IJE TRANSACTIONS A: Basics Vol. 37, No. 10, (October 2024) 1891-1900

International Journal of Engineering

Journal Homepage: www.ije.ir

Optimizing DC Microgrid Systems for Efficient Electric Vehicle Battery Charging in Ain El Ibel, Algeria

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PAPER INFO

Paper history:
Received 22 January 2024
Received in revised form 26 February 2024
Accepted 12 March 2024

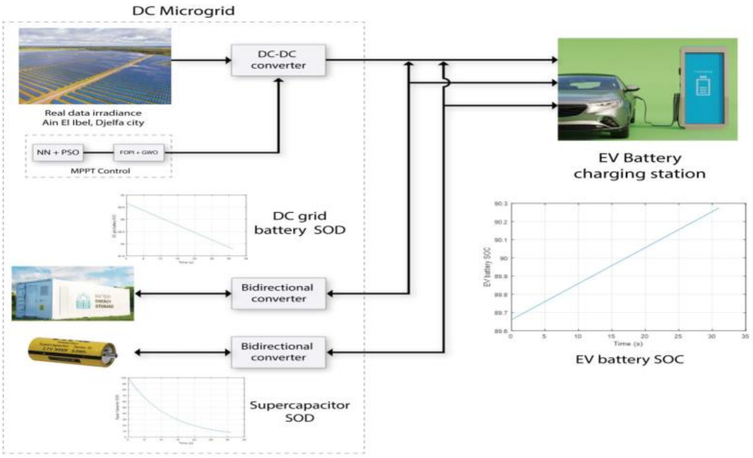
Keywords:
DC Microgrid System
Maximum Power Point Tracking
Grey Wolf Optimization
Particle Swarm Optimization
Fractional Order Proportional-Integral Controller
Neuronal Network

ABSTRACT

In addressing the critical challenge of developing sustainable energy solutions for electric vehicle (EV) battery charging, this study introduces an innovative direct current (DC) microgrid system optimized for areas with high solar irradiance, such as Ain El Ibel, Djelfa. The research confronts two primary difficulties: maximizing solar energy utilization in the microgrid system and ensuring system stability and response accuracy for reliable EV charging. To tackle these challenges, the study presents two original achievements. Firstly, it develops a neural network-enhanced Maximum Power Point Tracking (MPPT) controller, which is further optimized with Particle Swarm Optimization (PSO) to increase the efficiency of solar energy capture. Secondly, it refines the system's reliability through the advanced calibration of a Fractional Order Proportional-Integral (FOPI) controller using the Grey Wolf Optimization (GWO) technique, marking a notable improvement in microgrid system stability and response accuracy. The integration of a solar panel array, battery storage, and a supercapacitor, coupled with these advanced optimization techniques, exemplifies a significant leap forward in enhancing efficiency and reliability of EV battery charging through renewable energy sources. Comprehensive simulation and evaluation of the system underscore its superiority over conventional methods, demonstrating the effectiveness of combining neural network-based optimization with PSO and GWO. This breakthrough not only advances the field of renewable energy, particularly for solar-powered EV charging stations, but also aligns with global efforts towards sustainable transportation solutions.

***doi**: 10.5829/ije.2024.37.10a.03*

Graphical Abstract



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Please cite this article as: Younes B, Ait Abbas H, Laroussi K, Bousbaine A, Fergani O, Mazari A. Optimizing DC Microgrid Systems for Efficient Electric Vehicle Battery Charging in Ain El Ibel, Algeria. International Journal of Engineering, Transactions A: Basics. 2024;37(10):1891-900.

NOMENCLATURE

D_α, D_β, D_δ	The distance between the prey and the alpha, beta and omega wolves	I_{sc}	The short circuit current
A, C	Victors	I_{pv}	The light-generated current
G	Irradiance	I_s	The reverse saturation current
I	The output current of the PV cell.	R_p	The shunt resistance
T	Temperature	R_s	The series resistance
W	Inertia weight	N_s	The number of cells connected in series
$C(s)$	the controller function in the Laplace domain	X_α, X_β, X_δ	The position of alpha, beta and omega wolves
$X(t)$	The position of the wolf in the current iteration	K_p	Proportional gain
c1	Cognitive coefficient	K_v	Represents the ratio of open voltage circuit
c2	Social coefficient	K_i	Integrator gain
x_i^t	The previous position	K_1	Represents the ratio of short circuit current
$x_i^{(t+1)}$	The updated position	V_{oc}	The open circuit voltage
v_i^t	The previous velocity	k	Boltzmann constant
$v_i^{(t+1)}$	The updated velocity	q	Charge of an electron 1.602 19-^10*C
r_1, r_2	random numbers within the range [0, 1]	D_α, D_β, D_δ	The distance between the prey and the alpha, beta and omega wolves
$xBest_i^t$	The particle's best position	**Greek Symbols**	
$gBest_i^t$	The global best position	λ	The fractional order of the integral part ($0 < \lambda \leq 1$)
G_n	Nominal irradiance	ΔT	The variation of temperature

