Power Adaptive Grey Wolf Optimization for Efficient Power Allocation in Solar-Based Charging Stations

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Abstract: The design of solar-based charging stations promotes innovation in renewable energy technologies, energy storage systems, power management algorithms. The work has focused on designing of power adaptive grey wolf optimisation algorithm to handle the changes in the charging station during changes in the input irradiation levels from 1000 W/m^2 to 200 W/m^2. The proposed system takes into account varying solar irradiation levels, battery capacity, and charging demand to optimize the power allocation. The algorithm intelligently adapts the charging process based on real-time conditions, ensuring efficient energy utilization and load balancing across charging points. The work used loads in the form of EV batteries having different state of charge (SOC) which are 20%, 50% and 90%. The results demonstrate the effectiveness of the PA_GWO algorithm in achieving optimal power allocation, enhancing renewable energy utilization, and reducing stability issues of the DC line voltage at lower irradiation levels. Also algorithm is best suited for managing power across the fuel cell system when the power output from the solar energy system is reduced.

Key words: Charging Station (CS), Solar Energy system, Battery, Electric Vehicle (EV), Optimization Algorithm, Power Distribution, Fuel Cell system

I. INTRODUCTION

Electric vehicles (EVs) have become a trailblazing force in the transportation industry, revolutionising how we see mobility in the future. Electric vehicles have emerged as a possible solution to the urgent need to cut greenhouse gas emissions and battle climate change, providing a cleaner and more sustainable method of transportation [1]. The era of conventional internal combustion engines, which polluted the air and contributed to global warming, is over [2]. The popularity of electric vehicles has rapidly increased thanks to government programmes, technological improvements, and heightened environmental consciousness among the general public. With no need for fossil fuels and significantly lower carbon dioxide emissions, these cars run on electric motors supplied by rechargeable batteries [3].
There are several advantages associated with the rise of electric vehicles, which is more than just a fad. Their beneficial effect on air quality is one of the most important benefits [4]. EVs improve public health and contribute to cleaner, healthier urban settings by removing tailpipe emissions, which lower air pollution. Additionally, electric cars are much quieter than their conventional equivalents, which lessens noise pollution in cities and improves people's quality of life in general.

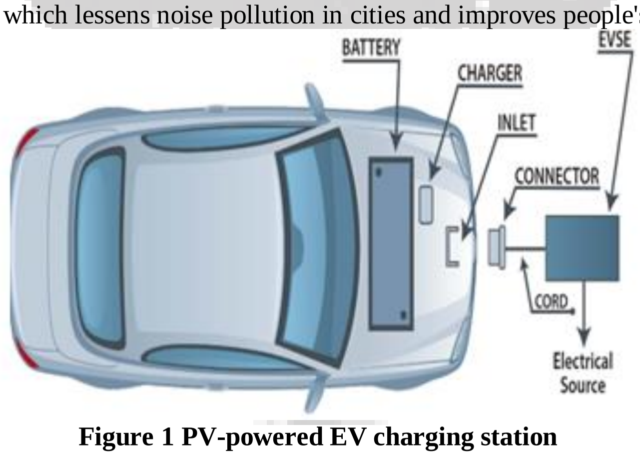

Figure 1 PV-powered EV charging station

Beyond the advantages they have for the environment, electric cars can save you a lot of money. EVs may still cost more up front than traditional cars, but overall ownership costs over their lifespan are frequently lower. Electric vehicles often have lower running expenses and are more energy-efficient, resulting in long-term savings for their owners. They also have fewer moving parts and simpler maintenance requirements. In addition, as the market for electric vehicles expands, technological breakthroughs and economies of scale are bringing down the price of batteries, making EVs more accessible and inexpensive.
The switch to electric vehicles is not just happening in passenger automobiles. Electric trucks, buses, and even motorbikes are being created and used, revolutionising numerous transportation industries. The advantages of electric vehicles are being recognised by fleet operators, who are embracing them as a way to cut emissions and increase the sustainability of their operations [5]. Additionally, governments all over the world are putting supportive policies into place to hasten the

adoption of electric vehicles on a larger scale, including financial incentives, the development of charging infrastructure, and stronger pollution standards.
Even though there are still issues with expanding the infrastructure for charging and increasing the operating range of EVs, the future of electric vehicles is bright [6]. Electric vehicles are poised to become the rule rather than the exception as technology advances and innovate. A cleaner, more environmentally friendly, and more sustainable future may be brought about by the electrification of transportation.

II. RELATED WORK

Due to its potential to lower greenhouse gas emissions and advance sustainable transportation systems, the shift to electric vehicles (EVs) has attracted a lot of interest. Numerous studies have concentrated on boosting the resiliency of the infrastructure for charging vehicles, optimising the placement of charging stations, and creating smart charging technologies in order to promote the wider adoption of EVs.

Hussain and Musilek (2022) research methods for EVs to increase their resilience and offer a framework to strengthen the resilience of the infrastructure used for charging EVs. The study emphasises the significance of integrating smart features into charging stations to guarantee continued charging services during power outages or emergencies, such as energy storage systems and microgrids. The authors contend that EVs can be a dependable source of power supply during critical events by integrating robust solutions, improving the overall resilience of metropolitan systems.

Zhou, Zhu, and Luo (2022) offer a cost model and use a genetic algorithm to discover the best sites for charging stations in their study on location optimisation. Their research highlights the need of taking into account aspects like charging demand, station fees, and infrastructural constraints when deciding where to locate charging stations. The findings offer insights into resource-efficient placement tactics that maximise user convenience and enable optimal placement techniques.

Focusing on creating smart charging station topologies for EVs, **Ghoderao et al. (2022)** analyze the capabilities of various topologies in terms of communication, control, and monitoring systems. The study demonstrates how dynamic power allocation, load balancing, and demand response may be made possible by smart charging stations, increasing the overall effectiveness and dependability of EV charging infrastructure.

A reliable model for choosing the sites of electric car charging stations is presented by **Li, Zhang, Ou, Wang, Zhou, and Ma in the year 2022,** taking energy storage and the integration of renewable sources into account. The analysis highlights how crucial it is to use renewable energy sources to run charging stations and suggests a solid optimisation strategy that takes production risks into account. The results imply that using renewable energy sources and energy storage can increase the sustainability and toughness of EV charging infrastructure.

In study of the growth of electric vehicles in Sub-Saharan Africa published in 2022, **Ampah et al.** evaluate the effectiveness of stand-alone renewable energy systems for hydrogen refuelling and electricity charging stations. In order to offer clean energy for hydrogen refuelling and EV charging, the study emphasises the possibilities of merging hydrogen production with renewable energy systems. The findings highlight the significance of decentralised and sustainable energy options to enable the expansion of EVs in areas with restricted access to centralised power networks.

Zu and Sun (2022) look into the placement selection of EV battery-swapping and charging stations in metropolitan areas. A multi-objective optimisation model is used in the study to take into account user travel demand, infrastructure costs for charging, and the incorporation of battery-swapping technology. According to the research, a charging network that combines charging and battery-swapping stations can be more effective and adaptable to the various needs of EV consumers.

III. METHODOLOGY

The objectives associated with this research work are focused on designing and optimizing a solar energy-based charging station for electric vehicles (EVs). The first objective involves the design of a charging station using MATLAB/Simulink that utilizes solar energy to charge multiple EVs, ensuring efficient energy conversion and utilization. The second objective is the development of a power flow controller that stabilizes the DC common line of the charging station, enabling smooth power delivery to both the station battery and the EVs. The third objective aims to design an optimization algorithm that effectively manages power in the charging station, especially when solar irradiation inputs vary, maximizing the utilization of available solar energy. Lastly, the integration of a fuel cell system as an energy backup resource in the charging station is explored, providing additional energy resilience and ensuring uninterrupted charging services for EVs. These objectives collectively contribute to the development of a robust and efficient solar-powered charging station for EVs, enhancing sustainability and promoting clean energy transportation.
The EV systems, are defined as interconnected local energy centres with control and management capabilities and clear boundaries. By giving the load centers higher-quality operation and a more dependable energy source, they enable

bidirectional and autonomous power exchange to avert power outages. PHEV chargers should be installed off-board and onboard in a vehicle. Onboard chargers are built with a small size, low power rating, and can be used based on a slow charging mechanism. Off-board EV chargers are located at specific places and provide either a slow or fast charging mechanism. DC/DC converters have been used to regulate and shift the output signal to the desired level. A bidirectional charging station can manage the power flow between charging stations and loads of electric vehicles in both directions.
PV cells have single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I Electrical equivalent representation of chemical reaction-based battery is the most challenging task in establishing a suitable battery model. A typical battery is demonstrated by terminal voltage which is a function of battery SOC and an internal resistance which is a function of battery SOC, temperature and the aging of battery cell. The voltage source is battery SOC dependent where Voc(s, SOC) is the internal voltage (voltage source), Rint(s, SOC) is the internal resistance and U_{DC} is the terminal voltage.

