSION

The results of the study suggest a new monitoring approach to optimize PV system operation and provide early fault warnings using fuzzy logic. This method ensures economic power dispatch while meeting load demand.

- Figure 10 shows the energy produced by the system based on measured temperature and solar radiation data.
- According to the calculations, energy losses due to system faults are quantified, and the reduction in power compared to normal operation is determined.

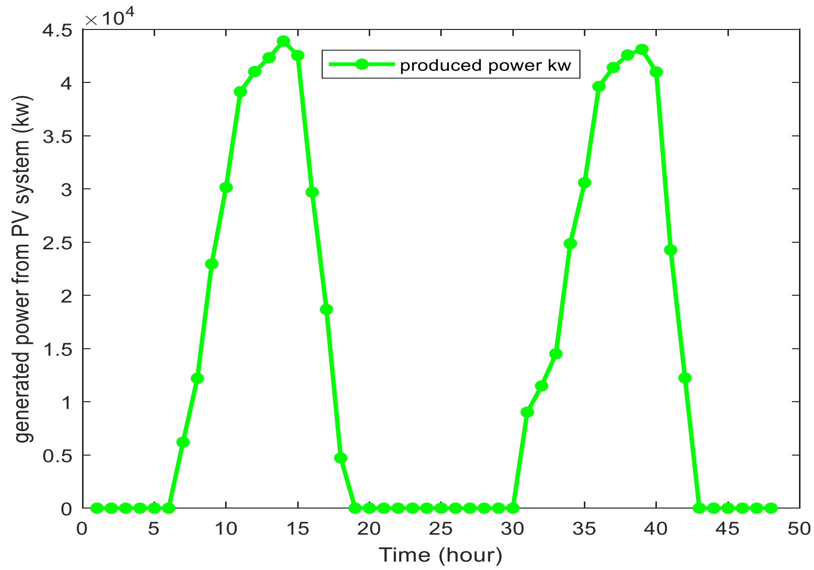

Figure 10. calculations of produced power are presented according to formula 3 from PV system on August 1st & 2nd, 2021 in Fadak farm

Figure 11 illustrates the amount of power lost as a percentage with respect to optimal producing of power due to a fault in PV system.