1. INTRODUCTION

The urgency to address environmental challenges and the volatile dynamics of fossil fuel markets have catalyzed the need for sustainable energy solutions (1). Among these, solar photovoltaic (PV) systems emerge as a viable alternative (2), particularly in geographically advantageous regions like Ain El Ibel which is located in the south of Algeria, at latitude 33.15 N longitude 4.68 E and altitude 361 m, known for their abundant solar resources (3). The integration of solar PV systems into the energy mix is critical in transitioning towards a more sustainable energy future (4). However, the reliability of these systems is frequently compromised by fluctuating weather patterns, a phenomenon that substantially impairs their efficiency and leads to significant power losses (5). Such variability poses a considerable obstacle to the consistent performance of solar PV systems, especially in applications demanding high reliability, such as electric vehicle (EV) charging stations (6).

Recent studies have significantly contributed to enhancing photovoltaic (PV) systems' efficiency through various methods. One study focused on improving the accuracy of state-of-charge predictions for lead-acid batteries, vital for prolonging battery life in renewable energy systems (5). Another research explored cooling PV panels using nanofluids, showing that ZnO nanofluids in a rectangular spiral configuration could significantly increase electrical efficiency (2). Additionally, the development of carbon-free gas diffusion electrodes with Ni and Co-based bifunctional electrocatalysts for zinc-air batteries was investigated, offering improved stability and efficiency for energy storage (7).

In this study two sophisticated optimization algorithms have been implemented: Particle Swarm Optimization (PSO) tuning a single hidden layer neural network and Grey Wolf Optimization (GWO) tuning a fractional order PI controller. These algorithms are utilized to enhance the operational efficiency of a specifically designed microgrid system dedicated to EV charging (8). The microgrid system, conceptualized for the high solar radiation in this region of Ain El Ibel, is an exemplary model of integrating renewable energy sources into modern infrastructures which has the following characteristics: Insulation time 3376 hours/year, Global irradiation received on a horizontal surface 2065 kWh/m²/year, Global irradiation received on a surface inclined to the latitude of the location 2399 kWh/m²/year, Energy produced 1613 MWh/MWp/year, "CO2" Carbon dioxide avoided 643.86 Tone/year, "C" Carbon avoided 175.57 Tone/year (7). By optimizing the performance of this microgrid, the study seeks to not only improve the efficiency and reliability of solar PV systems but also contribute to the broader goal of advancing renewable energy technologies for sustainable development. The integration of PSO and GWO in this context offers insightful perspectives on the optimization of energy systems under variable environmental conditions, thereby paving the way for more robust and efficient renewable energy solutions in the face of global climate change challenges.

2. COMPREHENSIVE ANALYSIS OF PHOTOVOLTAIC SYSTEMS IN MICROGRIDS

At the core of microgrid technology is the photovoltaic (PV) system, a pivotal component that harnesses solar radiation and transforms it into usable electrical energy. The intricate interplay between solar radiation and PV cells is fundamental to the generation of electricity in these systems. To attain maximum power output from PV systems, it is imperative to delve into detailed design methodologies (9) and implement sophisticated control strategies as illustrated in Figure 1 that represent equivalent electrical representation of a Photovoltaic Cell (10) (11).

Based on the equivalent circuit depicted in Figure 1, the subsequent equations are derived (10):

$$I = I_{pv} - I_S \left(e^{\frac{q(V+R_S I)}{N_S KTa}} - 1 \right) - \frac{V+R_S I}{R_p} \qquad (1)$$

$$I_{pv} = \frac{\left(I_{pv}+K_1 \Delta TI\right) G}{G_n} \qquad (2)$$

$$I_S = \frac{n+K_1 \Delta TI}{e^{\left(\frac{\frac{V_{oc,n}+K_V \Delta T}{N_S KTa}}{q}\right)} - 1} \qquad (3)$$

This necessity stems from the substantial influence that environmental variables exert on the performance of PV systems (9).

Several elements should be analyzed to fully understand PV systems in microgrids. These elements include the physical properties of the PV cells (9), the layout of the solar panel arrays, and their interconnection with energy storage and other power-generating components in the microgrid (12). Additionally, the effectiveness of PV systems is heavily contingent upon optimal alignment with environmental conditions such as solar irradiance (13), temperature fluctuations, and shading effects (14), all of which can markedly affect the energy output.