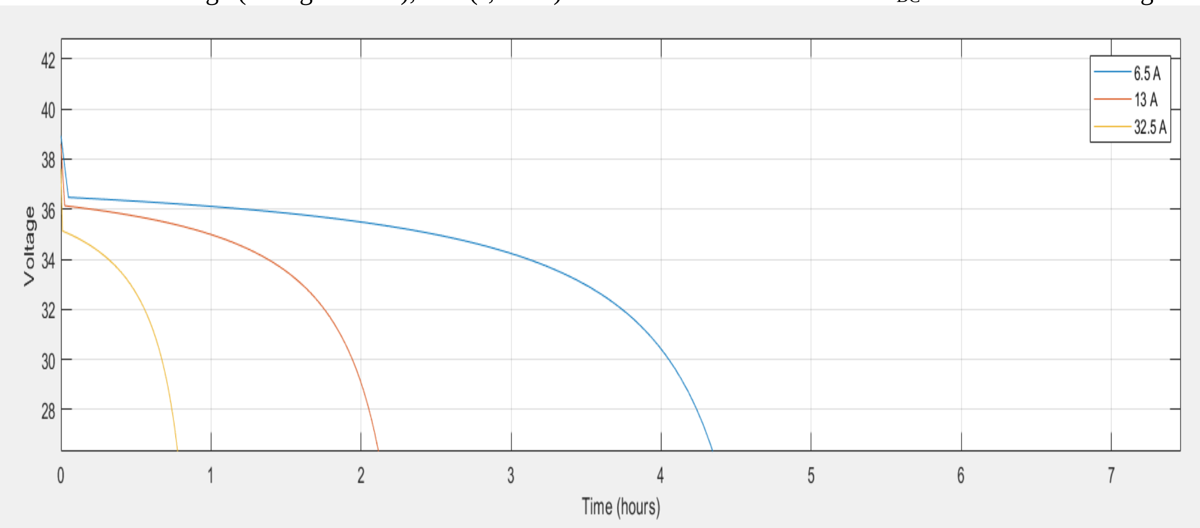

Figure 2 Station battery discharge characteristics for different current values

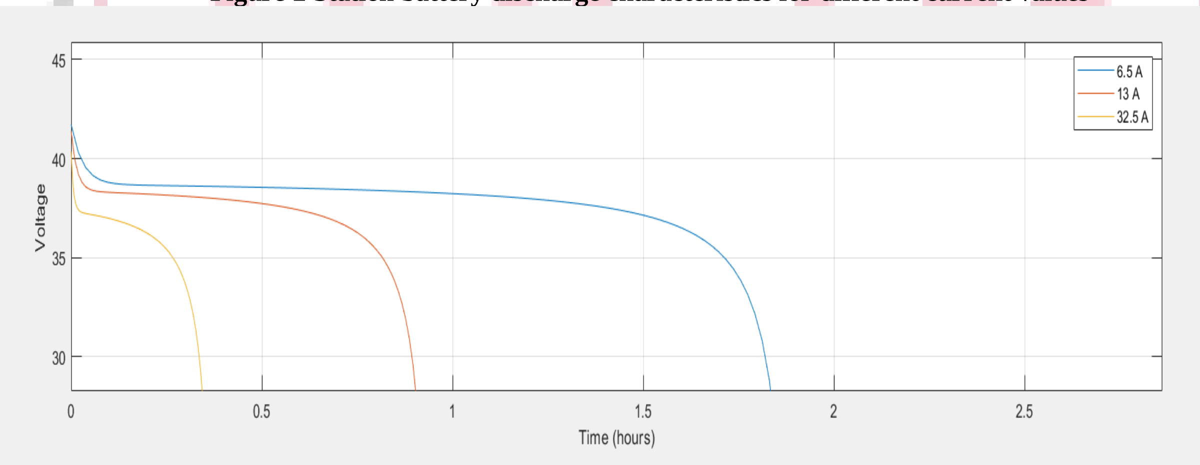

Figure 3 EV battery discharge characteristics for different current values

The Bidirectional DC-DC Converter is a device that increases or decreases DC voltage in the two sides of the converter to the other, the increase or decrease depends on a controller attached and gate signal generator, its works as a boost converter in 1st mode and as a buck converter in the 2nd mode, in the buck mode it is used to lower the bus voltage to meet the batteries voltage to be charged, and in the boost mode, it used to raise the voltage and back to the bus. Bidirectional DC-DC converter is useful for switching between energy storage such as in electric vehicles. In order to control the battery current during charge and discharge operations, a PI controller is added. The reference value of the current is positive for charging operations and negative for discharging activities.

Power Constrained Grey wolf Optimisation (P-CGWO) structure for the Charging Station Power Distribution

Grey Wolf Optimizer is aroused from grey wolves. It is a metaheuristic calculation for non-straight advancement issues from group of multitude insight. In nature it impersonates the position chain of importance and chasing behavior of dim wolves. There are four sorts of dark wolves to be specific (α, β, δ and ω) in GWO. α wolves are tops of the crowd and gives fittest arrangement of advancement issues, β-wolves helps in dynamic and furthermore they are subordinates to α-wolves, ω-wolves is incorporated under second rate class and δ wolves rules ω wolves and they need to submit to (α,β). Dim wolves have exacting social prevailing progressive system as demonstrated in Fig. 4.8 the strength of wolves increments from base to top.

IV RESULT ANALYSIS

With the increasing popularity of electric vehicles (EVs), the demand for efficient charging infrastructure has also grown. One promising approach is to integrate solar energy systems with charging stations, harnessing renewable energy to power EVs. MATLAB, a powerful programming language and simulation environment, provides a comprehensive platform for the development and optimization of such systems.

Case1: Analysis of the Solar based Charging station at irradiation input of 1000 W/m^2

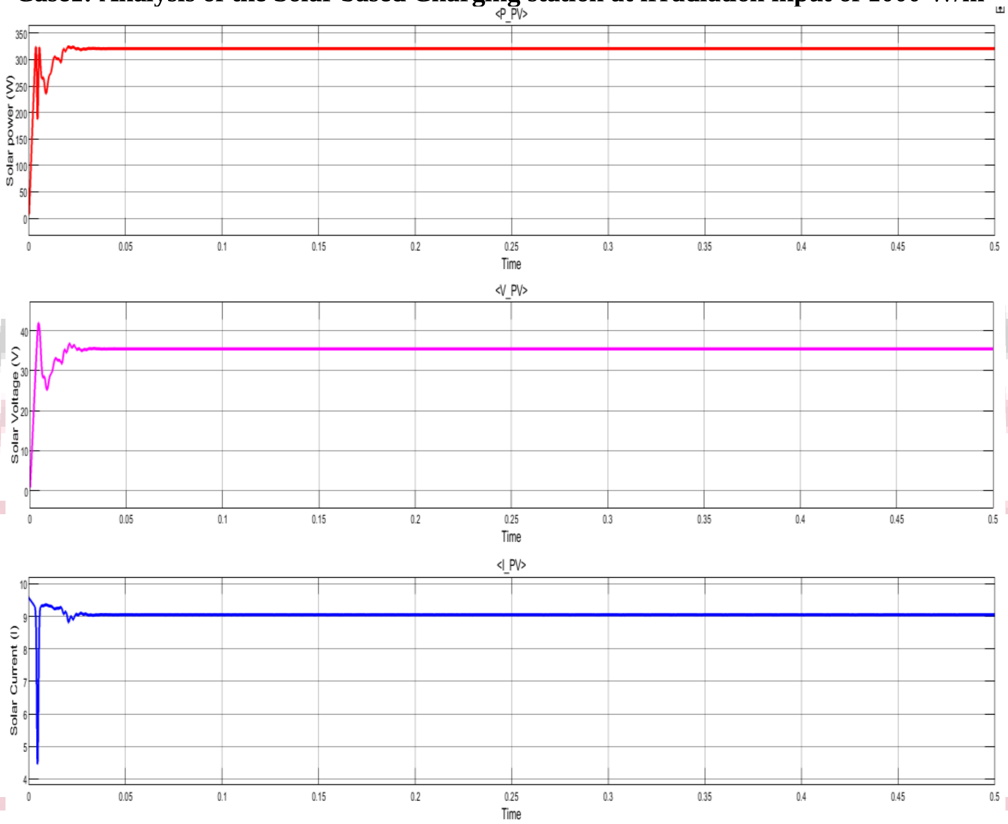

Figure 4 Solar Power/ Voltage/ Current Output at 1000 W/m2

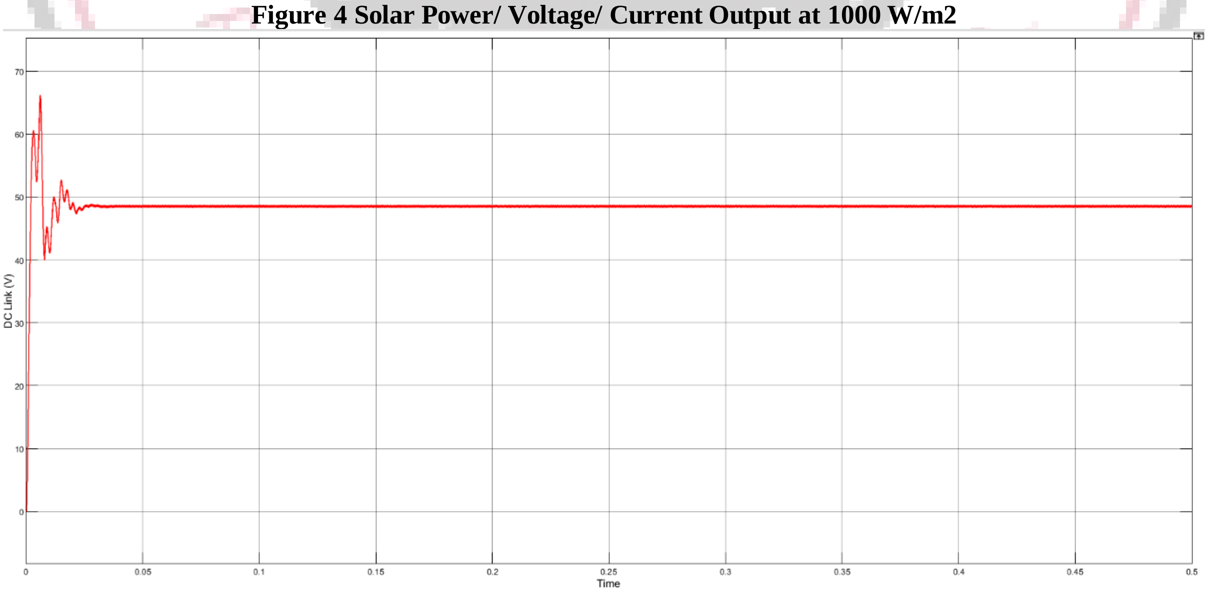

Figure 5 : DC line voltage of the charging station when the input irradiation level is 1000 W/m2

