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Whale optimization algorithm and internet of things for horizontal axis solar tracker-based load optimization

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ABSTRACT

Renewable solar energy is the future of all other resources because of its reliability and availability all over the earth. Optimization of the energy consumption and utilization of internet of things (IoT) devices deployed in such systems poses significant challenges. Axis tracker panel is the scope for the next decade to increase the performance of the existing panels. This research focuses on the development of intelligent energy optimization algorithms for IoT devices. The integration of renewable energy sources and IoT devices in solar-microgrid energy systems offers promising solutions for sustainable and efficient energy management. The proposed whale optimization algorithm (WOA) takes into account dynamic factors, including varying energy availability and fluctuating demand patterns, to optimize the overall performance. Leveraging real-time data from IoT sensors and smart meters, the algorithms balance energy generation and consumption, prioritize critical loads, and incorporate energy forecasting techniques to handle fluctuations in renewable energy production. Moreover, they integrate demand response mechanisms and dynamic pricing models to encourage flexible energy consumption patterns and minimize operational costs. The results of this study demonstrate the significant potential of the WOA algorithm in enhancing the sustainability of microgrid energy systems, paving the way for a greener and more reliable energy future.

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1. INTRODUCTION

One of the key challenges faced by microgrid energy systems is the inherent variability in energy production and demand. Solar energy generation is contingent on weather conditions, resulting in fluctuations in energy availability, while energy demand exhibits dynamic patterns influenced by various factors, including user behavior and time of day. The primary goal is to strike an optimal balance between energy generation and consumption, thereby optimizing the system’s efficiency and sustainability. By factoring in varying energy availability and demand patterns, the algorithms aim to minimize energy wastage, reduce operational costs, and ensure reliable power supply to critical loads. To achieve these objectives, the proposed algorithms leverage real-time data obtained from internet of things (IoT) sensors and smart meters. This data-driven approach empowers the system to respond dynamically to fluctuations in renewable energy production, energy demand, and other environmental parameters. Additionally, the algorithms draw insights from historical data to forecast energy availability, enabling proactive decision-making to manage energy deficits or surpluses effectively. The algorithms should consider factors such as energy generation forecasts, energy storage capacity, device power consumption profiles, and task priorities to make informed decisions on energy allocation and utilization.

IoT-based architecture is used to support the grid integration of a hybrid renewable energy system to track the different elements like the communication layer, network layer, and application layer. IoT-based devices are connected to the network to explore the parameters of the data center [1]. IoT-based smart hybrid renewable energy (100 Wh) can be harvested from the flow of stored water which can be used for low-voltage applications. With the suitable storage system only, both solar and wind systems are working very efficiently. This hybrid energy monitoring is an effective solution in remote areas with good efficiency [2], [3]. Hybrid solar and wind energy can be generated through a website using the ESP8266 Wi-Fi module [4]. The generated energy data can be monitored using IoT. An Intelligent control based on IoT can be needed to control the operation of a hybrid renewable energy system. Solar power can be monitored using IoT [5], [6]. Energy internet is a new concept with the support from IoT can be a very much sophisticated solution to implement smart grid systems [7], [8]. To meet the energy consumption of large buildings, how optimization algorithms can be adopted with renewable energy systems can be illustrated [9]. To maximize reliability and reduce cost, a hybrid method can be adopted to describe the volume and location for the integration of photovoltaic (PV) panels with battery storage operations in rural areas [10], [11]. Hybrid energy sources are depending on economic, environmental, and weather conditions. IoT architecture for the smart grid and its applications, services, challenges, and future work are discussed [12]. Renewable energy can be monitored using a new methodology to combine the supervisory control and data acquisition (SCADA) software wonderware intouch and the simulation model using Simulink can transfer data via an IoT-based scheme [13], [14]. Battery management system that consists of PV model, perturb and observation (P&O) maximum power point tracking (MPPT) technique, and system on chip (SoC) estimation of battery [15]. DSPACE 1104 monitoring component was added to the battery management systems (BMS) system to gather the data. IoT comprises of sensor network that collects details about the temperature, humidity, and air quality and stores it in the Thingspeak cloud. Digitizing the electric power ecosystem using IoT can help to better account for distributed energy resource (DER) integration [16], [17]. To ensure the reliability of wind energy conversion, IoT can be taken and used to analyze the parameters [18]. The cost of an existing system can be reduced from 10%-20% in the PV-wind hybrid generation and increased sustainability is attained [19]. The hybrid energy optimal system configuration is determined based on minimum cost of energy (COE) and reliability criteria defined by the specified value of loss of load probability (LOLP) using a firefly optimization algorithm-based approach [20]. Grid integrated mini-grids with storage (GIMS) can offer consistent power supply at a reasonable price by merging mini-grids and national grid amenities [21].

