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Optimizing Solar Energy Use in Electric Vehicle Charging for Sustainable Transport

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Abstract: A sustainable transportation goal is the integration of renewable energy into electric vehicle charging stations. This work aims at optimizing solar powered EV charging systems by means of novel techniques, which will lead to improving power flow management and ensuring system stability with Power Allocation Grey Wolf Optimization (PA_GWO). The effectiveness of the PA_GWO algorithm was evaluated under varying solar irradiation conditions with and without the optimization algorithm, on key performance metrics that include power quality, DC link voltage stability, and energy utilization. A fuel cell system was integrated into the system as an auxiliary source of energy to ensure the system runs continuously and offers consistent power supply during low solar irradiation periods. It improved the operational efficiency and management of power by integrating the fuel cell and PA_GWO. MATLAB/Simulink tools were used in modeling, simulation, and performance analysis for overall evaluation of the system's behavior and techniques for optimization. The results were positive and thus confirm better performance with potential to offer improved efficiency and reliability and more sustainable solar-based EV charging stations as solutions toward a shift in the entire world toward green transportation and renewable energy.

Keywords: Electric Vehicle Charging, Solar Energy, Power Distribution Grey Wolf Optimization (PA_GWO), Integration of Renewable Sources, MATLAB Simulation, Stability of DC Link Voltage, Fuel Cell Systems.

I. INTRODUCTION

Electric Vehicle (EV) charging stations are essential to the global shift toward sustainable and environmentally friendly transportation systems. With the rapid growth in the use of electric vehicles across the globe, driven by the need to address climate change and depletion of fossil fuels, a strong accessible charging infrastructure becomes more imperative [1]. Unlike the conventional gasoline car, EV needs an external source to recharge, and it becomes a criterion for the usage and marketability of these cars. Since the charging station eliminates the risk of anxiety and forces consumers away from internal combustion engine cars toward the electrified counterparts, it certainly helps to mitigate greenhouse emissions. The development of EV charging stations also addresses broader socioeconomic and environmental goals. By integrating renewable energy sources, such as solar and wind power, the stations can significantly enhance the sustainability of EV usage, thus reducing dependency on non-renewable energy and minimizing carbon footprint [2]. It also opens opportunities for innovation, investment, and job creation in the green energy and technology sectors. With ambitious targets set by nations for carbon neutrality, an extensive network of EV charging stations is necessary to develop a sustainable transportation ecosystem that is aligned with global environmental goals and promotes energy independence.

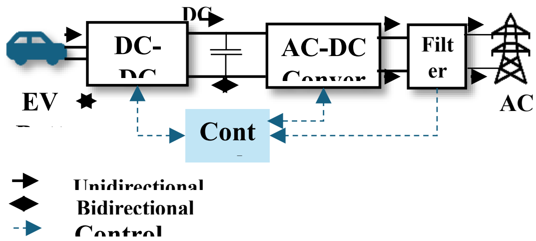

Figure 1 Block diagram of conventional EV charging system [3]

Optimization of solar energy is achieved by implementing strategies and technologies that increase the efficiency, reliability, and utility of harnessing sunlight for power generation. Being a clean and abundant source of energy, solar power offers significant potential in meeting growing energy demands with reduced environmental impact. To maximize its effectiveness, challenges such as variability in sunlight, inefficiencies in converting energy, and limitations in storage must be addressed. Focusing on the right areas, solar energy holds the key to transformation in achieving sustainable energy objectives [4]. Advanced photovoltaic (PV) technology, smart grid integration, and innovative energy storage solutions have become essential in optimizing the use of solar energy. For example, high-efficiency solar panels and concentrated solar power (CSP) systems can capture more energy even under suboptimal conditions. Energy storage technologies, such as lithium-ion and flow batteries, ensure a steady power supply by mitigating the intermittency of sunlight. Additionally, data-driven optimization techniques, such as AI-based energy management systems, provide an insight into the prediction of energy demand and allocation of resources using solar [5]. These technological developments enhance the performance of a solar energy system and build a more resilient and sustainable energy infrastructure.

A. Role of Renewable Energy in Sustainable Transportation

One of the vital parts is that renewable energy can greatly diminish the ecological effects of transport and therefore transportation is one of the leading causes of greenhouse gas emissions. It mainly depends on fossil fuel consumption and results in massive carbon emissions, air pollution, and resource depletion. The use of renewable energy sources such as solar, wind, and bioenergy will offer a cleaner, more sustainable alternative to fossil fuels, aligning with global efforts to combat climate change and achieve carbon neutrality. Renewable energy will thus allow transportation to be decoupled from fossil fuel dependency, creating a system that is both environmentally friendly and economically viable. Renewable energy in transportation refers to the use of clean energy sources to power electric vehicles and other transport modes [6]. For example, solar-powered EV charging stations use photovoltaic technology to generate electricity directly from sunlight, with no carbon footprint associated with conventional electricity grids. Wind and bioenergy can also support transportation needs by providing renewable power for trains, buses, and emerging technologies like hydrogen fuel cells. In addition to reducing emissions, these solutions promote energy independence, improve air quality, and support resilient, sustainable urban infrastructures. Not only do these solutions respond to immediate environmental concerns, but they also lay a base for a greener and more equitable future through integrating renewable energy into transportation.