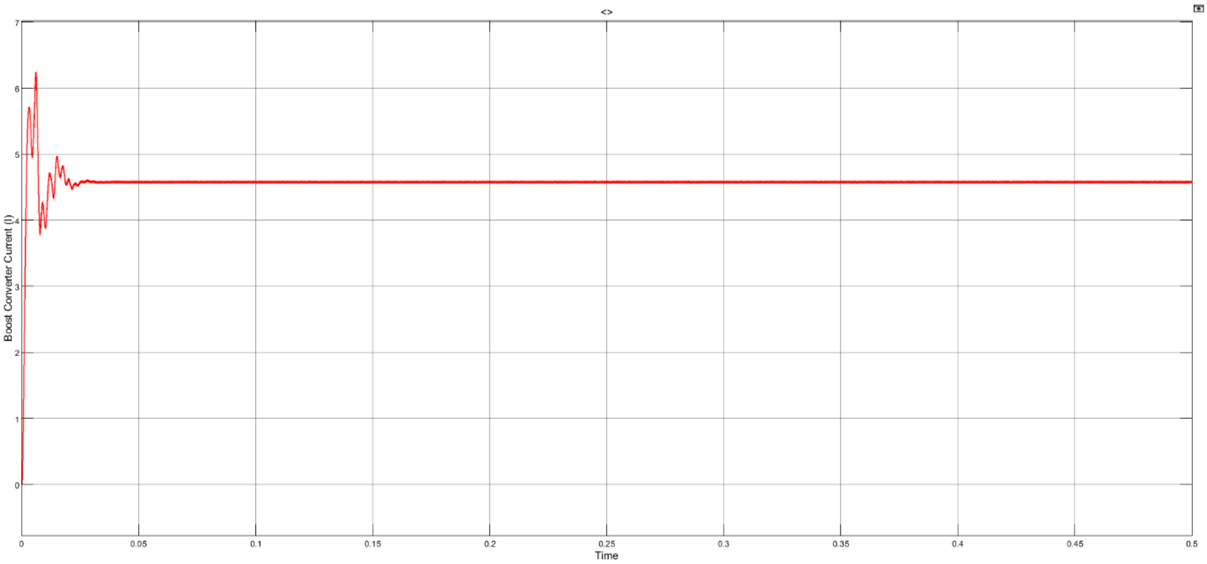

Figure 6 Boost Converter current of the charging station when the input irradiation level is 1000 W/m2

Station Battery Response in the charging station with input irradiation levels of 1000 W/m^2

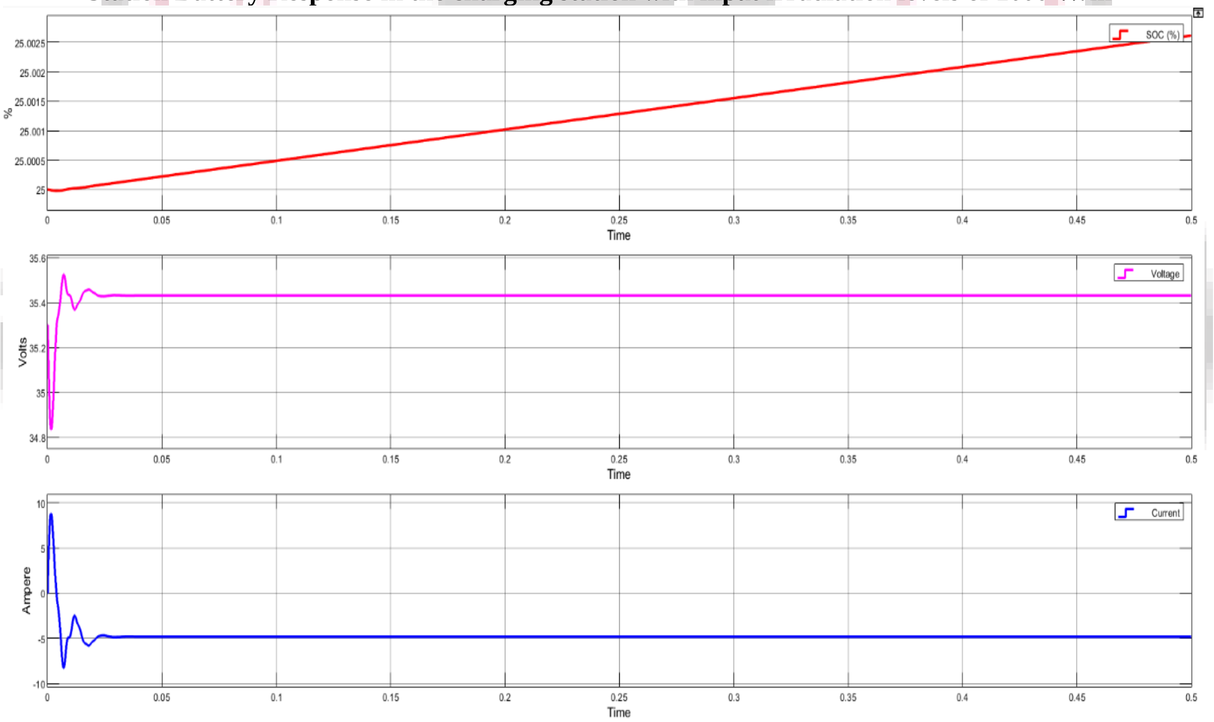

Figure 7 : Voltage/ Current and SOC% representation of Station battery in the CS

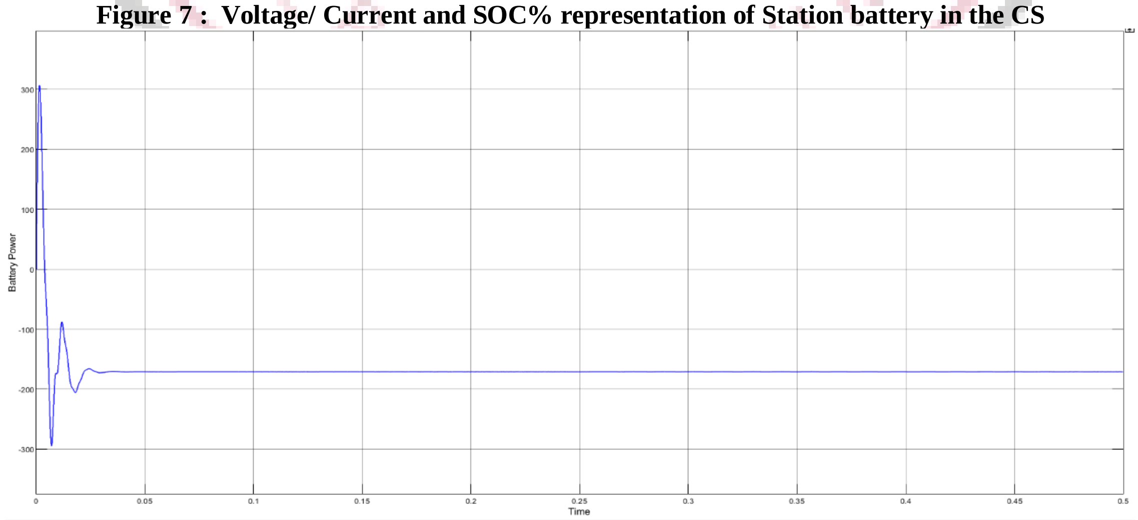

Figure 8 Power representation of Station battery in the CS with irradiation input 1000 W/m2

EV Battery load side Response in the charging station with input irradiation levels of 1000 W/m^2