2. METHOD

In this proposed system, it is horizontal axis solar tracker can be used to generate the electricity needs of a small remote place. Tracker panels are producing effective electricity than the fixed panels. IoT things can be used to utilize the tracking system and aligned with sun axis to produce more power with online data analytics. Load optimization is one of the problems associated with the energy management. Whale optimization algorithm (WOA) is one of the optimization algorithms to provide good results for the mentioned problem. So, it is been decided to adopt WOA and IoT for the horizontal solar axis tracker (HSAT) to solve the problems associated with the optimization of loads connected with the microgrid [22].

The IoT enables renewable energy providers to improve the efficiency, reliability, and safety of renewable energy systems while reducing their operational costs. IoT devices, or IoT devices, are connected devices that collect and exchange data over the internet. The IoT enables real-time monitoring of renewable energy systems, allowing providers to track and analyze energy production, consumption, and storage. Smart meters and sensors can be used to measure the energy output of solar panels, wind turbines, and other renewable energy sources. This data is then transmitted to cloud-based platforms for real-time analysis and visualization. An IoT-based solar microgrid system is a smart energy solution that integrates solar power generation with advanced IoT technologies. The system combines renewable energy sources, energy storage, and smart devices to create a more efficient and reliable energy infrastructure. The main part of the system is solar panels that capture sunlight and convert it into electricity. The Figure 1 has displayed the overall concept of the microgrid fed by solar panel which is connected by IoT enables the integration of smart devices, sensors, and communication systems to facilitate real-time monitoring and control of renewable energy sources.

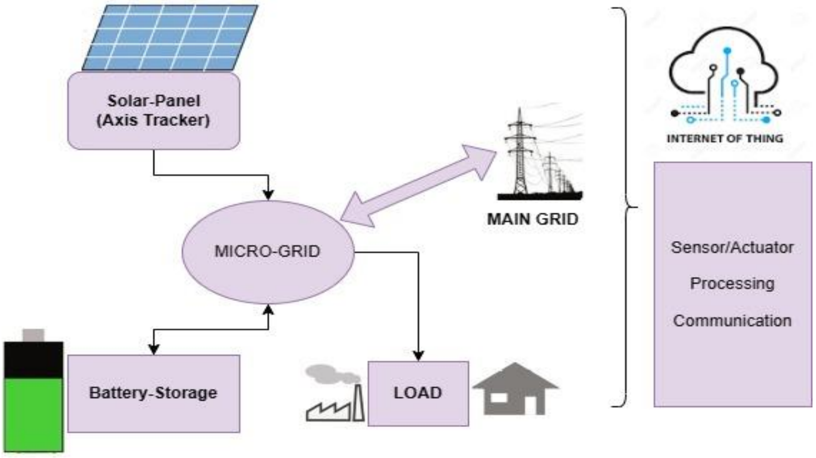

Figure 1. Block diagram representation of microgrid-renewable energy

To ensure a stable power supply even during periods of low sunlight or at night, energy storage systems like batteries are employed. These batteries store excess energy generated during peak sunlight hours and release it when demand exceeds solar generation. Smart inverters, integrated with IoT capabilities, can communicate with other system components and grid operators to optimize energy flow and grid stability. Sensors and smart meters are used to monitor energy generation, consumption, and grid conditions in real time. Data from these devices is transmitted to a central control platform. A cloud-based or on-premises control platform gathers and analyses the data collected from IoT devices. The control system optimizes energy distribution, ensures grid stability, and can even predict energy demand patterns for efficient energy management. IoT-enabled smart devices, such as smart appliances and thermostats, can adjust their energy consumption based on real-time electricity prices or grid conditions. This demand response and load management help balance energy demand and supply and reduce peak load on the grid [23].