B. Challenges in Integrating Solar Energy into EV Charging

This source, of course, poses extreme technical and logistical challenges regarding an increasing scale of solar energy-integrated electric vehicle charging system. The most critical problems encountered here are variability in producing solar energy based on variable factors like weather and time cycles [7]. Unlike the conventional type of energy source, energy from the sun is periodic with low or zero out when it is cloudy during dusk. This inconsistency makes it difficult to ensure a reliable power supply for EV charging stations, especially in areas with less favorable solar exposure. Efficient energy storage solutions are therefore essential to fill the gap between energy production and consumption.

The high initial investment is another challenge that comes with solar-powered EV charging stations. PV panels, energy storage systems, and advanced grid integration technologies require large amounts of capital investment to deploy. Although the savings on operational costs and the reduced carbon footprint are quite appealing, the upfront investments are enough to discourage investors, especially in developing countries where funds are limited [8]. Besides, bringing solar power into the existing infrastructure often necessitates high levels of retrofitting and system upgrade, which only adds to the technical and financial complexities.

Solar integration with the charging system of EVs also demands advanced energy management and interaction with the grid. A control system is required that balances the fluctuating solar output with the real-time charging demands of EVs. These are possible only through technologies like smart grids, demand-response mechanisms, and AI-driven energy optimization [9]. All these, however, add new challenges in terms of processing large amounts of data, maintaining cybersecurity, and standardization at scale. Ensuring smooth interoperability between the solar-powered stations and the existing energy grids remains the biggest challenge.

Finally, spatial and geographical constraints are also challenging. A solar-powered EV charging station needs a significant area of land or a rooftop to accommodate PV panels with sufficient capacity. In urban areas, land is usually scarce and expensive, which makes it difficult to install such a setup [10]. Regions with low solar insolation also have reduced efficiency, making solar energy less viable as a standalone solution. Addressing these challenges requires a combination of innovative technologies, policy support, and strategic planning to fully realize the potential of solar energy in transforming EV charging infrastructure.

II.LITERATURE REVIEW

According to **Williams, B. et al. (2024) [11],** by 2040, electric cars (EVs) are expected to account for 40% of the light vehicle fleet in Aotearoa, New Zealand. However, the lifespan of distribution network components and peak electricity demand will be impacted by EV drivers' charging decisions, such as whether to charge right away or postpone charging. Although the methodology is completely generalizable to other nations or areas, this study employs an agent-based model (ABM) of EV charging to examine the impact of varying EV penetration levels and owner charging decisions on components in New Zealand's home electricity networks. Based on a realistic residential distribution network, Monte Carlo simulation is run for 20 days to study EV charging in a neighborhood of 71 homes. The rate of "Exceedance" of the 300 kVA baseline transformer limit is the primary outcome indicator; a higher Exceedance means a shorter lifecycle and higher maintenance or capital expenses for the supplier. The findings indicate that while drivers who charge instantly (also known as "selfish charging") increase Exceedance, delayed-charging algorithms (also known as "altruistic charging") reduce peak electricity use and Exceedance. Since Exceedance is predicted to rise by less than 20% compared to Exceedance without EVs, New Zealand's household power networks should be able to support a 40% EV transition with 100% Altruistic charging. On the other hand, selfish charging raises the Exceedance rate by over 250%. Longer term, rising EV adoption and household electricity consumption will necessitate changes to the electrical network, more workplace charging facilities, and/or Demand Side Management (DSM) of EV charging that is automated and enabled by the Internet of Things (IoT) to prevent high rates of exceedance and higher maintenance and replacement costs.

Electric vehicles (EVs) and modest solar (PV) installations improve home power grids by reducing charging costs and promoting environmentally friendly operations, according to **Meng, Q. et al. (2024) [12]**. However, the unpredictability of EV charging poses problems for grid stability. This study presents a systematic charging approach that combines a "green electricity" pricing scheme with a joint optimization model for PV and EV management, as well as a Monte Carlo-based simulation for forecasting EV charging needs. An optimization technique that significantly improves grid performance is developed by using an improved ant lion optimizer (IALO) algorithm enhanced with differential evolution features. This "green electricity" model flattened the power load curve, increased grid stability, and decreased the mean square error of EV charging load by 11.82% in a park scenario. The IALO method considerably reduced carbon emissions by 159.6% and 31.6%, increased PV utilization by 162.3% and 37.1%, and raised overall revenue by 16.8% and 12.8% when compared to the particle swarm optimization (PSO) and grey wolf optimizer (GWO) algorithms. These results validate the economic, ecological, and practical advantages of our suggested strategy.