Table 1 encapsulates the salient electrical characteristics of a typical PV panel, which are vital for the effective operation and integration of the panel within a microgrid. Table 1 delineates parameters such as the maximum power output, open circuit voltage, short circuit current, and more. These parameters are essential for determining the panel's capacity to convert solar energy into electrical energy under different environmental conditions. Understanding these metrics is crucial for the design and optimization of PV systems within microgrids (10).

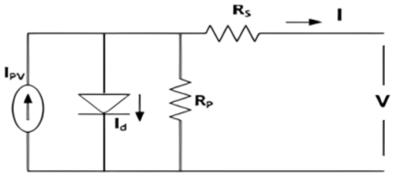

Figure 1. Equivalent electrical model of PV cell

TABLE 1. PV panel parameters (10)

Module data	Value
Maximum Power (W)	10.024
Open Circuit Voltage (V)	21.9
Short Circuit Current (A)	0.71
Maximum Voltage (V)	17.9
Maximum Current (A)	0.56

Advanced control mechanisms, therefore, play a critical role in ensuring that PV systems operate at their highest efficiency (14). These mechanisms must be adept at adapting to changing environmental conditions, managing energy flow within the microgrid, and maintaining a stable and reliable power supply (12). This level of control is achieved through the implementation of cutting-edge technologies such as Maximum Power Point Tracking (MPPT) (9) and sophisticated metaheuristic algorithms that adapt to environmental variations (13).

In conclusion, incorporating solar panel (PV) systems into smaller, localized power networks (microgrids) is a complicated but crucial task in the field of renewable energy (15). Achieving optimal functionality demands not only a comprehensive understanding of the interdependencies between solar radiation and PV technology (9) but also necessitates the deployment of advanced control systems (14). These elements together form the cornerstone for the efficient and sustainable operation of micro grids in harnessing solar energy.

3. ADVANCED STRATEGIES IN MPPT AND CONTROL OPTIMIZATION

The use of Maximum Power Point Tracking (MPPT) techniques is a vital aspect in optimizing the efficiency of photovoltaic (PV) systems. These techniques are designed to ensure that PV systems consistently operate at their maximum power output, a crucial factor in overall effectiveness of solar energy harvesting. Traditional MPPT methodologies, such as Perturb and Observe (P&O) and Incremental Conductance (INC) approaches, have established their utility in this domain. However, these classical methods have demonstrated certain limitations, particularly when subjected to rapidly changing environmental conditions, which can impact the energy harvesting efficiency of PV systems (16).

In response to these challenges, this study introduces an innovative approach by integrating an Artificial Neural Network (ANN)-based MPPT system in conjunction with a Fractional Order Proportional-Integral (FOPI) controller. This advanced combination is tailored to address the shortcomings of conventional MPPT methods. The ANN-based MPPT system leverages the power of intelligent algorithms to predict and adapt to varying solar irradiance and temperature conditions more accurately and swiftly (16). This predictive capability enables the system to maintain optimal operation close to the maximum power point under a wide range of environmental conditions.

Simultaneously, the FOPI controller, an enhancement over the traditional PI controller, offers a higher degree of control precision (17). Its fractional calculus approach allows for more nuanced adjustments in the control mechanism, leading to significant improvements in system response time and stability. This adaptability is particularly beneficial in managing the dynamic and non-linear characteristics of PV systems (16). Figure 2 illustrates the FOPI controller model.

3. 1. Fractional Order Concept

Fractional Calculus: Is an extension of traditional calculus Concerning the calculation of derivatives and integrals of arbitrary (non-integer) orders. The notation generally used is Dα, where α is a real (or complex) number.

Fractional Derivative/Integral: The concept extends the order of derivatives and integrals from integers to real numbers. In the context of control systems, this allows for more flexible and precise system dynamics tuning.

3. 2. Fractional Order PI Controller Model

Mathematical Form: The general form of a fractional order PI controller can be represented as follows (18):

$$C(s) = Kp + \frac{Ki}{s\lambda} \tag{4}$$

Integral Term with Fractional Order: The $\frac{Ki}{s\lambda}$ term represents the fractional integral part of the controller. Unlike the traditional integer order integral, this allows for more nuanced control action over time, which can be particularly beneficial in systems that exhibit anomalous behavior or require more precise control.

Empirical evaluations and simulations, as referenced in the study, have showcased that this integrated ANN-based MPPT and FOPI controller framework markedly outperforms traditional methods. The results indicate not only enhanced response time but also greater stability in the PV system's operation, even under fluctuating environmental conditions. These advancements in MPPT and control optimization techniques represent a significant leap forward in maximizing the efficiency and reliability of PV systems.