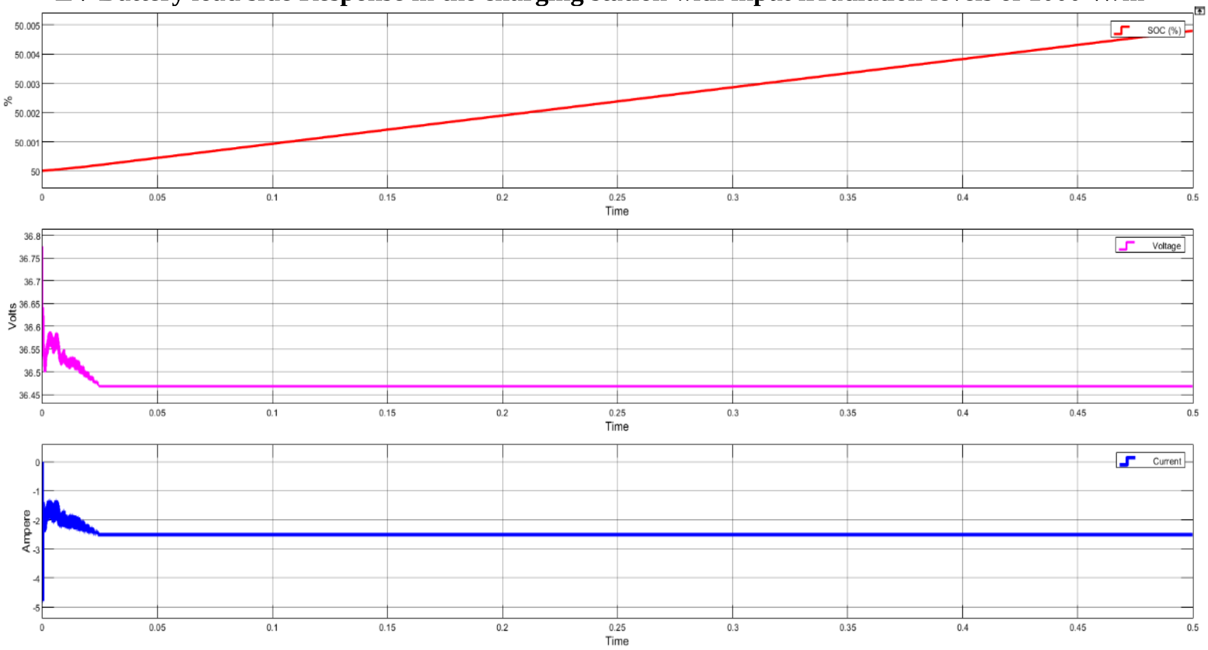

Figure 9 SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 50%

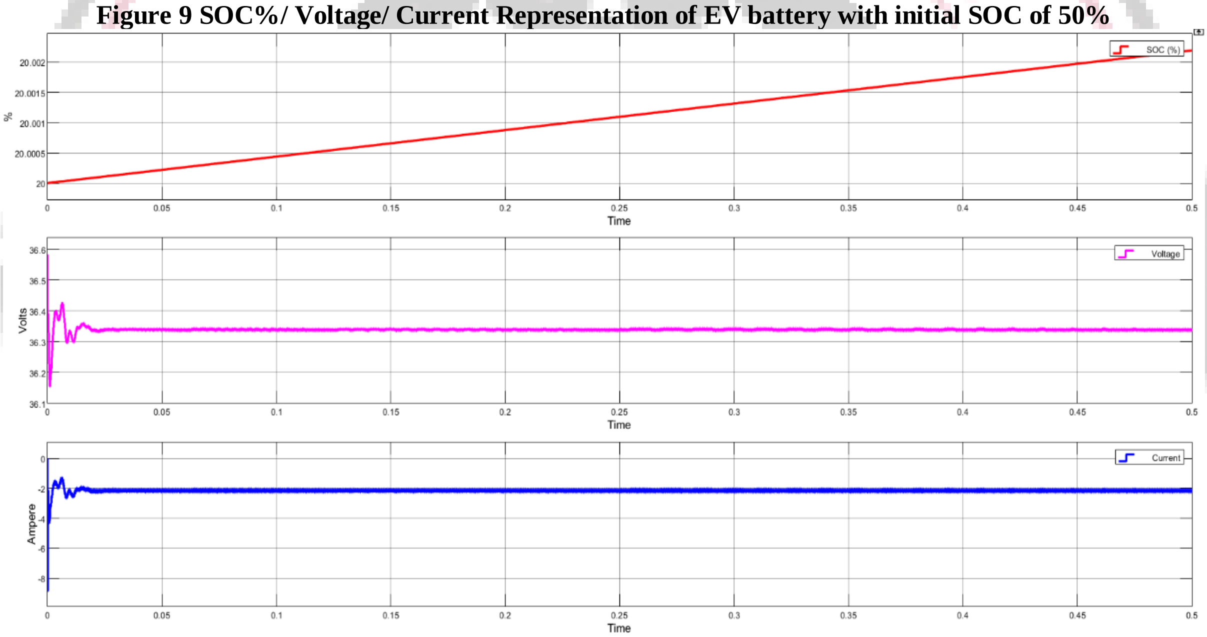

Figure 10 SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 20%

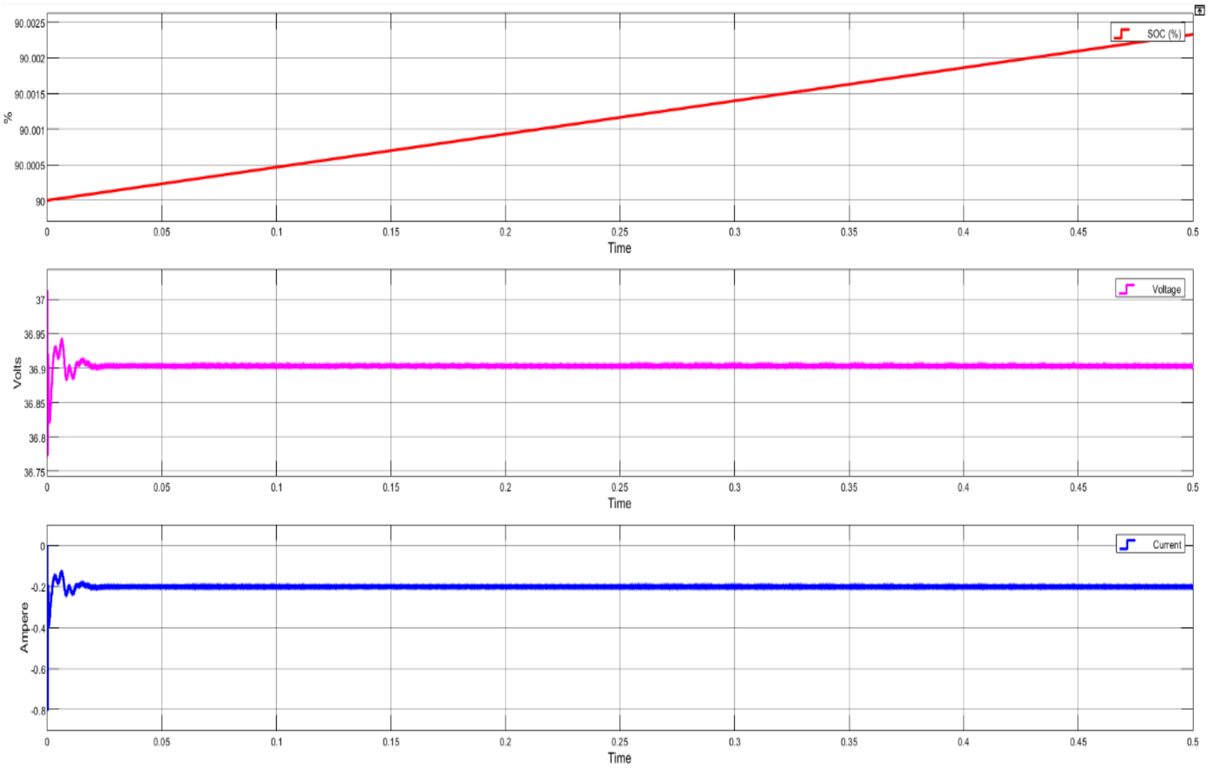

Figure 11 SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 90%

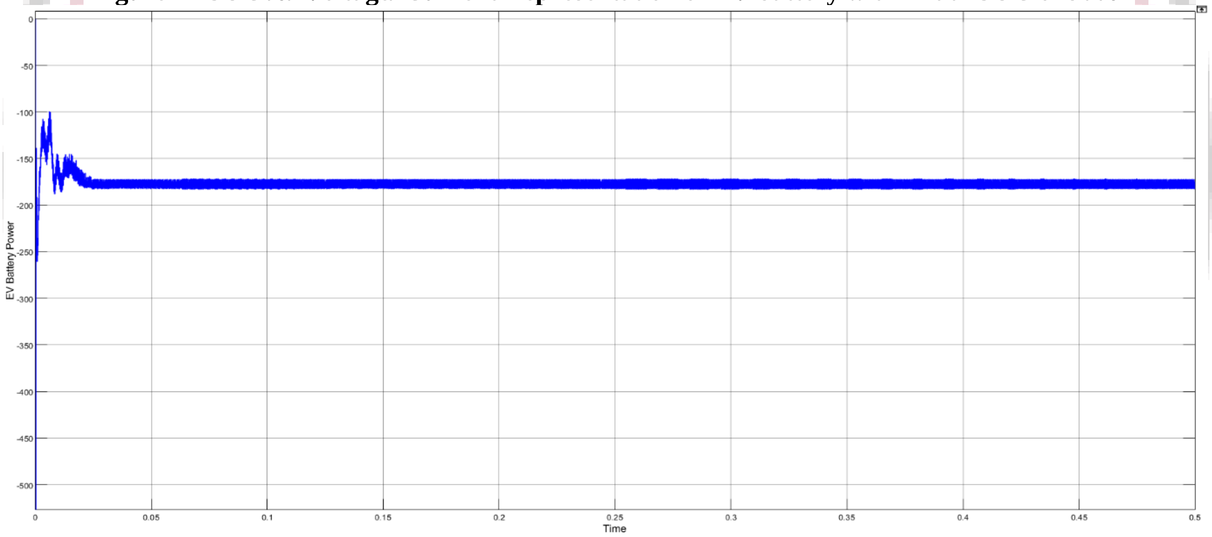

Figure 12 : Total load side power of EV battery with initial SOC of different values in the CS with 1000 W/m2

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

Solar based CS with irradiation input level of 200 W/m^2 and no optimisation algorithm for power flow and quality assessment