2.1. Load management-procedure

The main idea of the system is to produce an optimized solar-micro-IoT system. First, we need to install IoT sensors and smart meters throughout the microgrid to continuously monitor solar energy generation, battery storage levels, energy consumption patterns, and grid conditions. The data collected should be analyzed in real time using advanced analytics algorithms to make informed decisions. It needs to work with demand response strategies to manage energy consumption during peak periods. If the microgrid is part of a larger energy market, incorporate dynamic pricing mechanisms that encourage consumers to shift their energy consumption to off-peak hours [24].

- IoT-enabled smart devices can automatically adjust their energy usage based on real-time grid conditions and pricing signals.
- The IoT-based control system should determine the most efficient energy dispatch strategy, considering factors like solar energy availability, battery storage levels, and real-time demand.
- This confirms that the energy is used most efficiently and reduces wastage. Also, more attention is given to advanced BMS to monitor and control battery charging and discharging.
- The BMS should optimize battery usage to prolong its lifespan and maximize its efficiency.

Use the IoT data to monitor the grid's stability and quickly respond to any fluctuations [25]. From the derived algorithms it can autonomously stabilize the grid by adjusting energy distribution and load shedding in case of emergencies. By enabling remote monitoring and control of the microgrid system, it tends to lead the operators to manage the system efficiently from a central location. Optimized placement of energy storage systems is essential for the balance of energy generation and consumption very effectively. Interoperability of different IoT devices and protocols can be enabled by ensuring unified integration in the grid. Utilize historical data and machine learning algorithms to forecast solar energy generation, energy demand patterns, and weather conditions. These predictions can help in planning energy dispatch and storage strategies in advance.

2.1.1. Case-study

In Figure 2. Shows the case study the microgrid is connected to 10 houses which are installed with solar panels with trackers, without tracking, and also directly get power from the main grid. The following is the distribution of power requirement and generating capacity of the microgrid. A microgrid is a localized energy system that can operate autonomously or in conjunction with the main grid. It typically consists of DERs like solar panels, wind turbines, batteries, and other forms of on-site generation and storage. Microgrids are designed to supply electricity to specific areas, such as communities, campuses, industrial sites, or military bases. They can operate independently from the main grid or in a "grid-connected" mode where they can both import and export electricity to and from the main grid. A remote community located in a rural area with limited access to the national power grid has been facing challenges related to unreliable electricity supply:

- Provide a reliable and sustainable source of electricity for the community.
- Improve energy efficiency and optimize energy consumption.

in Table 1 for the case study taken, elements like consumer type, installed solar panel capacity, energy produced per day and typical demand in a day.