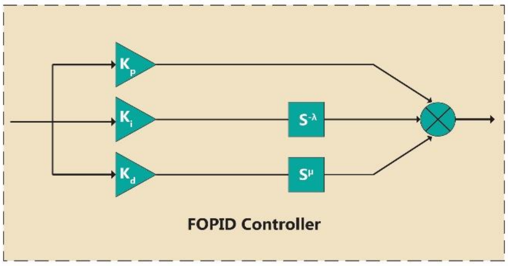

Figure 2. Fractional Order PI Controller Model

4. ENHANCED SYSTEM MODEL AND SIMULATION WITH INTEGRATED ENERGY STORAGE

This research encompasses the development of a sophisticated micro grid system, extensively modelled and simulated using the MATLAB/SIMULINK platform. The system's architecture is composed of a solar panel array, a DC-DC voltage boost converter, a high-efficiency battery (11, 19), and a super capacitor, all orchestrated by advanced controllers. This comprehensive design integrates diverse energy sources and storage mechanisms, ensuring a more resilient and efficient energy supply (11). The DC microgrid utilizes a Lithium battery, the characteristics are detailed in literature (10).

Table 2 outlines the configuration of the supercapacitor employed in this research:

For safe and efficient use of energy by the battery and supercapacitor, a voltage control system is implemented, the architecture is depicted in Figure 3 (10).

A key aspect of the microgrid system is the incorporation of both a battery and a supercapacitor. The battery serves as a reliable energy storage medium, providing sustained power supply and enhancing the system's capability to manage load variations (20). The supercapacitor, on the other hand, contributes to the system's performance by offering rapid charge-discharge cycles, ideal for managing short-term power fluctuations. This dual-storage approach significantly enhances the overall stability and responsiveness of the microgrid (21).

TABLE 1. Supercapacitor characteristics (10)

Super capacitor Parameters	Value
Rated Voltage (V)	16
Rated Capacitance (F)	58
Equivalent DC series resistance (Ω)	8.9×10^{-3}
Number of series capacitors	1
Number of parallel capacitors	1
Initial Voltage (V)	15
Operating Temperature (Celsius)	25

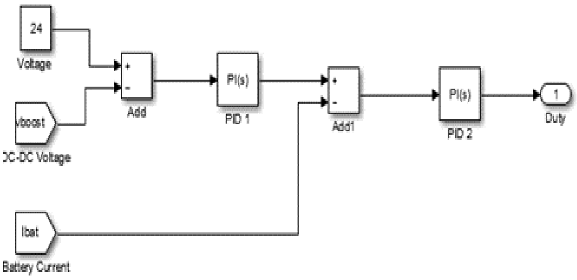

Figure 3. Voltage control for EMS

For the optimization of the system's controllers, two advanced methods were used: Particle Swarm Optimization Artificial Neural Network (PSOANN) (22) and Fractional Order Proportional-Integral (FOPI) enhanced with Grey Wolf Optimization (23). The PSOANN is pivotal in fine-tuning the system's operational parameters, leveraging the power of artificial neural networks and the global search capability of particle swarm optimization (24). This results in a highly adaptive and efficient control mechanism, capable of responding dynamically to changing environmental and load conditions (25).

The fundamental steps of the Particle Swarm Optimization (PSO) algorithm include (26):

1. Establish the initial position and velocity for each particle within the swarm. This is typically done randomly within a predefined search space.
2. Evaluate the fitness of each particle using a predefined fitness function. The fitness function is typically the output power of the PV system, but it can also be the efficiency or another measure of performance.
3. Update the personal best position of each particle based on its current fitness. The personal best position refers to the most optimal position a particle has attained to date.
4. Update the global best position based on the personal best positions of all the particles in the swarm. The global best position is the best position achieved by any particle in the swarm.
5. Revise the velocity and location of each particle considering its personal best and global best positions. The update of each particle's velocity involves a specific velocity update equation that incorporates its current velocity, personal best position, and global best position. Subsequently, the particle's position is adjusted in accordance with its updated velocity, i.e.:

$$x_i^{(t+1)} = x_i^t + v_i^t \tag{5}$$

$$v_i^{(t+1)} = wv_i^t + c_1 r_1 (xBest_i^t - x_i^t) + c_2 r_2 (gBest_i^t - x_i^t) \tag{6}$$

6. Repeat steps 2 through 5 until a satisfactory operating point is found or a predefined stopping criterion is met.
7. The final position of the particles represents the optimal solution.