B. A. Kumar et al. (2024) [13] This study combined photovoltaic (PV) systems with AC–DC Power Factor Correction (PFC) to suggest a novel method for increasing the charging efficiency of electric vehicles (EVs). By using bi-directional power flow management in the PFC system, the suggested method enables improved resource use and EV battery capacity in a range of environmental conditions. To give the PV array real-time Maximum Power Point Tracking (MPPT), a modified Lyapunov-based robust model adaptive controller (M-LRMRAC) is created. This controller adeptly adapts to changing radiation and temperature dynamics by rapidly recording the MPP. One significant achievement is that the M-LRMRAC achieves fast MPP convergence (0.54 s), outperforming conventional Perturb and Observe (P&O) approaches. Furthermore, this integrated system offers advantages beyond efficient MPPT. When charging EV batteries (EVB), this technique improves power quality by reducing total harmonic distortion and operating at unity power factor. This complex architecture's overall solution boosts energy efficiency and enhances the quality of electricity supplied to EV batteries. Through problem-solving and performance optimization, our research contributes to the development of reliable and sustainable EV charging infrastructure. With the help of M-LRMRAC technology, PV systems and AC-DC PFC offer a practical path to effective, clean, and high-quality EV charging, thereby promoting the transition to a more sustainable and greener transportation environment.

According to **Acharige, S. S. et al. (2023) [14],** because of their quick growth, electric vehicles (EVs) are expected to play a significant role in the worldwide energy transition in transportation. Planning, operation, stability, standards, and safety will all be hampered by the high-level EVs' integration into the electrical system. Therefore, to deliver desired charging solutions for EV batteries and to improve ancillary services, the widespread adoption of EVs necessitates research and development of charging systems and EV supply equipment (EVSE). To improve desired charging efficiency and grid support, find a remedy for adverse effects, and speed up EV adoption with sophisticated control strategies, it is critical to analyze the current state of EV charging technologies. The architecture of EV charging stations, international standards, power converter configurations, and EV charging technologies are all thoroughly reviewed in this article. To guarantee optimal performance and improve grid support, charging systems need a specific converter topology, a control strategy, standard compatibility, and grid codes for charging and discharging. In terms of onboard and offboard chargers, AC-DC and DC-DC converter arrangement, and AC and DC-based charging station architectures, a summary of various charging systems is assessed. The power train of contemporary charging stations is also identified by presenting newer charging systems that incorporate renewable energy sources. Lastly, the problems and trends for EV charging and grid integration are summed up as the future study.

The switch from internal combustion engines to electric vehicles (EVs) has drawn a lot of interest and investment because of its potential to lower greenhouse gas emissions **Alaee, P., Bems, J., & Anvari-Moghaddam, A. (2023) [15].** There are advantages and difficulties for energy management when EVs are incorporated into electric and transportation systems. Electric system congestion can be reduced, and EV owners' wait times can be shortened by scheduling EV charging. The unpredictability of these energy resources can be lessened by using renewable energy sources (RESs) for grid support and EV charging. Another strategy in the event of unexpectedly high grid demand is vehicle-to-grid (V2G) technology. For the future of e-mobility systems, cost reduction via extensive coordinated planning is also essential. This review study concentrates on the most recent developments in coordinated EV scheduling, considering the different characteristics and methods as well as the impact of various stakeholders, which are divided into aggregator and single- and multiple-charging station (CS) levels. Several strategies are offered to better manage the requirements and contentment of EV owners, as well as the financial gain of CS and the market trends of e-mobility systems, through the implementation of coordinated EV scheduling. In this context, the technical and financial aspects of the system hierarchy, including consumers, CSs, and aggregators, as well as EV charging strategies considering V2G, uncertainty evaluation of parameters, coordinated charging management, electrical line and CS congestion, and route mapping, are reviewed and discussed.

Table 1 Summary of Key Findings and Outcomes on EV Charging and Grid Integration Studies

References	Author(s)	Key Findings	Outcomes
[11]	Williams, B. et al. (2024)	EVs are expected to account for 40% of light vehicles in New Zealand by 2040; selfish charging increases transformer load exceedance by 250%.	Altruistic charging minimizes grid stress and maintenance costs; automated DSM and IoT-enabled charging are necessary for long-term grid reliability and cost management.
[12]	Meng, Q. et al. (2024)	Introduced "green electricity" pricing and IALO algorithm for joint optimization of PV and EV management; reduced grid instability and emissions.	Flattened power load curve, reduced carbon emissions by up to 159.6%, increased PV utilization by 162.3%, and improved grid stability and overall revenue.
[13]	Kumar, B. A. et al. (2024)	Combined PV systems with AC-DC PFC for enhanced EV charging; developed M-LRMRAC for fast MPPT under varying conditions.	Improved power quality with reduced harmonic distortion, achieved fast MPP convergence (0.54 s), and enhanced energy efficiency for sustainable EV charging infrastructure.
[14]	Acharige, S. S. et al. (2023)	Reviewed EV charging systems, standards, and grid integration challenges; highlighted renewable energy integration.	Identified control strategies, converter configurations, and grid standards for optimal charging performance and grid support with renewable energy sources.
[15]	Alaee, P., Bems, J., & Anvari-Moghaddam, A. (2023)	Reviewed coordinated EV scheduling strategies, including V2G and RES integration, to reduce grid congestion and enhance system efficiency.	Suggested methods for efficient scheduling, stakeholder coordination, and cost reduction, improving e-mobility system management and reducing environmental impact.