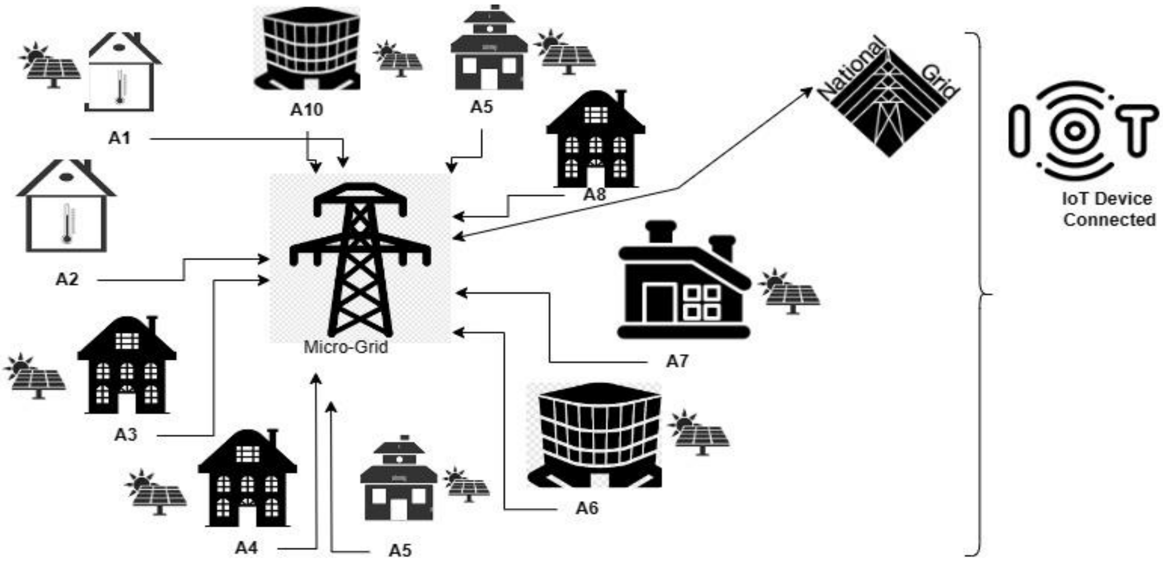

Figure 2. Microgrid representation-case study

Table 1. Case study of microgrid connected area

No.	About consumer	Renewable solar install capacity	Energy production/day	Demand in a day
A1	Remote house	1 kW solar panel-HSAT	6-7 kWh	3-4 kWh
A2	Small house	No solar panel	Nil	1 kWh
A3	Apartment	500 W of solar panel	2 kWh	3 kWh
A4	2 Consumers	1 kW solar panel	4-5 kWh	2-3kWh
A5	Building	500 W solar panel	3 kWh	2 kWh
A6	Commercial	1 kW solar panel-HSAT	6-7 kWh	7-8 kWh
A7	Small industrial	2 kW solar panel-HSAT	12-14 kWh	15 kWh
A8	Apartment	No solar panel	Nil	7-8 kWh
A9	Remote building	500 W solar panel-HSAT	3-3.5 kWh	2 kWh
A10	Complex	1 kW solar panel-HSAT	6-7 kWh	5 kWh
	Total	7.5 kW	48.5 kWh	51 kWh

2.2. Solution for the problem through multi-objective genetic optimization algorithm

A WOA is a powerful optimization technique that can be applied to address the complex and conflicting objectives in the load management of IoT-based microgrids. WOA allows for the simultaneous optimization of multiple objectives, enabling the system to find a set of solutions that represent the trade-offs between these objectives. Define the multiple objectives that need to be optimized in the energy management of the IoT-based microgrid. These objectives could include minimizing energy costs, maximizing the utilization of renewable energy sources, reducing carbon emissions, and ensuring grid stability. The algorithm utilizes three operators named prey, encircling of prey and whale bubble-net foraging. All these processes can be used for maximum food or prey in the sea. This technique is utilized to find the optimized load management in the microgrid based on solar panels [26].

$$WOA_{\text{objective function}} = Ma\,x\,\Sigma(\,Loadfactor, Demandfactor.\,Powerfactor\,) + Max\,\Sigma(\,Battery\ Discharged\ -\ Batterycharged\,)$$

$$OF = \mathrm{Max}(P_{\mathrm{and}}\,\mathrm{mat}/P_{\max}) \cdot (D_{\mathrm{mad}}/T_{\mathrm{had}}) \cdot PF + \mathrm{Max}\big(2SOC_{mi} - 2SOC_{fwi}\big) \tag{1}$$

a) PV modeling

From the (2) solar pv power can be described [12].

$$P_{pv} = \eta * G_{pv} * \mathrm{A} \tag{2}$$

η=efficiency of the solar panel.
G_{pv}=solar irradiance in W/m^2.
A=area of the solar panel.