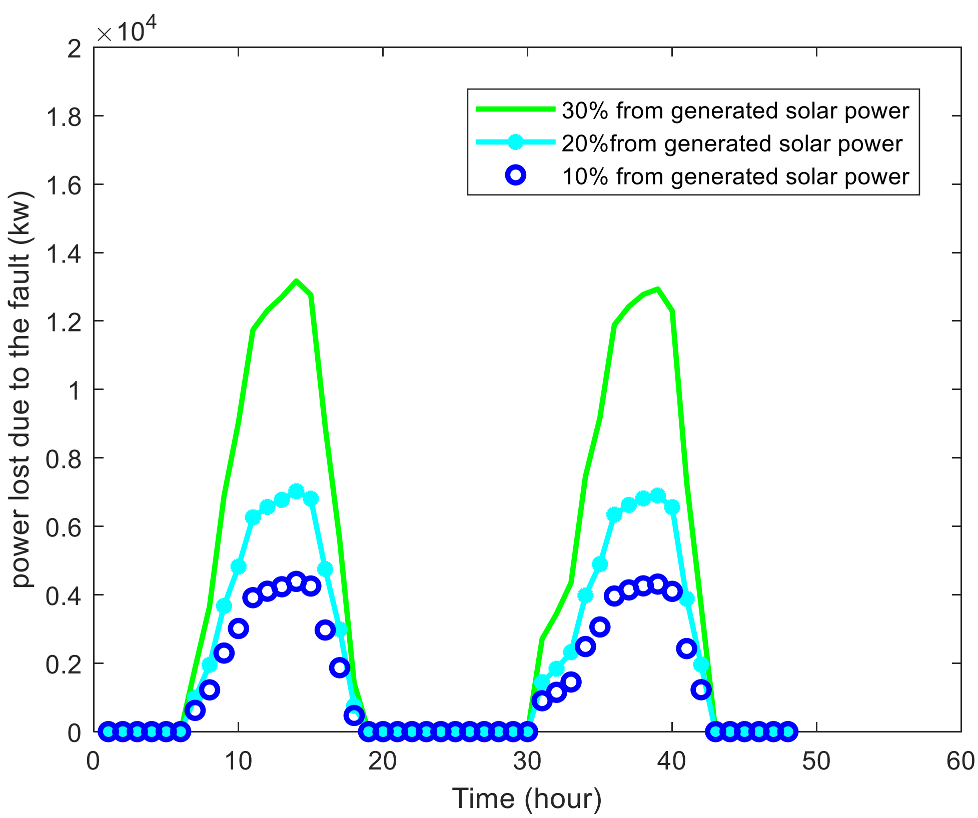

Figure 11. Percentage of power lost since occurring fault in PV system

Economic cost of lost energy through the different time interval which occurring fault until time of repairing it and return to normal system 's operation. The cost /ID throughout several numbers of hours 's fault as shown in Figure 12 where the case of fault is acting 10% loss of generated power in PV system which is based on calculating DP and the price of kwh is equal to 120 Iraqi Dinar according to ministry of electricity. The cost is evaluating according to number of hours per fault, occurring of fault is continuing for 1,2,3….,8 hours in day as shown in Figure 12.

Additionally, the calculations of cost are estimating for different interval time of fault based on daily occurring fault in PV system in one month as well one year as shown in Figures 13-14.

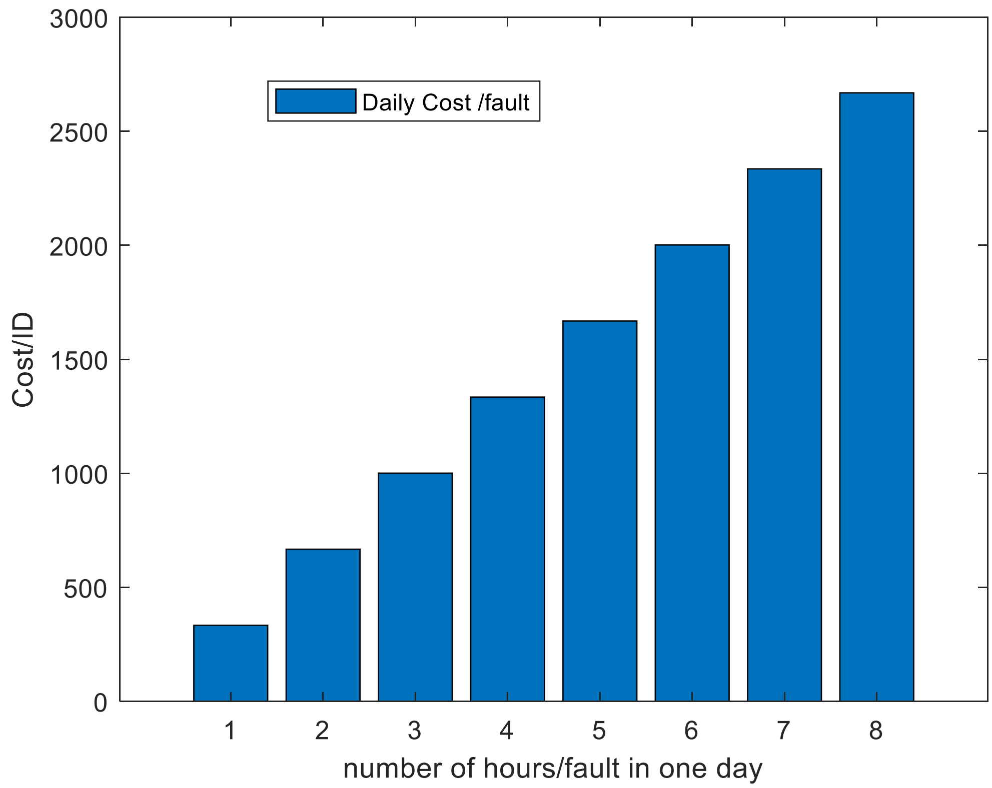

Figure 12. Amounts of cost in ID is evaluated according to number of fault's hours at situate of 10% lost Produce power in one day.