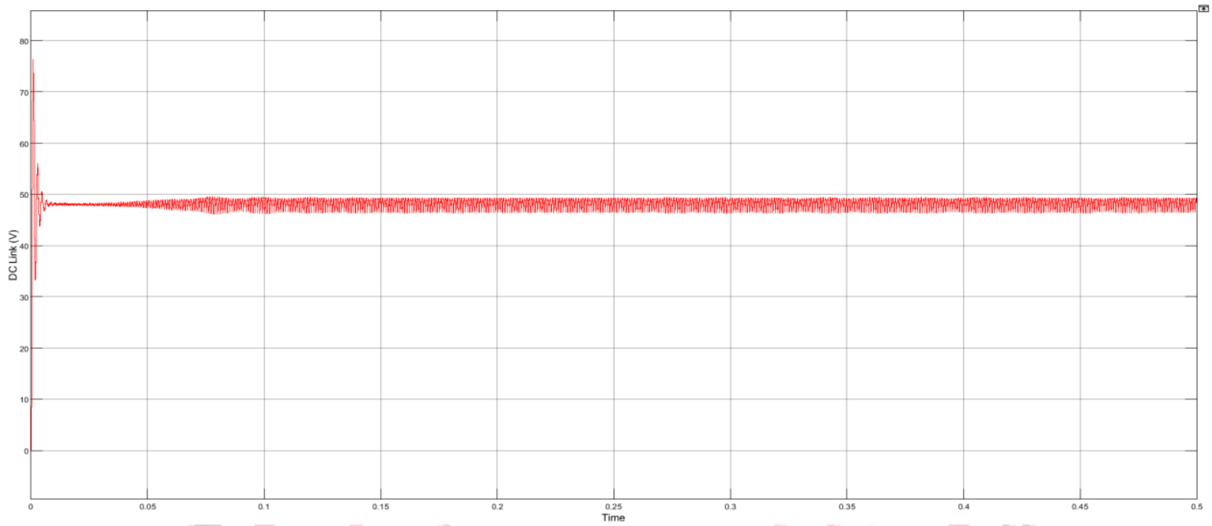

Figure 13 DC line voltage in the CS of the system 1

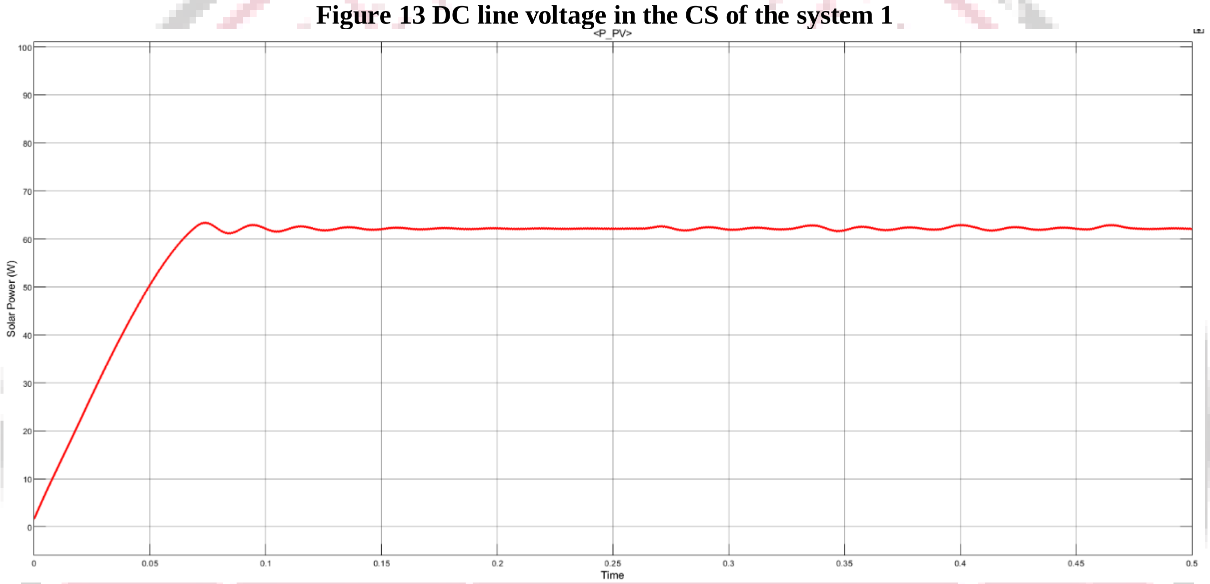

Figure 14 Solar output power of the CS of the system 1 for irradiation input level of 200W/m2

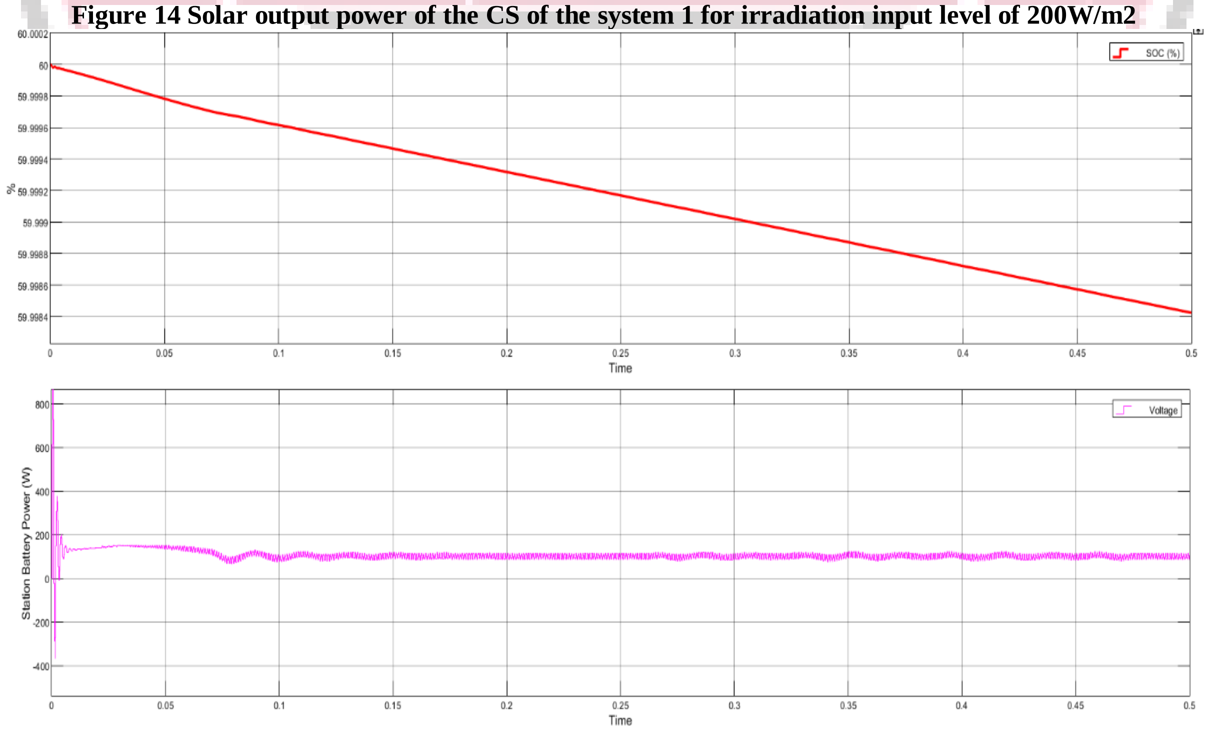

Figure 15 : station battery SOC and power in the CS of the system 1 for irradiation input level of 200W/m2

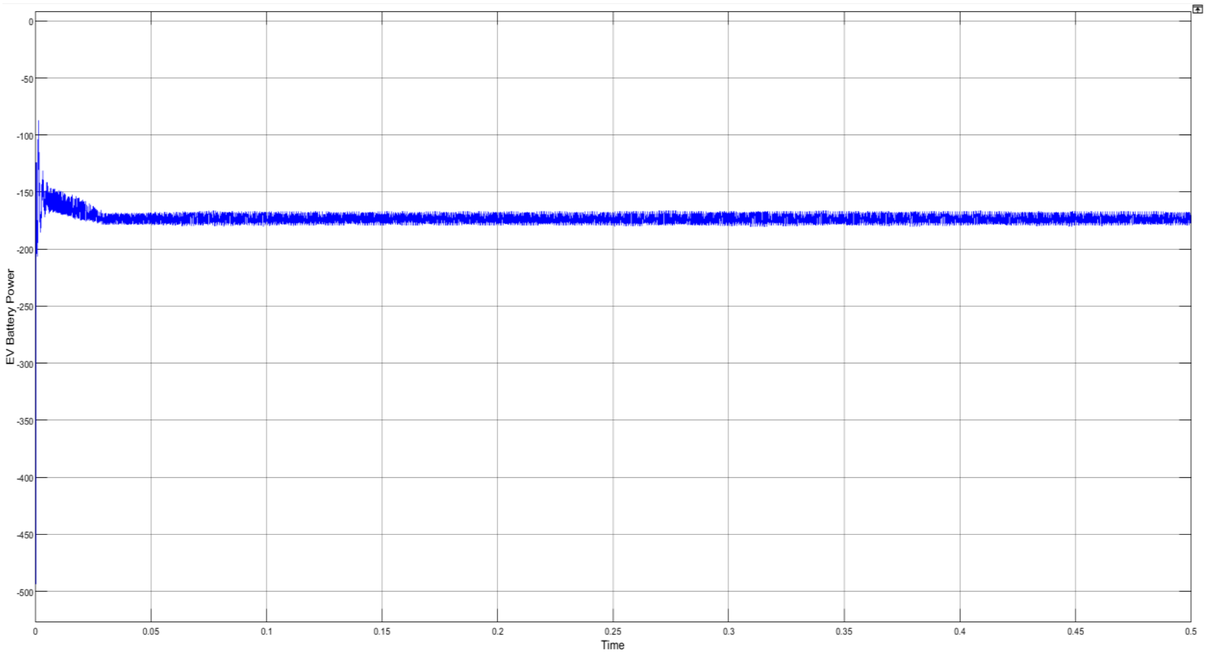

Figure 16 : EV power in the CS of the system 1 for irradiation input level of 200W/m2

Solar based CS with irradiation input level of 200 W/m2and PA_GWO algorithm for power flow and quality assessment.