III. OBJECTIVES

- Designing a solar energy-based charging station using MATLAB/SMULINK that is meant to charge multiple EVs
- Development of a Power flow controller for enabling smooth delivery of power to the station

battery as well as EV by stabilizing the DC common line of the charging station

- Designing of Optimization Algorithm to achieve the objective of effective power management in the charging station when solar is subjected to variable irradiation inputs
- Integration of the fuel cell system as an energy back resource in the Charging station.

IV.RESEARCH METHODOLOGY

In recent years, renewable energy, especially solar energy, has been widely discussed as a sustainable solution for powering charging stations, with benefits such as reduced carbon emissions and less dependence on fossil fuels. The development of solar-powered charging systems includes integrating components such as solar panels, batteries, power electronics, and bidirectional DC/DC converters for efficient energy management. Tools like MATLAB are utilized widely for modeling and optimization purposes, and AI techniques such as artificial neural networks (ANN) and Grey Wolf Optimization (GWO) improve control, forecasting, and power delivery. Such charging systems offer bidirectional energy flow, supporting reliable autonomous operations, and enable slow onboard and fast offboard charging mechanisms for EVs in improving energy utilization and the efficiency of the system.

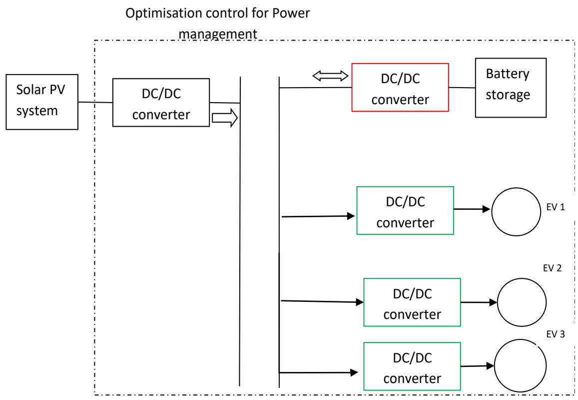

Figure 2 System Architecture designed in MATLAB/SIMULINK

A. Solar Energy system Modelling in MATLAB

PV cells operate at a single point where current (I) and voltage (V) yield maximum power, corresponding to a specific resistance (V/I). Their equivalent circuit includes series resistance (Rs), in series with a parallel combination of photocurrent (Iph), an exponential diode (D), and shunt resistance (Rsh), defining the cell's current (Ipv) and voltage (Vpv).

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh} \quad (1)$$

Where:

I_{ph} - Solar-induced current

I_S - Diode saturation current

q - Electron charge (l.6e^{-19}C)

K - Boltzmann constant (l.38e^{-23}J/K)

n - Ideality factor (l~2)

T - Temperature ^{0}K

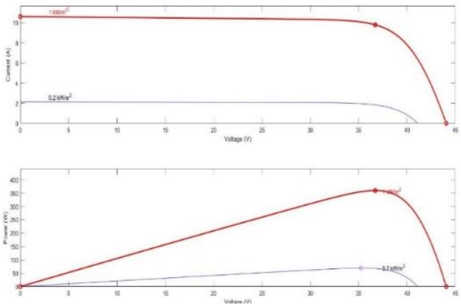

Figure 3 P/V and I/V characteristics of the solar PV array designed in MATLAB

Table 2 Input parameters for PV modeling

Parameters	Symbols	Values
Short circuit current	Isc	5.31
Irradiation	R	Variable
Open circuit voltage	Voc	44.06
Maximum current	Imp	4.9
Temperature	K	25
Maximum Power	Pmax	180
Maximum voltage	Vmp	36.72
Parallel	-	2
Series	-	1

The solar-induced current (I_ph) of a PV cell, influenced by solar irradiation and temperature, is given by

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000} \quad (4.2)$$

The maximum power point (MPP) lies at the curve's knee, showing the exponential current-voltage relationship.

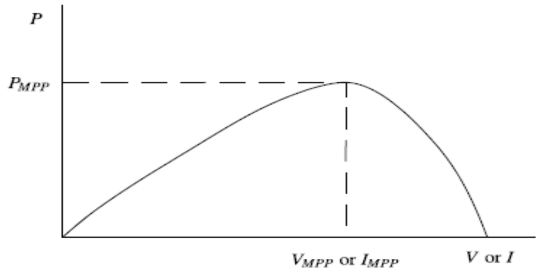

Figure 4 Characteristic PV array power curve

The charging system's maximum power supply for the loads will be monitored by the P&O algorithm. The model's derivation is predicated on the premise that the PVs' behavior can be used to represent the optimal current source. The algorithm is then modified to power Constrained Grey wolf Optimization (P-CGWO) to attain this objective along with managing the power flow across the charging station improving its quality.