In the PSO-tuned ANN-based Maximum Power Point Tracking (MPPT) system, the Particle Swarm Optimization (PSO) algorithm optimizes the weights and biases of the Artificial Neural Network (ANN). This optimized ANN is then applied to manage the MPPT process (27, 28). The PSO algorithm runs for 100 iterations with a population size of 100. Key parameters include an inertia weight (w) of 1, cognitive coefficient (c1) of 1.5, and social coefficient (c2) of 2. At each iteration, the performance of the ANN is assessed, leading to updates in its weights and biases.

The PSO-tuned ANN-based MPPT is noted for its enhanced performance and robustness compared to conventional approaches, making it a promising solution for solar power systems (29). The ANN's hidden layer comprises 10 neurons. Training data for the ANN is generated from measurements of temperature and irradiance on the photovoltaic (PV) panel used in the simulation. The training method employed is the Levenberg-Marquardt algorithm, utilizing 10,000 data points, with mean square error serving as the performance metric. The weights and biases in the ANN are determined using the PSO algorithm (10). Figure 4 illustrates a flow chart of the proposed PSO-ANN algorithm (26).

Similarly, the FOPI controller, optimized using Grey Wolf Optimization, provides a nuanced control strategy over the system's power conversion processes. This optimization method is modeled after the social hierarchy and hunting tactics observed in grey wolves, offers an enhanced level of precision in system control, contributing to improved stability and efficiency (30).

The basic steps of the GWO algorithm are (26, 31) :

1. Initialization: The algorithm starts by generating a random population of solutions, called "wolves," which represent solutions to the problem.
2. Fitness evaluation: The fitness of each wolf is

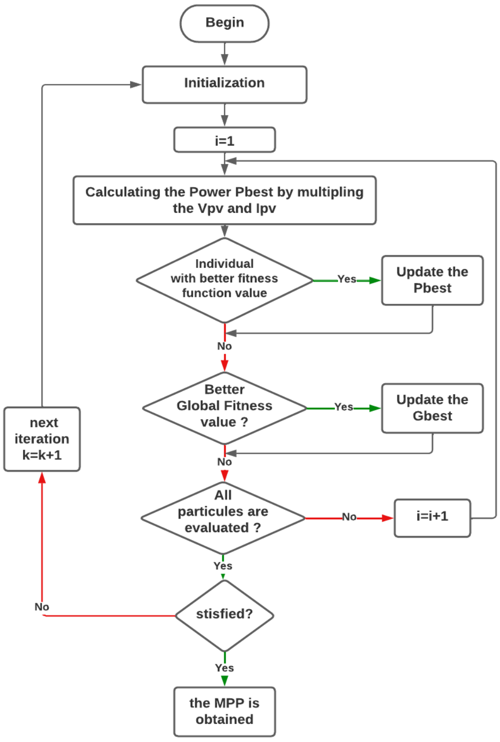

Figure 4. PSO algorithm (26)

3. evaluated based on a predefined objective function. The objective function maps the solution represented by each wolf to a value that represents its fitness.
4. Selection: The best wolves, called "alpha wolves," are selected based on their fitness. The alpha wolves are the ones with the highest fitness values.
5. Update: The positions of the alpha wolves are used to update the positions of the other wolves. The other wolves move towards the alpha wolves, with the distance and direction of the movement determined by a set of random parameters.

$$D_\alpha = |C_1 X_\alpha - X(t)| \tag{7}$$

$$D_\beta = |C_2 X_\beta - X(t)| \tag{8}$$

$$D_\delta = |C_3 X_\delta - X(t)| \tag{9}$$

$$X_1 = |X_\alpha - A_1 D_\alpha| \tag{10}$$

$$X_2 = |X_\beta - A_2 D_\beta| \tag{11}$$

$$X_3 = |X_\delta - A_3 D_\delta| \tag{12}$$

where A and C are vectors calculated as follow:

$$A = 2r_1 a - a \tag{13}$$

$$C = 2r_2 \tag{14}$$

The positions of the wolves are updated as follow:

$$X(t+1) = \frac{X_1 + X_2 + X_3}{3} \tag{15}$$

6. Repeat: The process of fitness evaluation, selection, and update is repeated for a specified number of iterations or until a stopping criterion is met.
7. Result: Once the algorithm has completed its iterations, the best solution is returned as the final result. This is the position of the wolf with the highest fitness value.

Figure 5 shows the flowchart GWO Based MPPT.