$$E\ fficiency\ (\%) = (P/P_{\mathrm{solar}}\,) * 100 \tag{3}$$

P: power output from the solar panel (W), P_{solar}: Incident solar power on the panel (W)

$$\mathrm{T} = \mathrm{T_a} + (\mathrm{NOCT} - 20) * \big(\mathrm{I_{rradiance}}\,/\mathrm{I_{rradiance\_NOCT}}\,\big) + \mathrm{K_{wind}}\ * \mathrm{V_{wind}} \tag{4}$$

T: temperature of the solar panel (in deg), Ta: ambient temperature (in deg),
NOCT: nominal operating cell temperature (in deg), solar irradiance (in W/m^2)
Irradiance NOCT: Standard reference irradiance used for NOCT (800 W/m^2)
K_wind-coefficient of temperature increase per unit wind speed.
V_wind: wind speed (in m/s)

b) Battery modeling

The battery power is bidirectional because of charging/discharging modes [14]. It is expressed as (5):

$$BP(t) = (1 - w)B_{p,d}(t) + B_{p,\,\mathrm{dix}}\,(t) \tag{5}$$

where, $B_{P,\ ch}(t)$, $B_{P,\ dis}(t)$ are the battery power at the charge anddischarge modes and the state of charge CSOCdetermines the amount of energy accessible in the battery storage and is estimated by (6):

$$Depth\ of\ Discharge\colon DOD(t) = 1 - SOC(t) \tag{6}$$

c) Algorithm steps:

```
A. Initialize IoT devices, sensors, and communication protocols.
B. Initialize data structures for storing sensor data and system parameters.
C. WHILE TRUE:
    a. Read data from solar panels, batteries, weather sensors, energy meters, and grid
    b. Store the data in appropriate data structures.
    c. Calculate solar energy generation based on solar irradiance data.
    d. Adjust solar panel angles and positions for optimal energy generation.
    e. Monitor battery levels and health using IoT sensors.
    f. Implement battery charging and discharging strategies for optimal usage.
    g. Analyze historical energy consumption patterns to forecast future demand.
    h. Determine total electricity demand and available generation.
    i. Balance load between solar, battery, and grid to meet demand efficiently.
    j. Implement smart load management strategies to optimize consumption.
END WHILE
```

d) Iteration results:

Table 2 elaborates the whale optimization iteration results for the given objective function. In Figure 3 it shows the optimization plot for the given multi objective function and the corresponding best score obtained for the given problem. From the tabulation it is desired to keep the demand factor value above 0.85 and load factor value below 0.5. By doing so, power factor value will get a good value and optimized power system.