B. Station Battery Modelling

Battery modeling involves representing terminal voltage and internal resistance, influenced by SOC, temperature, and ageing. Bidirectional DC-DC converters regulate voltage for charging and discharging, using controlled switches to enable two-way current flow, essential for energy storage in systems like electric vehicles.

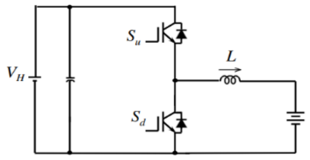

Figure 5 Bidirectional buck-boost Converter Circuit

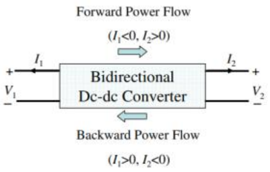

Figure 6 DC-DC converter operational logic block diagram representation

Table 3 Station Battery Parameters Used for modelling

Parameters	Symbols	Values
Nominal Voltage	V	36
Rated Capacity	Ah	28
Initial State of Charge	%	25/60
Battery Response Time	sec	0.0003
Internal resistance	Ohms	0.012857
Cutoff Voltage	V	27
Nominal discharge current	I	5.6

Table 4 EV Battery Parameters Used for modelling

Parameters	Symbols	Values
Nominal Voltage	V	36
Rated Capacity	Ah	12
Initial State of Charge	%	20/50/90
Battery Response Time	sec	0.0001
Internal resistance	Ohms	0.03
Cutoff Voltage	V	27
Nominal discharge current	I	5.2

C. Power Constrained Grey Wolf Optimization (P-CGWO) structure for the Charging Station Power Distribution

The Grey Wolf Optimizer (GWO) algorithm, inspired by the social hierarchy and hunting behavior of grey wolves, is a metaheuristic approach for optimization problems. In GWO, alpha, beta, and delta wolves represent the best solutions, guiding the search process. It is applied to optimize power management in charging stations by allocating resources like solar and grid energy efficiently, maximizing PV cluster power output through iterative adjustments of the duty ratio within defined limits. The algorithm reinitializes for changes in solar irradiation and converges to optimal solutions, ensuring cost efficiency and enhanced system performance.

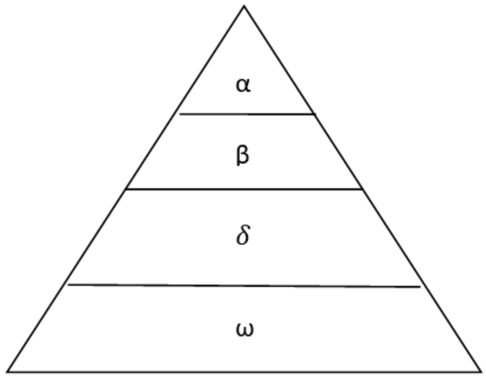

Figure 7 Hierarchy of grey wolves

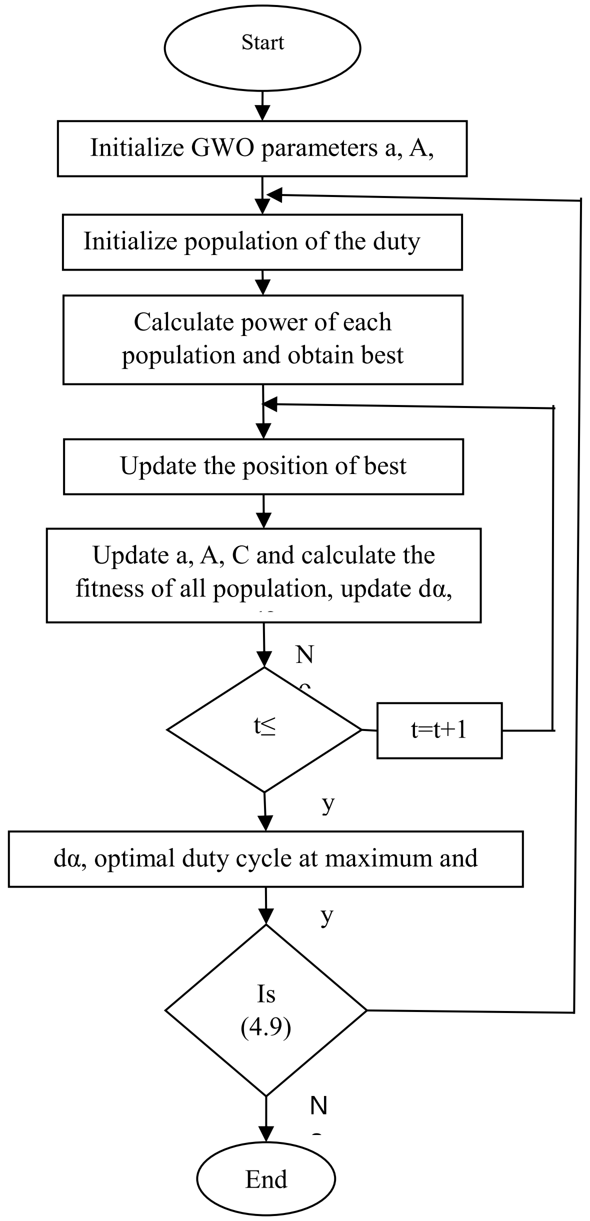

Figure 8 Flow chart for GWO MPPT Algorithm for power optimization.