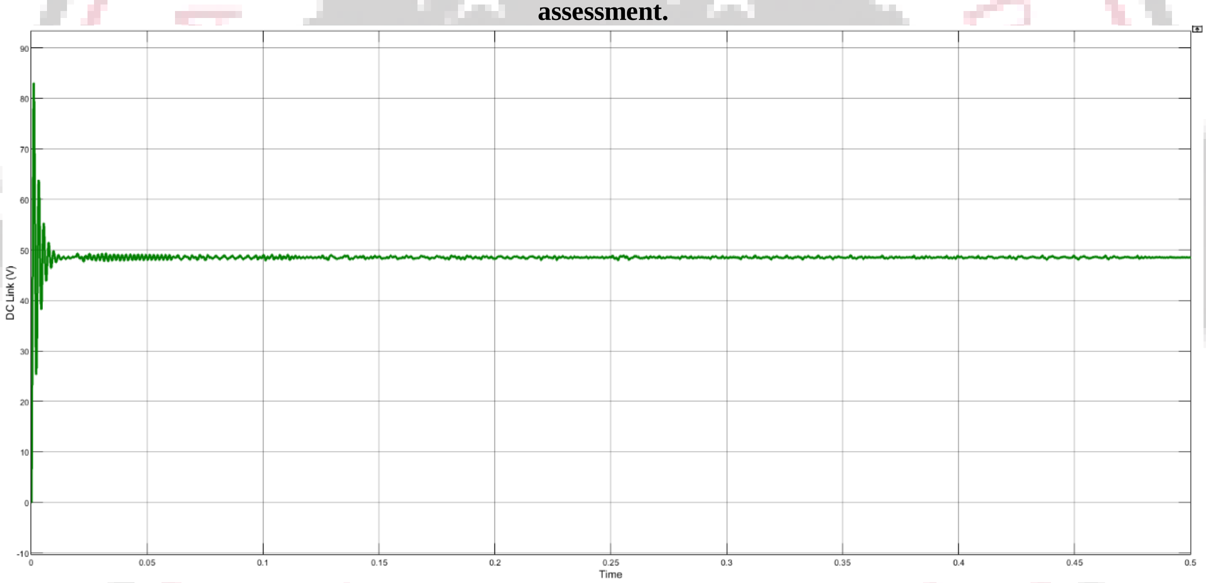

Figure 17 DC line voltage in the CS of the system 2

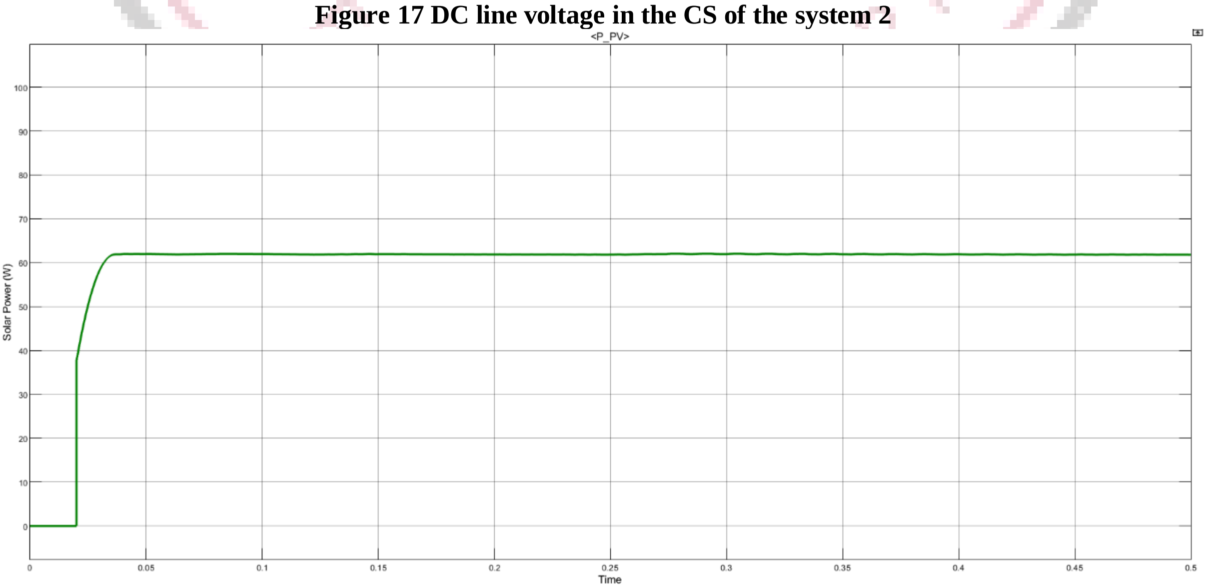

Figure 18 Solar output power of the CS of the system 2 for irradiation input level of 200W/m2

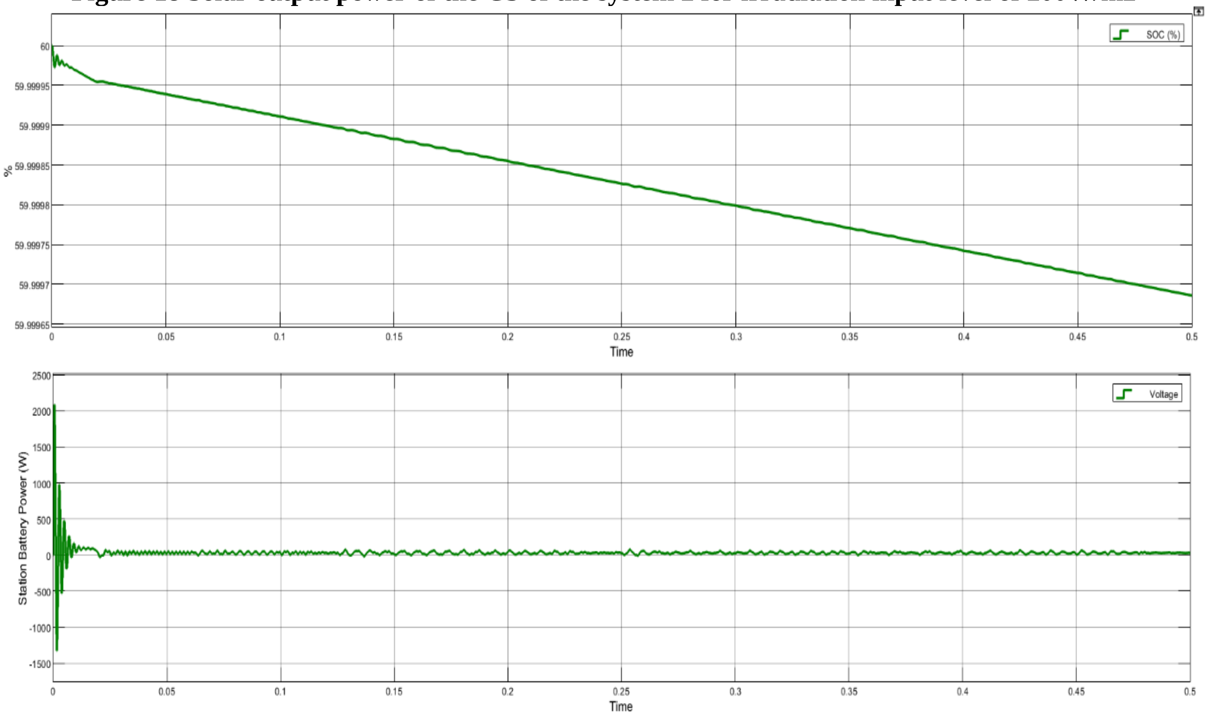

Figure 19 : Station battery SOC and power in the CS of the system 2 for irradiation input level of 200W/m2

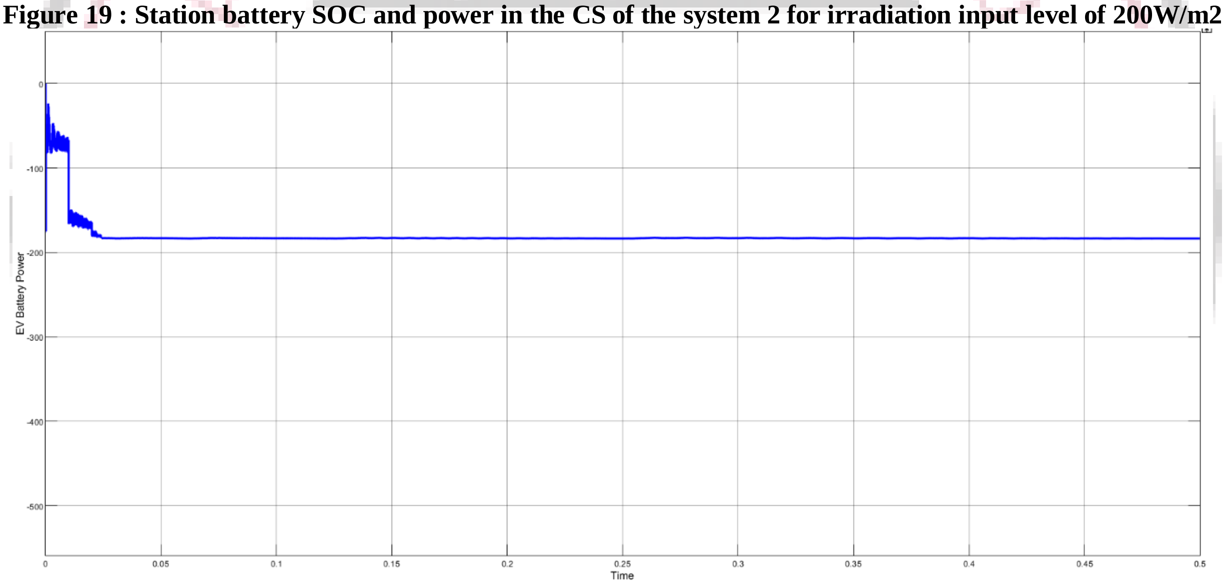

Figure 20 : EV power in the CS of the system 2 for irradiation input level of 200W/m2