Table 2. The best solution obtained by WOA

Power	DF	LF	PF
7,432	0.77	0.55	0.88
7,447	0.82	0.68	0.91
7,490	0.71	0.62	0.93

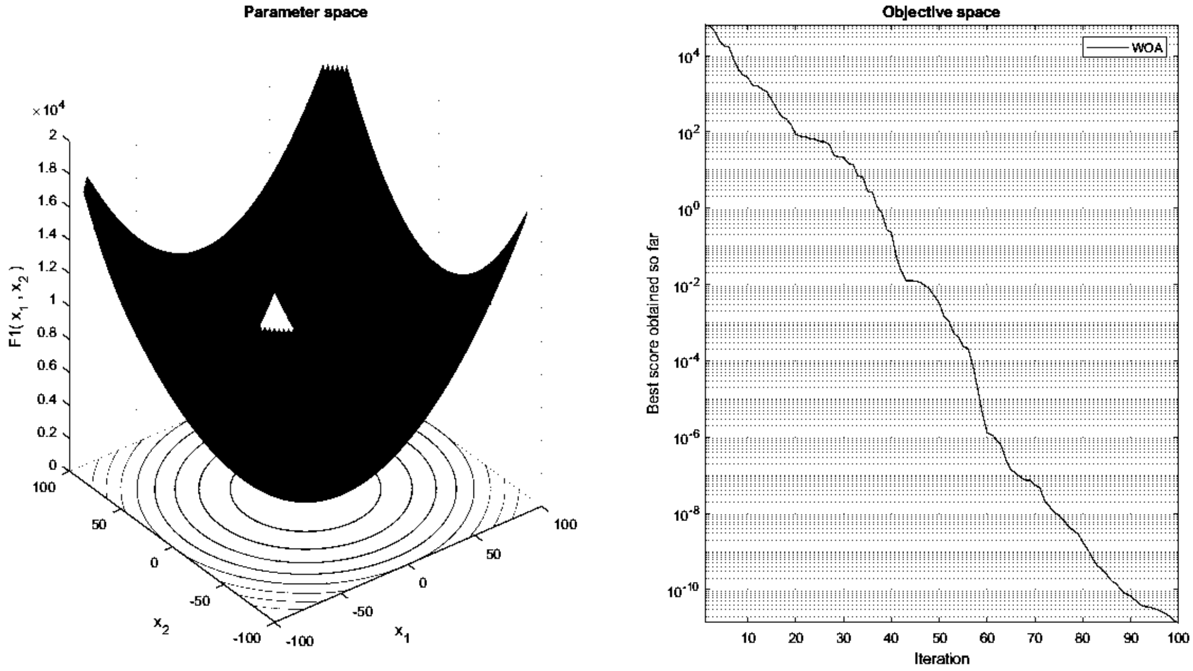

Figure 3. WOA graphical result for given objective function

3. RESULTS AND DISCUSSION

The table shows the different solar panel axis tracking with the sun axis for different periods. IoT sensor data represents the temperature, humidity, and output voltage of the solar panel. It is possible to track the sun axis horizontally to get more output than the fixed or not moving panel. From this, it is ensured to get 1,415 times of output than the fixed one [25], [26]. In Table 3 sensor values related to the solar panel is shown. The values like temperature, humidity and voltage sensor reading, angle tracking is mentioned.

Table 3. IoT sensor values for solar panel and axis details

Timestamp	IoT sensor data	Solar panel axis orientation
2023-08-03 12:00	25 °C, 45% RH,48.0 V	90°s
2023-08-03 12:05	26 °C, 50% RH, 48.4 V	95°s
2023-08-03 12:10	27 °C, 51% RH, 48.8 V	100°s
2023-08-03 12:20	26 °C, 50% RH, 48.4 V	105°s
2023-08-03 12:30	25 °C, 49% RH, 48.8 V	110°s
2023-08-03 01:00	24 °C, 48% RH, 48.9 V	130°s

The Table 4 correlates the dataset for the different parameters of solar panels like generated power, battery power charging and discharging, the demand of the load, and power retrieved from the grid. From this, it's understood that the power is delivered in the forward as well as backward direction whenever it's necessary or excessive. So, micro-grid is effectively handling the power from the IoT-based solar panel and also from the national grid. The next section expands, on solar panel power generated at a particular time and the power consumption of different load appliances of the house. Also, solar panel generation versus load profile simulation was done for the given power rating. Also, explains solar panel parameters data set is compare for the months of a year. We summarize the abbreviations contained in Table 4: a) GlobHor: global horizontal irradiation, b) E_Solar: energy from the sun, c) T_Amb: ambient temperature, d) E_Grid: energy injected to the grid, e) E_Array: effective energy output of solar array, f) EfrGrid: energy from the grid, and g) E_User: energy supplied to the user.

Table 4. Parameters for solar power generation and grid power with irradiance, temperature

	GlobHor kWh/m²	T_Amb °C	E_Array MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	149.5	25.90	2.075	0.744	0.446	1.391	0.298
February	156.9	26.30	1.900	0.672	0.411	1.262	0.261
March	190.3	28.50	2.278	0.744	0.482	1.530	0.262
April	185.4	30.20	2.231	0.720	0.467	1.504	0.253
May	182.2	32.20	2.304	0.744	0.489	1.539	0.255
June	157.8	31.20	2.291	0.720	0.480	1.542	0.240
July	161.5	30.60	2.389	0.744	0.494	1.622	0.250
August	153.9	29.70	2.327	0.744	0.488	1.570	0.256
September	155.6	28.80	2.167	0.720	0.454	1.464	0.266
October	134.3	27.80	2.155	0.744	0.462	1.442	0.282
November	113.7	26.00	2.008	0.720	0.442	1.326	0.278
December	113.0	24.39	2.025	0.744	0.449	1.333	0.295
Year total	1854.1	28.48	26.150	8.760	5.564	17.524	3.196

In Figure 4 it derives the bar graph shows the available solar energy for the 1 KW solar panel, about 3,635 kWh which is the same output from the inverter. Also, the performance ratio of the panel indices is about 0.7937 for the installed panel. Figure 5 explains the battery profile of the microgrid. It shows the important parameters like the average state of charge during the period is 0.2729 and charging, and discharging. That means 50% SoC is applicable which is good for the installed solar panels.