D. Fuel Cell system Designing in MATLAB

The PEMFC is an electrochemical device that converts chemical energy from hydrogen and oxygen into electrical energy through reactions at its electrodes. Protons pass through the PEM to the cathode, where they combine electrons to produce hydrogen gas. Fuel cells, known for their efficiency (35-60%) and quiet operation, are prominent in transportation and energy generation. They can be integrated into solar-powered systems, as shown with a 300W DC-DC converter setup.

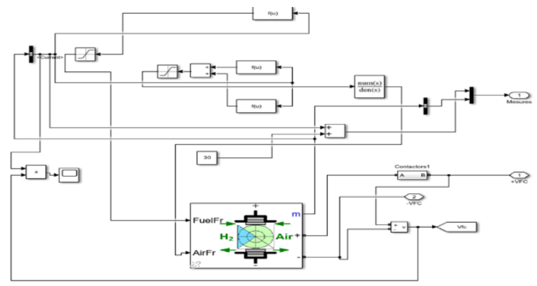

Figure 9 MATLAB/SIMULINK model of fuel system

V.RESULTS AND DISCUSSION

With increasing demand for electric vehicles, solar-charging stations have become one promising source of renewable energy converting sunlight into electricity to either store it or directly make use of it. With MATLAB, the authors optimized their system's performance with PA-GWO in power quality and stability in terms of DC line under various irradiation and compared with a non-optimized system.

A. Case1: Analysis of the Solar based Charging Station at irradiation input of 1000 W/m²

The solar panels are chosen by specifications and efficiency under standard test conditions (irradiance 1000 W/m²) to power the charging station. In the case of input irradiance 1000 W/m², the panel produces around 300-310W to charge EV batteries with initial SOCs of 20%, 50%, and 90% as well as the station battery. Without any optimization, the power is transferred through the DC link; the energy is distributed through the system.

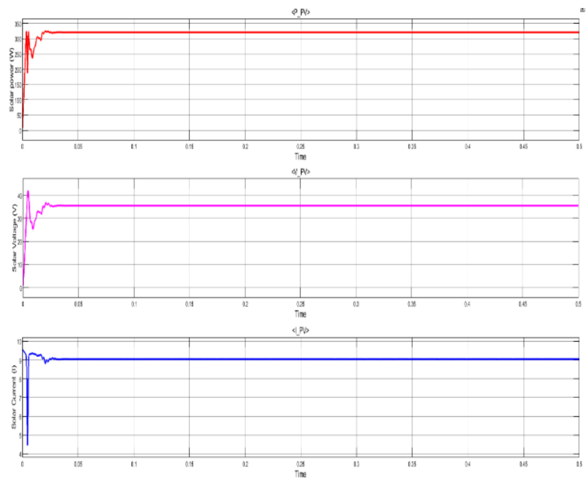

Figure 9 Solar Power/ Voltage/ Current Output at 1000 W/m²

B. Case 2: Analysis of the Solar based Charging Station at irradiation input of 200W/m²

A solar-based charging station at 200 W/m² is generating about 65W, and therefore power control and efficient utilization requires DC-DC converters. Two systems are analyzed: the one without optimization and another one using the PA_GWO algorithm for power flow and quality assessment. The performance of both systems is compared in terms of DC link voltage stability and power delivery to the station and EV batteries.

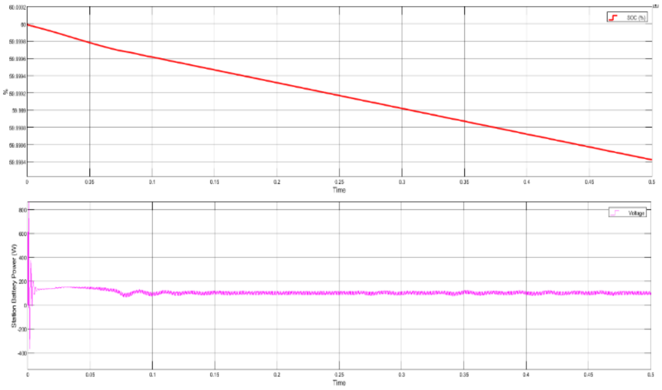

Figure 10 station battery SOC and power in the CS of the system 1 for irradiation input level of 200W/m^2

Figure 10 represents the station battery SOC which is reducing and power which is positive meaning that battery is supplying extra power to the load when the input irradiation levels are reduced to 200W/m2 in the CS without any optimization algorithm.