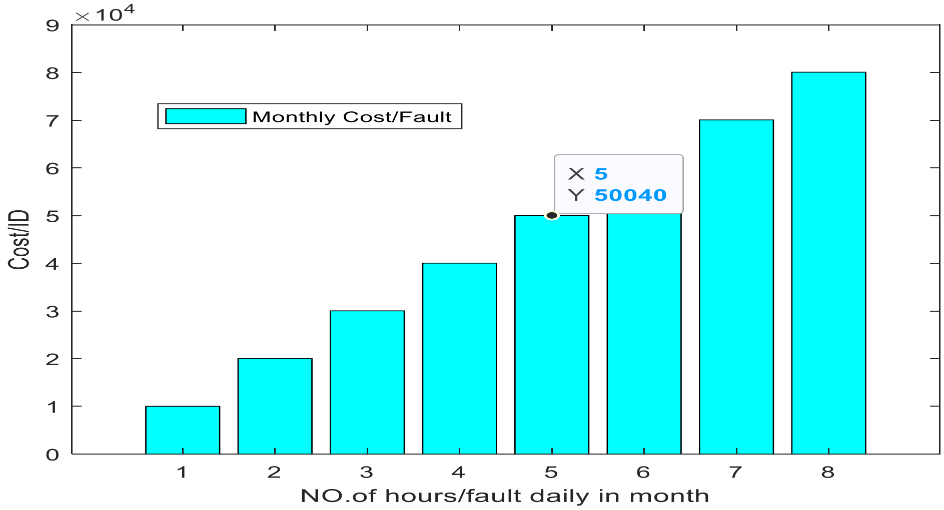

Figure 13. Monthly cost (in ID) is estimated based on daily numbers of fault's hours at 10% loss of generated power from PV system.

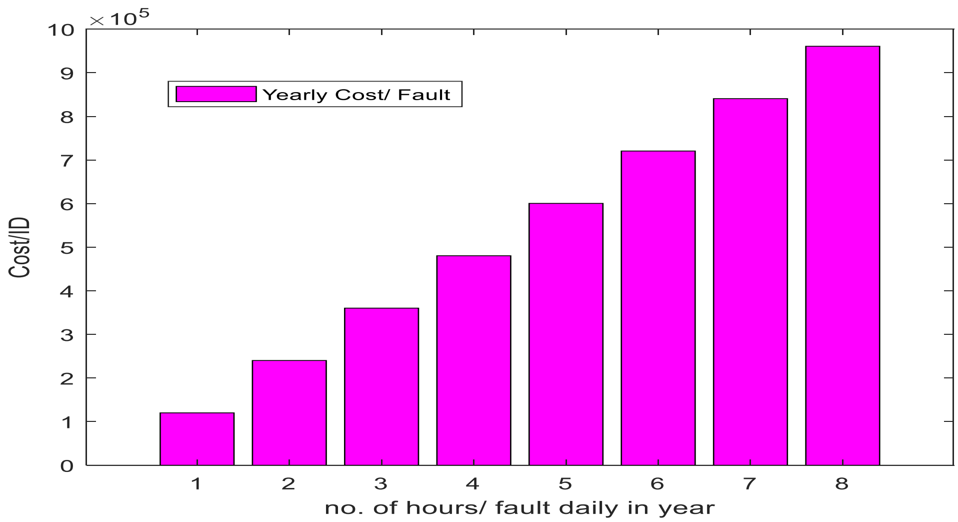

Figure 14. Yearly cost (in ID) is estimated based on daily numbers of fault's hours at 10% loss of generated power from PV system.

The table 4 below shows the saved power and cost achieved through maintenance actions by identifying system faults and their repair times. It demonstrates the economic and energy benefits of restoring the PV system to normal operation.