5. RESULTS AND DISCUSSION

The simulation stage of the research was significantly guided by solar irradiance data specific to Ain El Ibel extracted from NASA POWER, Prediction of Worldwide Energy Resources during August 2022, a key factor that guarantees the precision and applicability of the model. By simulating the micro grid under realistic environmental conditions, the study provides valuable insights into the system's performance, particularly in terms of energy conversion efficiency, storage capability, and overall stability. This detailed modeling and simulation work lays a robust foundation for the practical implementation of such micro grid systems, especially in regions with significant solar energy potential, paving the way for more sustainable and reliable energy solutions.

Figure 5. Flowchart GWO Based MPPT (26)

Simulations revealed that the ANN-based MPPT with the FOPI controller outperformed classical techniques, delivering higher precision and stability. The optimization algorithms significantly reduced oscillations, a common issue with traditional MPPT methods, thereby enhancing power extraction efficiency. The EV battery load power is shown in Figure 6.

Observation: Figure 6 likely illustrates the variation in power demand by the EV over time.

Analysis: Key points to consider are the peaks in power demand, which could indicate moments of high energy usage of 30 KW, possibly due to acceleration or uphill driving. The consistency or variability of these peaks can inform the robustness of the microgrid in handling fluctuating loads. Figure 7 demonstrates the EV battery load current.

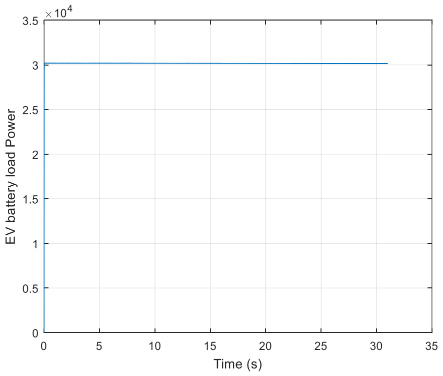

Figure 6. EV battery Load Power

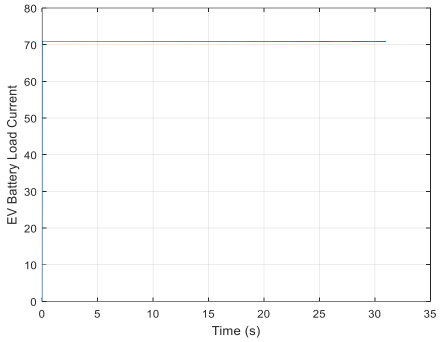

Figure 7. EV battery Load Current

Observation: Figure 7 shows the current drawn by the EV, which is directly related to its power consumption.

Analysis: Sudden spikes or consistently high current of 71 A draw may indicate demanding driving conditions or potential inefficiencies in the EV's power usage. This could also stress the microgrid’s energy storage and distribution components

Observation: Figure 8 represents the battery load voltage supplied to the EV.

Analysis: Stability in voltage is crucial for the safe and efficient operation of the EV. Voltage fluctuations might indicate issues with the microgrid's ability to maintain a stable output under varying load conditions with maximum value of 425 V.

Figure 9 shows Ain Ibel Irradiance. Observations from the above graph include:

1. Fluctuations: The solar irradiance exhibits considerable fluctuations within a relatively short time frame, suggesting that the conditions during the measurement period were highly variable. This could be due to cloud cover, atmospheric conditions, or other environmental factors affecting the sunlight reaching the sensor.
2. Trends: There are periods where the irradiance increases sharply, for instance, around the 10-second mark and again near the 30-second mark. There are also noticeable drops, such as the one occurring just before the 20-second mark.

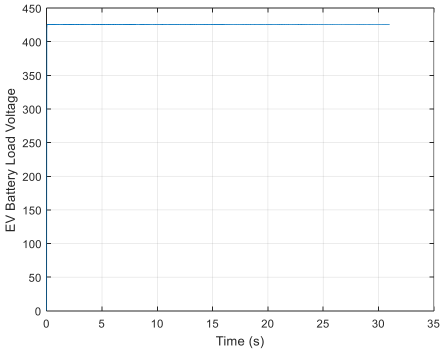

Figure 8. EV battery Load Voltage

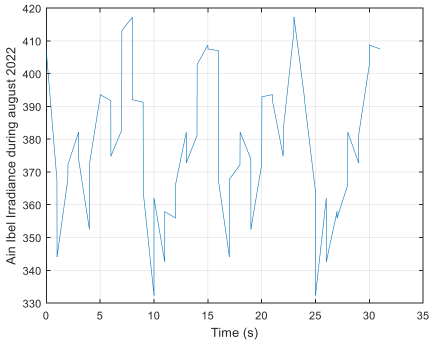

Figure 9. Ain Ibel Irradiance's.