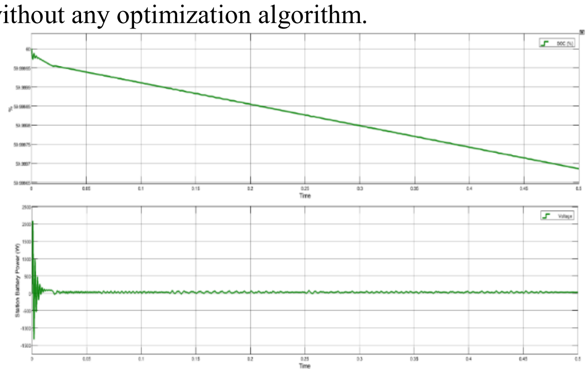

Figure 11 Station battery SOC and power in the CS of the system 2 for irradiation input level of 200W/m^2

Figure 11 represents the station battery SOC which is reducing and power which is positive meaning that battery is supplying extra power to the load when the input irradiation levels are reduced to 200W/m^2 in the CS with PA_GWO optimization algorithm.

C. Case 3: System analysis with charging station integration with fuel Cell system

A fuel cell connected to the solar-based charging station makes power reliable and efficient. By using efficiency, temperature, and voltage characteristics of this model, it can be considered an integration of a real-time electric and electrochemical model because it's possible with Simulink or Simscape through MATLAB. This manages the power flow from the fuel cell, solar panels, energy storage, and EV loads, optimizing the use of renewable energy and smooth station operation by using the PA_GWO strategy. Simulation results based on varying solar irradiation ranging from 1000 W/m² to 200 W/m² prove that when solar power diminishes, the constant output of the fuel cell, being 300W, well supports system demands.

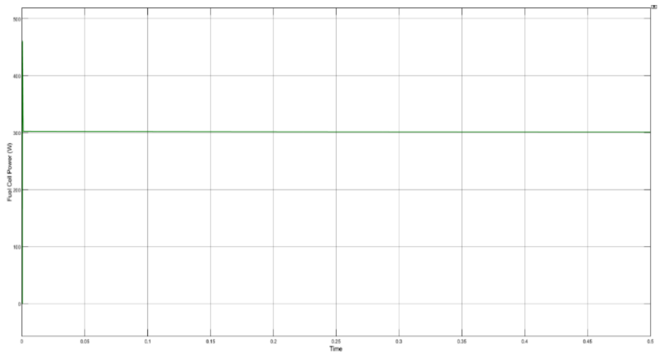

Figure 12 Fuel Cell System Power integrated with solar in the charging station

D. Validation

The charging station with the PA_GWO algorithm significantly outperformed the one without it. Based on solar energy availability, charging demand, and conditions of the battery, the PA_GWO algorithm optimizes the power allocation for efficient energy utilization. It ensures that improved DC line voltage stability occurs along with enhanced power quality at the EV load, especially during times of reduced solar irradiation, in which disturbances are minimized.

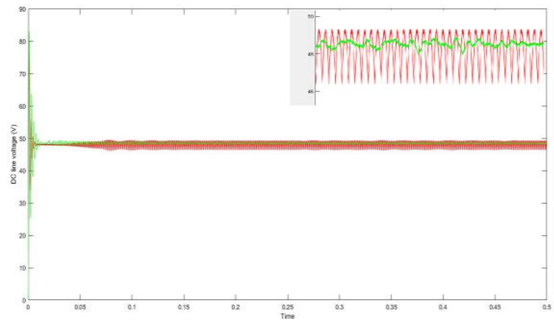

Figure 13 Comparison of DC line balancing by the proposed algorithm

Figure 13 is a comparison of two algorithms about DC link voltage control, where the red graph about System 1 is not optimized and shows the fluctuations in between 47 to 49 V. The green graph of the system with PA_GWO algorithm reveals better stability and quality improvement in DC link voltage control due to the capability of maintaining better power quality and distribution in PA_GWO.

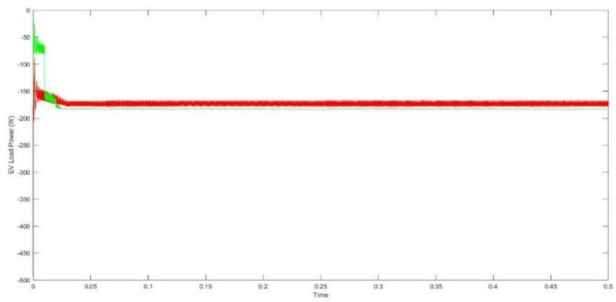

Figure 14 Comparison of power delivered to the EV load by the proposed algorithm

The red graph depicts the power output profile without an optimization algorithm; this one show fluctuations and instability. The green graph, by utilizing the PA_GWO algorithm, indicates a stable and continuous curve showing a steady and improved power output with time.

VI.CONCLUSION

This study emphasizes the prospect of incorporating renewable energy sources, mainly solar, into EV charging infrastructure towards sustainable transportation. With the application of the PA_GWO algorithm, there were improvements seen in power quality, DC link voltage stability, and utilization of energy. The fuel cell system integration also increased reliability when solar irradiation was low. Simulation results reveal superior performance of the optimized system over a traditional setup, indicating the crucial need for advanced optimization techniques in the development of renewable energy solutions. These results help form a basis for developing efficient, reliable, and sustainable electric vehicle charging solutions that meet global environmental needs.