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

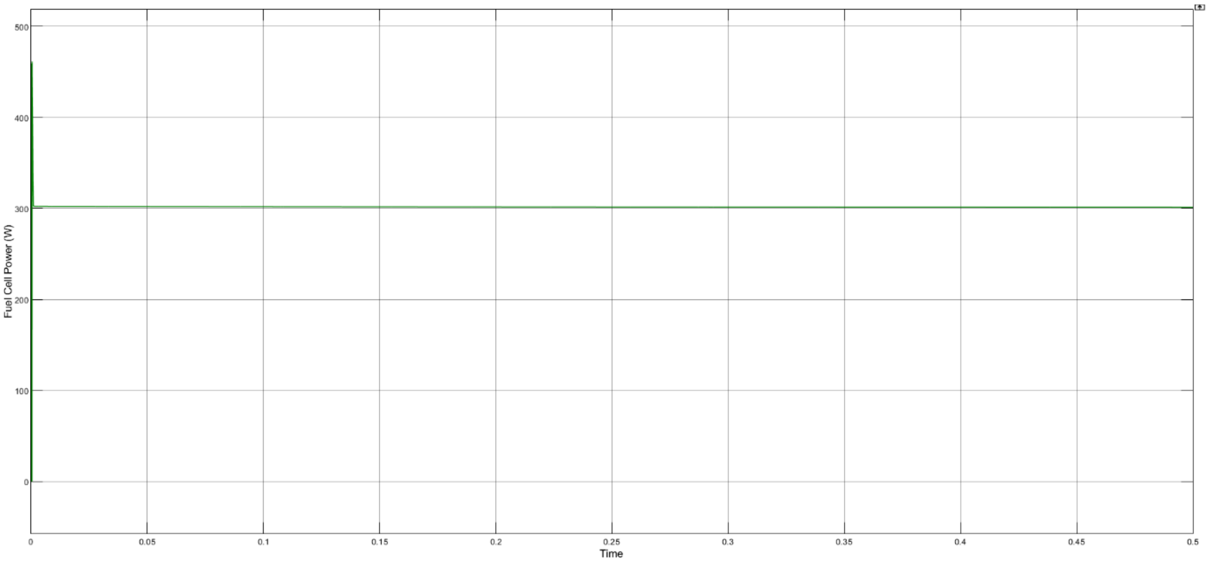

Figure 21 Fuel Cell System Power integrated with solar in the charging station

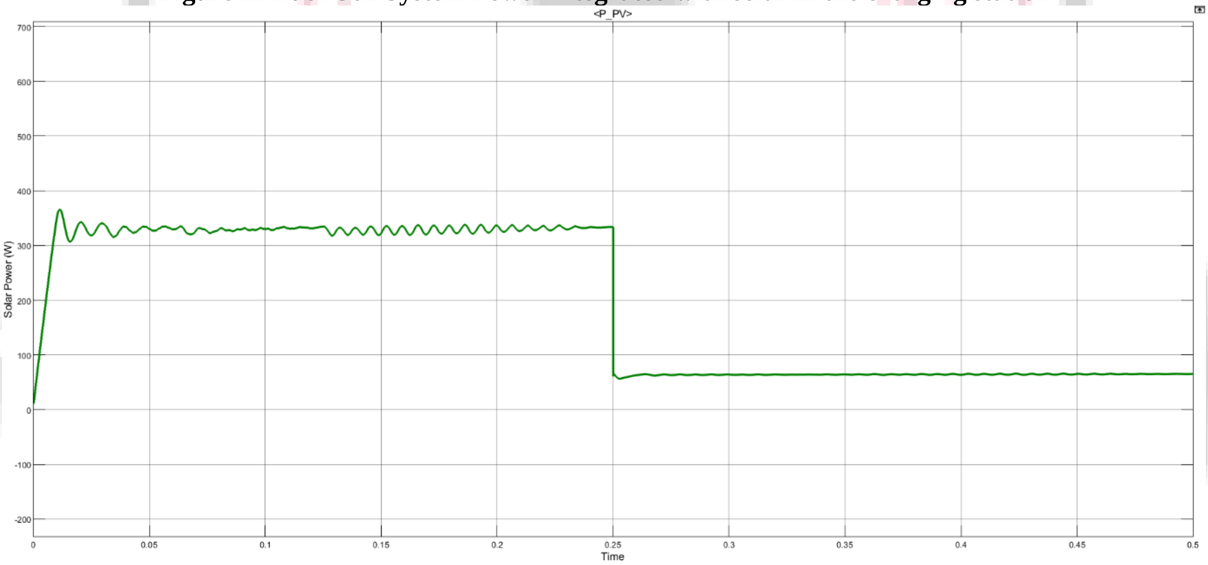

Figure 22 : Solar output power with irradiation varying form 1000W/m2 to 200 W/m2 in the CS

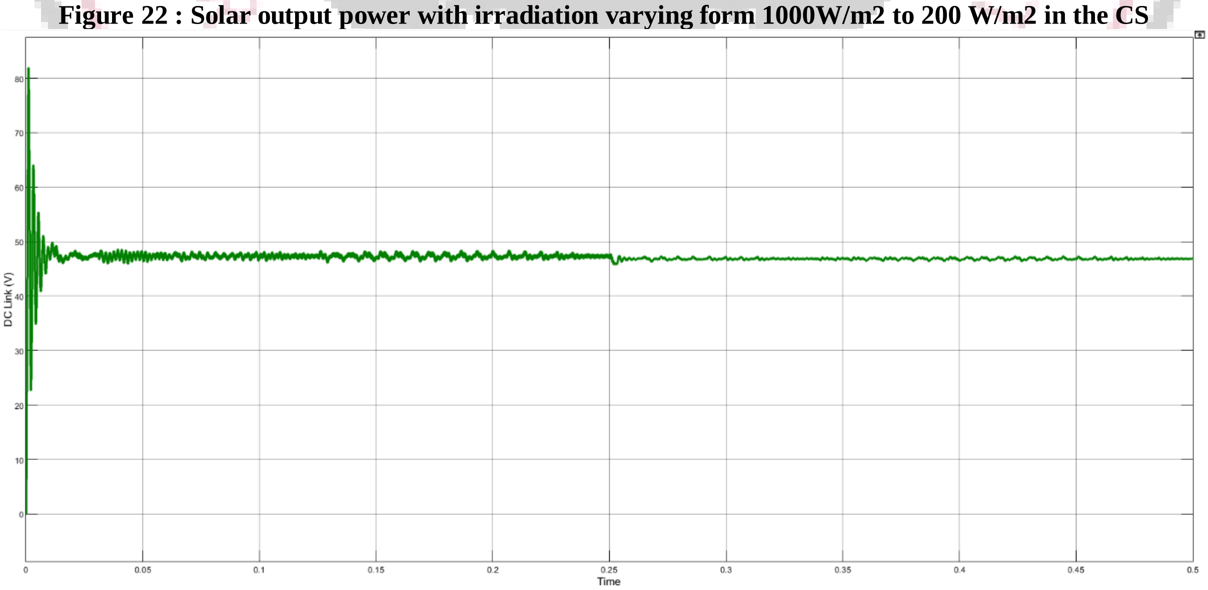

Figure 23 DC line voltage in the charging station with both solar and fuel cell system

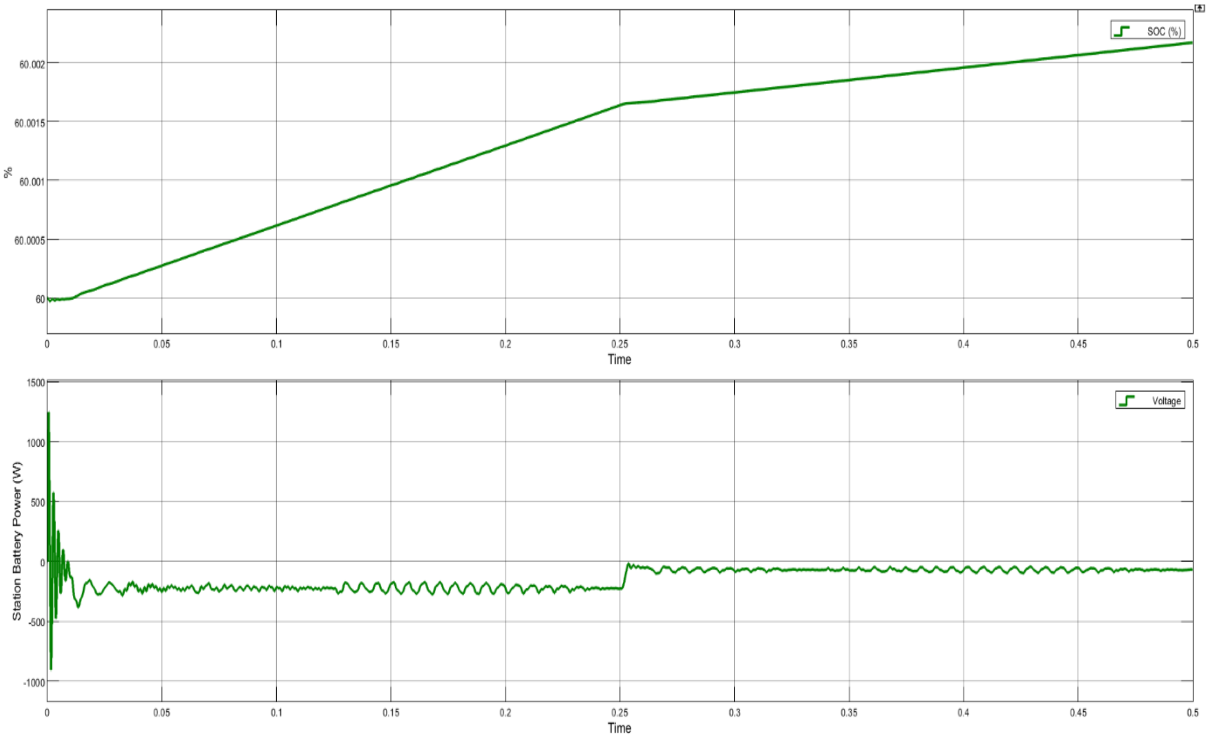

Figure 24 : Station battery response in the charging station with both solar and fuel cell system

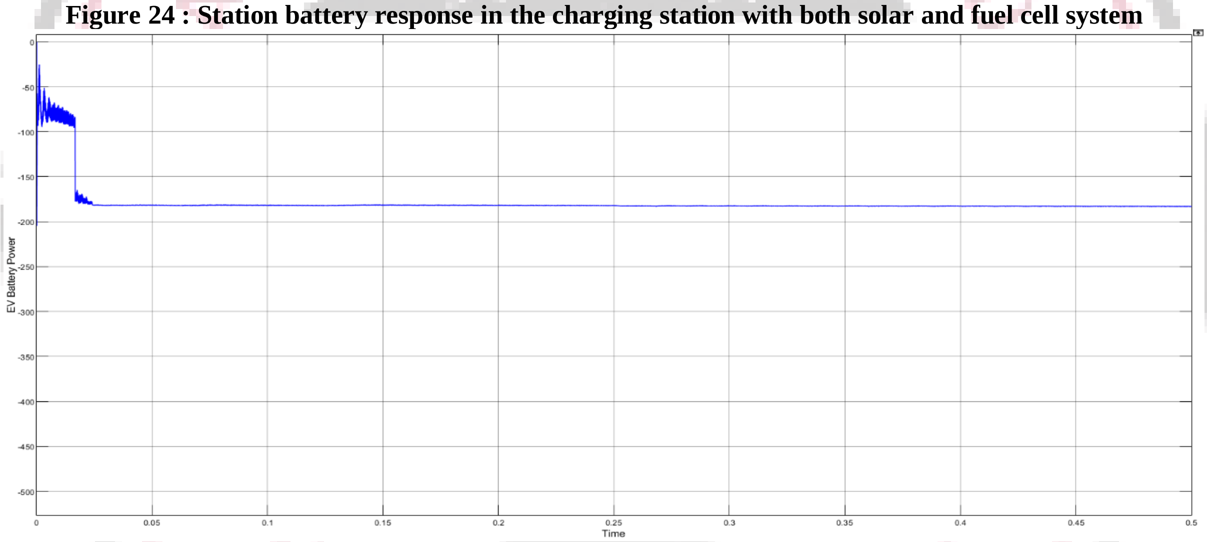

Figure 25 EV battery in the charging station with both solar and fuel cell system