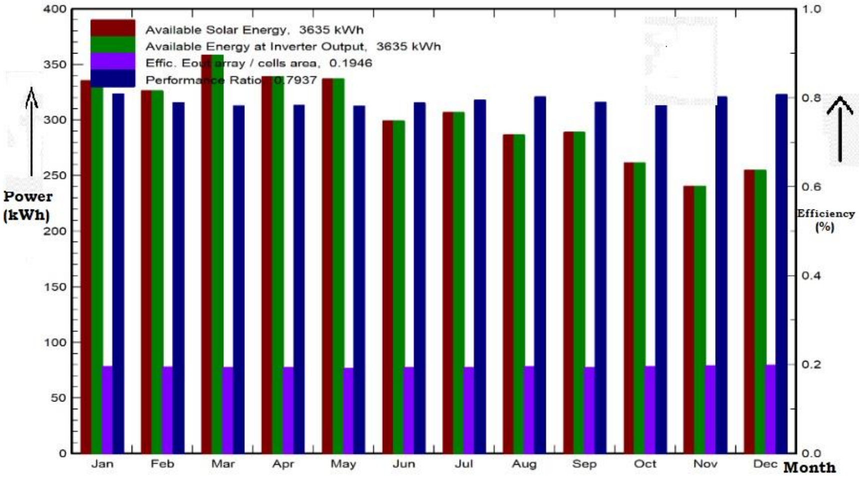

Figure 4. Power available in PV array, inverter output, efficiency of PV ratio and performance ratio

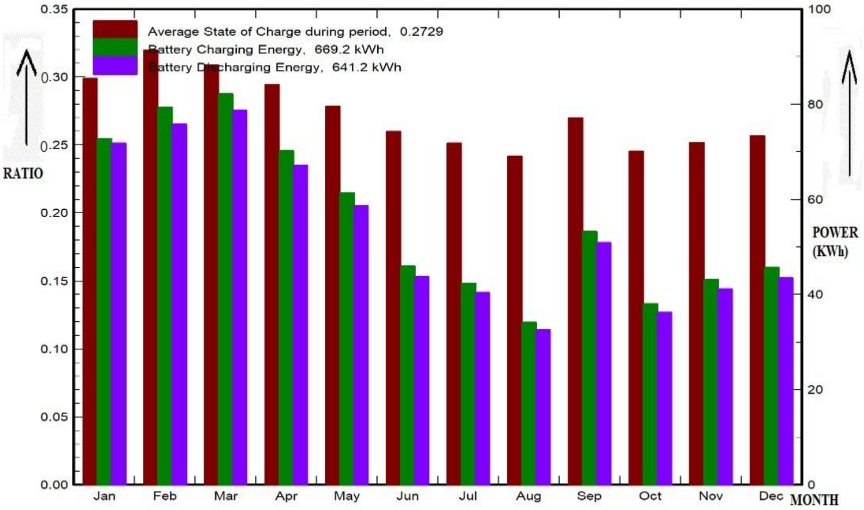

Figure 5. Average battery SOC, charging, discharging

In Figure 6 the graph displays multi objective genetic algorithm fed optimized for the various elements like energy demand, energy generation and CO_2 emissions. In Figure 7 it shows the comparison of performance between IoT enabled with the normal microgrid. From the graph, it is visible that the overall performance factors like demand factor, load factor, power factor is improved. So, it is advisable to convert as IoT enabled in the future make it efficient in the operating point of view even if the initial cost is high.