References

[1] Yuvaraj, T., Devabalaji, K. R., Kumar, J. A., Thanikanti, S. B., & Nwulu, N. (2024). A comprehensive review and analysis of the allocation of electric vehicle charging stations in distribution networks. *IEEE Access*. https://doi.org/10.1109/ACCESS.2023.3349274

[2] Yao, M., Da, D., Lu, X., & Wang, Y. (2024). A review of capacity allocation and control strategies for electric vehicle charging stations with integrated photovoltaic and energy storage systems. *World Electric Vehicle Journal*, *15*(3), 101. https://doi.org/10.3390/wevj15030101

[3] Acharige, Sithara & Haque, M.E. & Arif, Mohammad & Hosseinzadeh, Nasser & Hasan, Kazi & Oo, Aman. (2023). Review of Electric Vehicle Charging Technologies, Standards, Architectures, and Converter Configurations. IEEE Access. PP. 1-1. 10.1109/ACCESS.2023.3267164.

[4] Falope, T., Lao, L., Hanak, D., & Huo, D. (2024). Hybrid energy system integration and management for solar energy: A review. *Energy Conversion and Management: X*, 100527. https://doi.org/10.1016/j.ecmx.2024.100527

[5] Adekanbi, M. L., Alaba, E. S., John, T. J., Tundealao, T. D., & Banji, T. I. (2024). Soiling loss in solar systems: A review of its effect on solar energy efficiency and mitigation techniques. *Cleaner Energy Systems*, *7*, 100094. https://doi.org/10.1016/j.cles.2023.100094

[6] Raihan, A., Paul, A., Rahman, M. S., Islam, S., Paul, P., & Karmakar, S. (2024). Artificial intelligence (AI) for environmental sustainability: A concise review of technology innovations in energy, transportation, biodiversity, and water management. *Journal of Technology Innovations and Energy*, *3*(2), 64-73.

[7] Bastida-Molina, P., Rivera, Y., Berna-Escriche, C., Blanco, D., & Álvarez-Piñeiro, L. (2024). Challenges and Opportunities in Electric Vehicle Charging: Harnessing Solar Photovoltaic Surpluses for Demand-Side Management. *Machines*, *12*(2), 144. https://doi.org/10.3390/machines12020144

[8] Gnanavendan, S., Selvaraj, S. K., Dev, S. J., Mahato, K. K., Swathish, R. S., Sundaramali, G., ... & Azab, M. (2024). Challenges, solutions and future trends in EV-Technology: A Review. *IEEE Access*. https://doi.org/10.1109/ACCESS.2024.3353378

[9] Dimitriadou, K., Rigogiannis, N., Fountoukidis, S., Kotarela, F., Kyritsis, A., & Papanikolaou, N. (2023). Current trends in electric vehicle charging infrastructure; opportunities and challenges in wireless charging integration. *Energies*, *16*(4), 2057. https://doi.org/10.3390/en16042057

[10] Barman, P., Dutta, L., Bordoloi, S., Kalita, A., Buragohain, P., Bharali, S., & Azzopardi, B. (2023). Renewable energy integration with electric vehicle technology: A review of the existing smart charging approaches. *Renewable and Sustainable Energy Reviews*, *183*, 113518. https://doi.org/10.1016/j.rser.2023.113518

[11] Williams, B., Bishop, D., Hooper, G., & Chase, J. G. (2024). Driving change: Electric vehicle charging behavior and peak loading. *Renewable and Sustainable Energy Reviews*, *189*, 113953. https://doi.org/10.1016/j.rser.2023.113953

[12] Meng, Q., Tong, X., Hussain, S., Luo, F., Zhou, F., Liu, L., ... & Li, B. (2024). Revolutionizing photovoltaic consumption and electric vehicle charging: a novel approach for residential distribution systems. *IET Generation, Transmission & Distribution*, *18*(17), 2822-2833. https://doi.org/10.1049/gtd2.13232

[13] Kumar, B. A., Jyothi, B., Singh, A. R., Bajaj, M., Rathore, R. S., & Berhanu, M. (2024). A novel strategy towards efficient and reliable electric vehicle charging for the realisation of a true sustainable transportation landscape. *Scientific Reports*, *14*(1), 3261. https://doi.org/10.1038/s41598-024-53214-w

[14] Acharige, S. S., Haque, M. E., Arif, M. T., Hosseinzadeh, N., Hasan, K. N., & Oo, A. M. T. (2023). Review of electric vehicle charging technologies, standards, architectures, and converter configurations. *IEEE Access*, *11*, 41218-41255. https://doi.org/10.1109/ACCESS.2023.3267164

[15] Alaee, P., Bems, J., & Anvari-Moghaddam, A. (2023). A review of the latest trends in technical and economic aspects of EV charging management. *Energies*, *16*(9), 3669. https://doi.org/10.3390/en16093669