Table 4. The saved power (kw) and the saved cost (ID) for repair 's time (hour) in three case of occurring 's fault

No. of hour	Saved power kw case 10%	Saved cost ID case 10%	Saved power kw case 20%	Saved cost ID case 20%	Saved power kw case 30%	Saved cost ID case 30%
1	1.840532	220.8638	0.992872	119.1446	1861.634	223396.1
2	4.135954	496.3145	2.944851	353.3821	5521.596	662591.5
3	7.149652	857.9583	6.617527	794.1032	12407.86	1488944
4	11.06317	1327.581	11.43944	1372.733	21448.96	2573875
5	15.16629	1819.954	17.70108	2124.129	33189.52	3982742
6	19.39931	2327.917	24.26606	2911.927	45498.86	5459863
7	23.78889	2854.667	31.0389	3724.668	58197.94	6983752
8	28.04335	3365.202	38.06223	4567.467	71366.67	8564001

7. CONCLUSION

The presence of battery banks in these configurations is essential, as they ensure a stable and reliable electricity supply during environmental fluctuations or periods of low solar irradiance, such as nighttime. Battery storage systems help maintain continuous operation, improve system reliability, and support load demand when solar generation is insufficient.

User energy requirements are met without interruptions. PV generation is matched to the electrical load. Surplus power is stored in batteries for later use. Economic efficiency is considered in electricity consumption.

- Addresses power outages and ensures that energy needs for base load demand are met.
- Prioritizes renewable energy sources and supplies excess energy to the grid in the case of grid connected.

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REFERENCES

[1] Teddy Surya Gunawan," Prototype Design of Smart Home System using Internet of Things ", Indonesian Journal of Electrical Engineering and Computer Science Vol. 7, No. 1, July 2017, pp. 107 ~ 115 doi: 10.11591/ijeecs. DOI: 10.11591/ijeecs. v7. i1. pp107-115.

[2] C. Stolojescu-Crisan, C. Crisan, and B.-P. Butunoi, "An IoT-based smart home automation system," *Sensors*, vol. 21, no. 11, May 2021, doi: 10.3390/s21113784.

[3] A. Kebede, "A techno-economic optimization and performance assessment of a 10 kWP photovoltaic grid-connected system," *Sustainability*, vol. 12, no. 18, Sep. 2020, doi: 10.3390/su12187648.

[4] Z.Tshemese ; F.Dziike;K.Roro, " Reliability Study of Solar Photovoltaic systems for Long –Term Use, " In book: Electrode Materials for Energy Storage and Conversion (pp.309-320) ,DOI:10.1201/9781003145585-14.

[5] C. P. Ohanu, G. N. Egbo, and T. Sutikno, "Sizing and analysis of a standalone photovoltaics system for a three-bedroom residence in Nigeria," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 33, no. 1, pp. 1–9,2024, doi: 10.11591/ijeecs. v33.i1.pp1-9.

[6] T. Jothi, M. Arun, and M. Varadarajan, "Power flow analysis in a distributed network for a smart grid system," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 33, no. 1, pp. 42–52, 2024, doi: 10.11591/ijeecs. v33.i1. pp42-52.

[7] M. H. Elkholy, T. Senjyu, M. E. Lotfy, A. Elgarhy, N. S. Ali, and T. S. Gaafar, "Design and implementation of a real-time smart home management system considering energy saving," *Sustainability*, vol. 14, no. 21, Oct.

[8] A. Kebede, "A techno-economic optimization and performance assessment of a 10 kWP photovoltaic grid-connected system," *Sustainability*, vol. 12, no. 18, Sep. 2020, doi: 10.3390/su12187648.

[9] F.Sh. Zainulabdeen; J.O. Dahloos; N.K. Kasim, "Optical Measurement and Performance Prediction of Solar PV system in Al-Khidhir Zone/Iraq", Karbala International Journal of Modern Science, vol.8,2022, Vol.8,2022dio:10.33640/2405-609x.3216.

[10] A. Al-Samawi and H. Trabelsi, "New Nine-Level Cascade Multilevel Inverter with a Minimum Number of Switches for PV Systems," Energies, vol. 15, no. 16, p. 5857, 2022, doi.org/10.3390/en15165857.