1. Peak Values: The highest irradiance value recorded in this interval is just above 420, while the lowest dips to around 330. The range of variability is quite broad, indicating a difference of about 90 units of irradiance, which can significantly impact solar power generation.
2. Time Intervals: The rapid changes in irradiance suggest that the data collection was done at high-frequency intervals, capturing the variability in fine detail.

Analysis: The information displayed in this graph is sourced from the NASA Power, Prediction of Worldwide Energy Resources website, specifically for the city of Ain Ibel in August 2022 and it could be crucial for understanding the performance of solar PV systems in Ain Ibel.

The significant variability in irradiance can affect the efficiency and predictability of solar power generation. For instance, power output from a PV system would mirror this variability, with moments of high productivity when irradiance peaks and reduced output when it falls.

For applications sensitive to power consistency, such as EV charging stations mentioned in the context of your article, this variability could pose challenges. The systems would need to be designed to either store excess energy during peaks or to manage usage during troughs, possibly using batteries or supercapacitors as part of a microgrid system.

In conclusion, the graph underscores the importance of considering environmental factors when designing and deploying solar energy systems. Moreover, it highlights the need for advanced control systems, like MPPT with optimization algorithms, to manage the variability in solar irradiance effectively. This is especially relevant for regions like Ain Ibel, where the solar potential is high, but the consistency of available sunlight may be compromised by environmental fluctuations.

Observation: Figure 10 shows the DC grid battery SOD. This plot likely represents the battery's state of

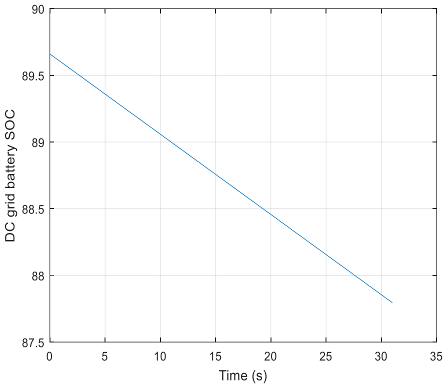

Figure 1. DC grid battery SOD

discharge over time.

Analysis: Patterns in the SOD can indicate the battery's health and its usage efficiency with coefficient of 0.05. Rapid discharges might suggest heavy reliance on the battery, possibly due to inadequate power generation from other sources like PV panels. The super capacitor SOD is shown in Figure 11.

State of Discharge (SOD) Curve Analysis:

The SOD curve of a supercapacitor is nonlinear, as depicted in the graph. This is characteristic of the discharge behavior of supercapacitors, differing from the linear discharge curves of traditional batteries.

Supercapacitor Performance:

The relatively steep initial slope indicates a rapid initial release of energy, which then tapers off. This is typical of supercapacitors, which are designed to deliver quick bursts of energy rather than prolonged power output.

Efficiency and Power Management:

The shape of the curve suggests that the supercapacitor is effectively delivering power. In applications where energy demand peaks for short durations, supercapacitors excel by rapidly supplying the needed energy without the long-term energy density that batteries provide.

Implications for Energy Systems:

The usage pattern indicated by the SOD curve suggests that the supercapacitor can handle sudden spikes in power demand, which is essential for stabilizing power grids or in applications such as regenerative braking systems in electric vehicles, where they absorb and then quickly release energy. Figure 12 shows the EV battery SOC.

Observation: This plot indicates the state of charge of the EV's battery.

Analysis: The SOC is a crucial metric for the EV's operational range. Variations in the State of Charge (SOC) provide insights into the charging and discharging patterns, which are affected by driving behaviors as well as the efficiency of the microgrid's power management system.

6. GENERAL DISCUSSION

System Integration: The interplay among the PV panels, batteries, supercapacitor, and the EV load needs to be managed efficiently. The PSO-tuned neural network for MPPT is a critical component here, optimizing power flow under varying conditions.

Efficiency and Stability: Ensuring minimal energy loss during conversion and distribution, and maintaining system stability under different loads and generation conditions are key challenges.

Resilience and Adaptability: The system's ability to adapt to changing conditions like variable solar irradiance and fluctuating EV load demands is crucial for its long-term sustainability and reliability.