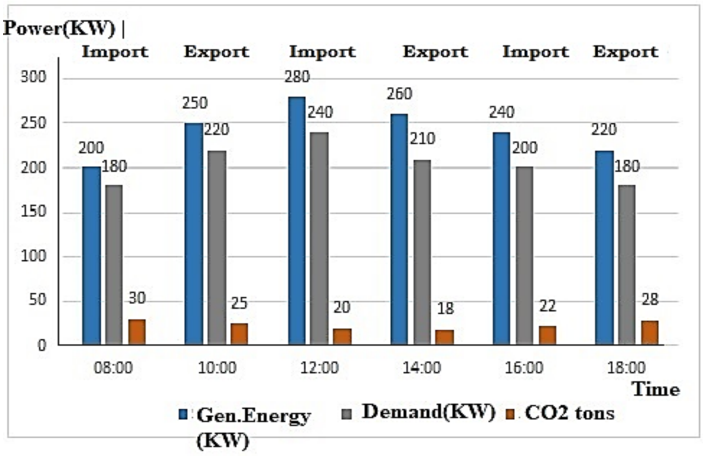

Figure 6. WOA optimizer microgrid performance evaluation

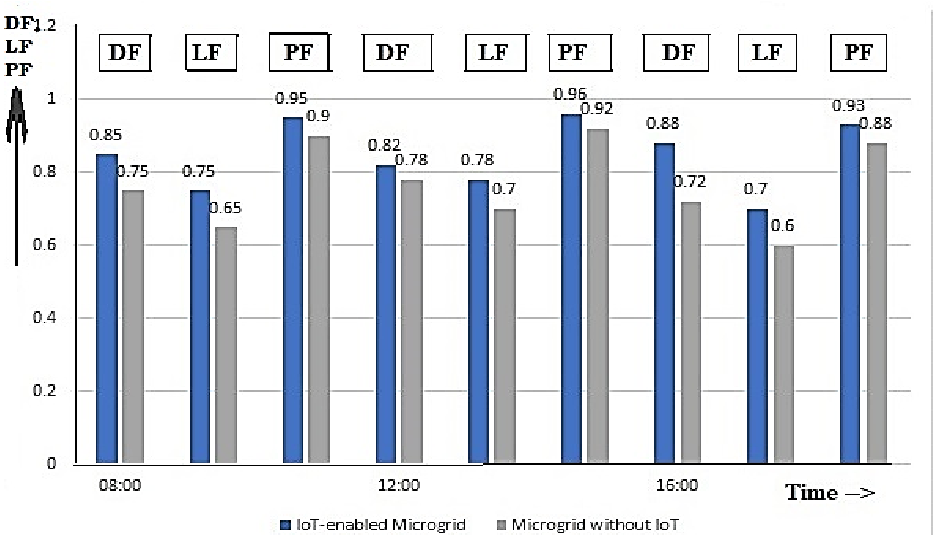

Figure 7. IoT enabled microgrid performance evaluation

4. CONCLUSION

The study leveraged IoT technology to establish real-time communication and control capabilities within the microgrid. IoT-enabled sensors and actuators facilitated data acquisition and analysis, enabling the optimization model to make dynamic adjustments to energy distribution and management based on real-time conditions. The results demonstrated that the WOA-IoT approach outperformed conventional optimization methods in terms of system performance. The framework achieved a higher percentage of energy capture from solar PV systems, minimizing energy wastage and maximizing the utilization of renewable energy resources. They compared its results with traditional optimization methods and static control strategies to assess its effectiveness in achieving higher energy utilization efficiency, increased energy capture, and improved grid stability. The real-time adjustments enabled the microgrid to effectively balance supply and demand, ensuring reliable power delivery to consumers even during fluctuations in solar energy generation. It reduced the risk of voltage fluctuations, frequency deviations, and blackouts, thus promoting a more reliable and resilient energy infrastructure. By efficiently utilizing solar PV energy and reducing dependence on non-renewable sources, the framework demonstrated its potential in mitigating greenhouse gas emissions and supporting efforts to combat climate change.

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