[11] A. Lashab; D. Sera ;F. Hahn; L. Camurca; Y. Terriche; " Cascaded Multilevel PV Inverter with Improved Harmonic Performance during Power Imbalance Between Power Cells, " IEEE Transactions on Industry Application, vol.56, Issue 3,P. 2788–2798,2020, **DOI:** 10.1109/TIA.2020.2978164.

[12] A. Yoza et al., "Optimal Scheduling Method of Controllable Loads in Smart Home Considering Re-Forecast and Re-Plan for Uncertainties," Applied Sciences, vol. 9, no. 19, p. 4064, 2019, doi:10.3390/app9194064.

[13] H.H. Shakir, F.B. Salem, "Energy management enhancement of a smart home supplied by renewable energy system", Indonesian Journal of Electrical Engineering and Computer Science Vol. 35, No. 1, July 2024, pp. 20~31 ISSN: 2502-4752, DOI: 1591/ijeecs. v35.i1. pp20-31 *35*(1), 20-31.

[14] M.J. Yaseen; N.K. Kasim; A.F. Atwan, "Predication of the performance of a solar PV system in Baghdad, Iraq, Journal of Physics: Conference Series ,2322(2022)012079, doi:10.1088/1742-6596/2322/1/012079.

[15] S. Taha, "The effect of climate characteristics on the efficiency of solar panels and obstacles to their investment: Karbala Governorate as an example," *Journal of Geographical Research*, 2021, doi: 10.36328/0833-000-033-010.

[16] A. Balloutia, M. Chouiekh, H. Latrach, A. Abad, "Enhancing grid connected photovoltaic systems performance using a bio-inspired MFB algorithm for efficient maximum power point tracking", Energy Reports, vol.15, June 2026, doi: 101016/j.egyr.2026.109210.

[17] L. CARRERA, E. SANTANA, "Energy Efficiency Analysis of East-West Oriented Photovoltaic Systems for Buildings: A Technical-Economic-Environmental Approach", IEEE Access, vol.,11,2023, dio:10.1109/ACCESS.2023.3340145.

[18] AL-SAMAWI, Ali Abedaljabar; TRABELSI, Hafedh. New nine-level cascade multilevel inverter with a minimum number of switches for PV systems. *Energies*, 2022, 15.16: 5857.

[19] OBAIDI, Marwah Qasim; DERBEL, Nabil. IoT-based monitoring and shading faults detection for a PV water pumping system using deep learning approach. *Bulletin of Electrical Engineering and Informatics*, 2023, 12.5: 2673-2681.

[20] A. Rahimi, "Integrated Fuzzy Control of Temperature, Light and Emergency Conditions for Smart Home Application," International Journal of smart Electrical Engineering, pp. 93-99, Spring 2016.

[21] Z.A. SHAH, "Fuzzy Logic Based Direct Load Control Scheme for Air Conditioning Load To Reduce Energy Consumption," IEEE Access, vol.4,2016.

[22] F. Chekired, "Fuzzy logic energy management for a photovoltaic solar home," Energy Procedia, pp. 723-730, September 2017.

[23] S. Bissey, "The Fuzzy Logic Method to Efficiently Optimize Electricity Consumptions in Individual Housing," energies, 1701, October.2017.

[24] D. Alberto, S. Leva, G. Manzolini. "Comparison of different physical models for PV power output prediction." *Solar energy*, vol.119 ,2015. p. 83-99, doi: 101016/j.solener.2015.06.017.

[25] C.P. Ohauu, G.N. Egbo, and T. Sutikuo, "Sizing and analysis of a standalone photovoltaics system for a three-bedroom residence in Nigeria," Indonesian Journal of Electrical Engineering and Computer Science, vol.33, no.1,2024, pp. 0-9, doi:10.11591/ijeecs. v33.i1. pp.1-9.

[26] H. Mahamudul, "Photovoltaic System Modeling with Fuzzy Logic Based Maximum Power Point Tracking Algorithm," International Journal of Photo energy, October 2013.

[27] Iraqi Ministry of Transport, Meteorological Authority, the weather forecast office in Karbala province, unpublished data [27].

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