7. CONCLUSION

This comprehensive study successfully highlights the enhanced performance of an optimized microgrid system, specifically designed for electric vehicle (EV) battery charging in the variable weather conditions of Ain

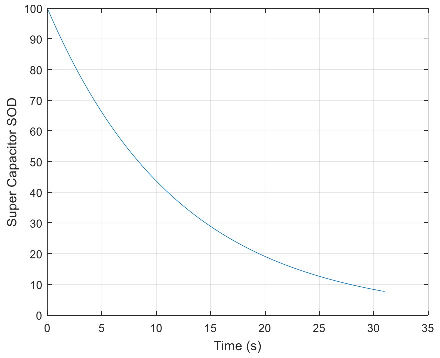

Figure 2. Super capacitor SOD

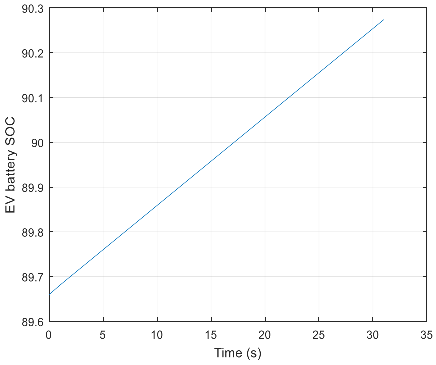

Figure 3. EV battery SOC

El Ibel. The implementation of a particle swarm optimization tuning Artificial Neural Network (ANN)-based Maximum Power Point Tracking (MPPT) system, in synergy with the Fractional Order Proportional-Integral (FOPI) controller optimized using grey wolf algorithm, stands out as a robust and innovative solution. This approach significantly enhances the effectiveness and dependability of photovoltaic (PV) systems in regions experiencing fluctuating solar irradiance, like Ain El Ibel.

The findings of this study bear significant implications for the future of renewable energy harvesting, particularly in high-irradiance regions. The application of this optimized microgrid system opens up new possibilities for establishing sustainable EV charging stations, not only in Ain El Ibel but also in other regions with similar solar profiles. This could catalyze a transformative shift in the adoption of electric vehicles, supporting a more sustainable transportation sector. Ain El Ibel, with its unique environmental conditions, serves as an ideal model for deploying such advanced energy systems, setting a precedent for similar initiatives globally. Looking ahead, future work could focus on expanding the application scope of this technology. This includes integrating the microgrid system with smart grid technologies to further enhance its efficiency and adaptability to varying load demands. Additionally, exploring the scalability of the system for larger or more diverse energy applications could provide valuable insights. Investigating the long-term operational resilience and cost-effectiveness of the system in real-world conditions will also be crucial in assessing its viability for widespread implementation.

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Persian Abstract

چکیده

در پرداختن به چالش بحرانی توسعه راه حل‌های پایدار برای شارژ باتری خودروهای برقی (EV)، این مطالعه یک سیستم میکروگرید جریان مستقیم (DC) نوآورانه‌ای را معرفی می‌کند که برای مناطقی با تابش خورشیدی بالا مانند عین الابل، جلفا بهینه‌سازی شده است. این تحقیق با دو مشکل اصلی روبرو است: به حداکثر رساندن استفاده از انرژی خورشیدی در سیستم میکروگرید و اطمینان از ثبات سیستم و دقت پاسخگویی برای شارژ قابل اعتماد EV. برای رویارویی با این چالش‌ها، مطالعه دو دستاورد اصلی ارائه می‌دهد. نخست، آن توسعه یک کنترلر ردیابی نقطه قدرت حداکثر (MPPT) تقویت‌شده توسط شبکه عصبی را ارائه می‌دهد، که با بهینه‌سازی دسته ذرات (PSO) بیشتر بهینه می‌شود تا کارایی جذب انرژی خورشیدی را افزایش دهد. دوم، آن دقت و قابلیت اطمینان سیستم را از طریق کالیبراسیون پیشرفته یک کنترلر نسبتی–انتگرالی مرتبه کسری (FOPI) با استفاده از تکنیک بهینه‌سازی گرگ خاکستری (GWO) بهبود می‌بخشد، که پیشرفت قابل توجهی در ثبات سیستم میکروگرید و دقت پاسخگویی را نشان می‌دهد. ادغام یک آرایه پنل خورشیدی، ذخیره‌سازی باتری و یک ابرخازن، همراه با این تکنیک‌های بهینه‌سازی پیشرفته، نمونه‌ای قابل توجه از پیشرفت قابل توجه در افزایش کارایی و قابلیت اطمینان شارژ باتری EV از طریق منابع انرژی تجدیدپذیر را نشان می‌دهد. شبیه‌سازی و ارزیابی جامع سیستم برتری آن را نسبت به روش‌های معمولی زیر سوال می‌برد و اثربخشی ترکیب بهینه‌سازی مبتنی بر شبکه عصبی با PSO و GWO را نشان می‌دهد. این پیشرفت نه تنها زمینه انرژی تجدیدپذیر، به ویژه برای ایستگاه‌های شارژ EV مبتنی بر خورشید، را پیش می‌برد، بلکه با تلاش‌های جه انی برای راه حل‌های حمل و نقل پایدار نیز همسو است.