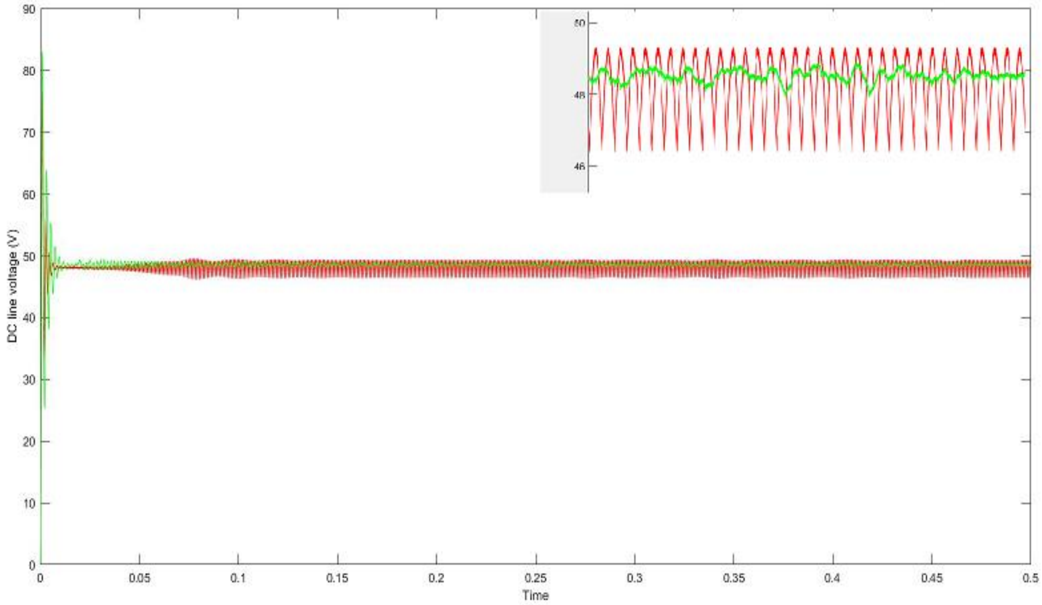

Figure 26 Comparison of DC line balancing by the proposed algorithm

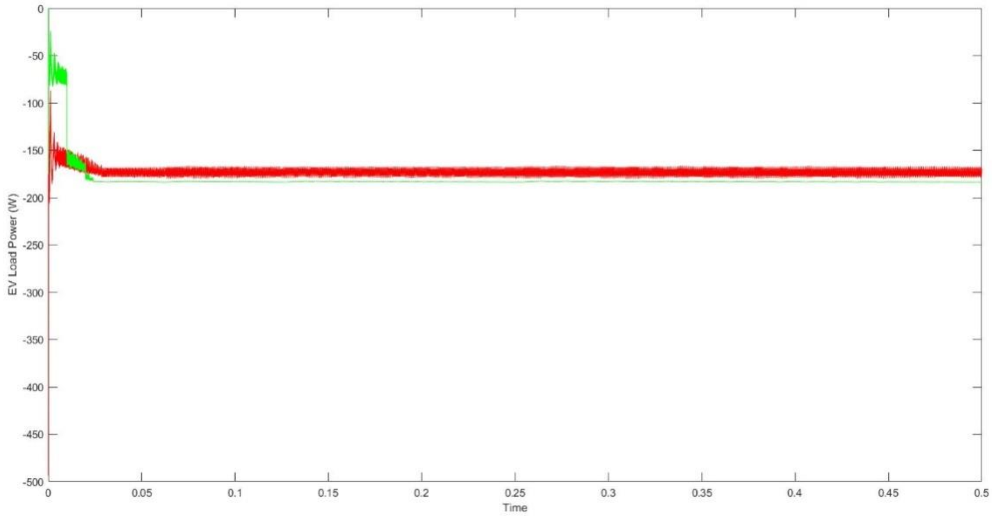

Figure 27 Comparison of power delivered to the EV load by the proposed algorithm

V.CONCLUSION

The development of a charging station with different irradiation inputs involves designing and implementing a system that can adapt to varying solar irradiation levels. Development of algorithms or control strategies to manage the power flow in the charging station is done in the work. These algorithms will consider the available solar irradiation, charging demand, battery status, and grid connection. They should Optimize the power allocation and distribution to ensure efficient charging while minimizing reliance on the grid. The work has compared the performance of solar based charging station operating under irradiation levels of 200W/m2 by employing the power management strategy based on power adaptive grey wolf optimisation control (PA_GWO) directed towards driving DC-DC converters in the Charging station. The following key conclusions were drawn from the work:

- The proposed algorithm based on PA_GWO approach has better stabilisation time of DC link voltage when compared with that of system without it for power flow control which effects the power quality delivered to the loads.

- The analysis was done by taking variable loading conditions having EV battery of SOC 20%, 50% and 90% and proposed PA_GWOalgorithm delivered more stabilised power to them.

• The final fuel cell integration was done with the solar system which enhanced the available source power and the algorithm was very neatly able to control the power flow across the system where the solar system was subjected to variable irradiation levels of 1000W/m2 to 200 W/m2

The PA_GWO algorithm optimizes the power allocation between the solar panels and the fuel cell system based on real-time conditions. It intelligently determines the appropriate distribution of power from each source to maximize overall system efficiency and minimize energy waste. This ensures optimal utilization of both renewable energy (solar) and stored energy (fuel cell) to meet the charging demand effectively. It balances the load across the charging points, preventing overloading of any specific point and ensuring stable and consistent charging operations..

REFERENCES

[1] Islam, S., Iqbal, A., Marzband, M., Khan, I., & Al-Wahedi, A. M. (2022). State-of-the-art vehicle-to-everything mode of operation of electric vehicles and its future perspectives. Renewable and Sustainable Energy Reviews, 166, 112574.

[2] Ravi, S. S., & Aziz, M. (2022). Utilization of electric vehicles for vehicle-to-grid services: Progress and perspectives. Energies, 15(2), 589.

[3] Xia, X., & Li, P. (2022). A review of the life cycle assessment of electric vehicles: Considering the influence of batteries. Science of the Total Environment, 152870.

[4] Thiel, C., Amillo, A. G., Tansini, A., Tsakalidis, A., Fontaras, G., Dunlop, E., ... & Yamaguchi, M. (2022). Impact of climatic conditions on prospects for integrated photovoltaics in electric vehicles. Renewable and Sustainable Energy Reviews, 158, 112109.

[5] Sadeghian, O., Oshnoei, A., Mohammadi-Ivatloo, B., Vahidinasab, V., & Anvari-Moghaddam, A. (2022). A comprehensive review on electric vehicles smart charging: Solutions, strategies, technologies, and challenges. Journal of Energy Storage, 54, 105241.

[6] Li, Z., Khajepour, A., & Song, J. (2019). A comprehensive review of the key technologies for pure electric vehicles. Energy, 182, 824-839.

[7] Sun, X., Li, Z., Wang, X., & Li, C. (2019). Technology development of electric vehicles: A review. Energies, 13(1), 90.

[8] Husain, I., Ozpineci, B., Islam, M. S., Gurpinar, E., Su, G. J., Yu, W., ... & Sahu, R. (2021). Electric drive technology trends, challenges, and opportunities for future electric vehicles. Proceedings of the IEEE, 109(6), 1039-1059.

[9] Islam, S., Iqbal, A., Marzband, M., Khan, I., & Al-Wahedi, A. M. (2022). State-of-the-art vehicle-to-everything mode of operation of electric vehicles and its future perspectives. Renewable and Sustainable Energy Reviews, 166, 112574.

[10] Hussain, A., & Musilek, P. (2022). Resilience enhancement strategies for and through electric vehicles. Sustainable Cities and Society, 103788.

[11] Zhou, G., Zhu, Z., & Luo, S. (2022). Location optimization of electric vehicle charging stations: Based on cost model and genetic algorithm. Energy, 247, 123437.

[12] Ghoderao, R. B., Balwe, S. R., Chobe, P. S., Pardeshi, D. B., & William, P. (2022, May). Smart Charging Station for Electric Vehicle with Different Topologies. In 2022 6th International Conference on Intelligent Computing and Control Systems (ICICCS) (pp. 243-246). IEEE.

[13] Li, C., Zhang, L., Ou, Z., Wang, Q., Zhou, D., & Ma, J. (2022). Robust model of electric vehicle charging station location considering renewable energy and storage equipment. Energy, 238, 121713.

[14] Ampah, J. D., Afrane, S., Agyekum, E. B., Adun, H., Yusuf, A. A., & Bamisile, O. (2022). Electric vehicles development in Sub-Saharan Africa: Performance assessment of standalone renewable energy systems for hydrogen refuelling and electricity charging stations (HRECS). Journal of Cleaner Production, 376, 134238.

[15] Zu, S., & Sun, L. (2022). Research on location planning of urban charging stations and battery-swapping stations for electric vehicles. Energy Reports, 8, 508-522.

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