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The Rise of Electric Vehicles: Global Adoption, Challenges and Future Prospects

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Abstract: *Electric vehicles (EVs) are poised to transform the automotive industry, offering significant environmental benefits, enhanced efficiency, and lower operating costs compared to traditional internal combustion engine (ICE) vehicles. By 2022, it is estimated that there will be more than 35 million EVs worldwide, driven by governmental initiatives and increasing consumer awareness of environmental issues. This study examines the current state and future prospects of EV technology, focusing on advancements in battery trends, charging infrastructure, and the integration of renewable energy sources. The analysis highlights the challenges related to EV adoption, including the need for widespread charging infrastructure and the impact on power quality and grid stability. Finally, the paper discusses innovative solutions such as solar-powered charging stations and smart grid integration to address these challenges and promote sustainable transportation.*

Keywords: *Electric Vehicles (EVs), Battery Technology, Charging Infrastructure, Renewable Energy, Sustainable Transportation , Environmental Impact , Power Quality..*

I. INTRODUCTION

There will be more than 35 million EVs worldwide by 2022, according to estimates. In light of the potential for electric cars (EVs) to reduce pollution and their numerous additional advantages including improved economy, simple speed control, and high torque comparing with traditional internal combustion engines (ICEs) The Indian government has set ambitious targets to accelerate the use of electric vehicles. [1]. On top of that, a study carried out by the European Union [1] found that the transportation sector is responsible for over 28% of all carbon dioxide (CO2) emissions, with road traffic making up more than 70% of these emissions. Most developed countries have encouraged the use of electric cars, or EVs, in an effort to lower the quantity of air pollutants like CO2 and other greenhouse gases in the environment. More specifically, they provide a range of initiatives that promote eco-friendly and efficient transportation. mostly by securing grants, tax breaks, or other unique legislation such as unrestricted access to public roads or free parking in designated locations. In comparison to Zero emissions: the exhaust of these automobiles doesn't release any carbon dioxide (CO2) or nitrogen dioxide (NO2). Although the industrial techniques used to create batteries are often more environmentally friendly, capacitors still have a negative carbon footprint during production.

- **SIMPLICITY:** Electric vehicles (EVs) have fewer engine components, but their maintenance costs are substantially lower. The engines are smaller, simpler, and operate without the requirement for a cooling circuit, gearbox, or any other component that might reduce engine noise.
- **RELIABILITY:** Trustworthiness is the quality of these automobiles having fewer, simpler parts, which makes them less likely to break down. Furthermore, regular wear and tear brought on by vibrations, oxidation of petroleum, and engine explosions do not affect electrically powered automobiles.
- **COST:** In comparison with typical combustion vehicles, the cost of electricity and vehicle maintenance is significantly lower for this type of vehicle Compared to traditional automobiles, EVs offer a significantly lower energy cost per kilometer.
- **COMFORT:** Driving an electric vehicle (EV) is more pleasant since there are no engine sounds or vibrations.
- **EFFICIENCY:** When EVs are compared to conventional cars, they are more productive. However, the efficiency of the power plant will also have an impact on the total well-to-wheel (WTW) efficiency. For instance, the overall WTW efficiency range for cars driven by gasoline is 11% to 27%, whereas the range for vehicles fueled by diesel is 25% to 37% [2]. On the other hand, the WTW efficacy of EVs fueled by natural gas power plants ranges from 13% to 31%, whereas EVs supported by renewable energy sources can have an average effectiveness of up to 70%. • Accessibility: Compared to other combustion cars, this kind of vehicle is able to enter metropolitan areas (such as low emissions zones).

Large cities do not impose the same driving limits on EVs, especially while experiencing severe pollution periods. Interestingly enough, a new OECD analysis indicates that EVs will regrettably not help the state of air quality, at least not in terms of PM emissions [3].

A. ELECTRIC VEHICLES

The automobile sector has emerged as one of the most important worldwide in the fields of R&D, economics, and the technical components that are added to cars to increase passenger and pedestrian safety. In addition, more people can travel faster and more easily as a result of driving more automobiles, but In addition to this, the amounts of air pollution in urban areas have dramatically increased (i.e., hazardous substances, such as PM, nitrogen oxides (NOX), CO, sulphur dioxide (SO2), etc.)Furthermore, according to a study released by the European Union [4], the transportation sector is accountable for around 28% of the nation's total (CO2) emissions, with road transportation accounting for more than 70% of the industry's emissions. The governments of the majority of developed nations are encouraging the use of electric automobiles, or EVs, in an effort to lower the quantity of air pollutants like CO2 and other gases the fact that contribute to global warming. A rising number of people are choosing electrically powered cars and trucks due to their affordability and increased awareness of environmental and climate change problems. This study examines the advancements in ‘electric vehicle (EV)’ technology, including new developments in battery trends and charging techniques. research challenges and prospects. In particular, the state of the global EV market is assessed both now and in the future. This page provides a thorough review of several battery technologies, including lead-acid and lithium-ion, as batteries are an essential component of electric vehicles (EVs). We also go over the various electrical vehicle charging standards that are out there, as well as battery energy management and power control issues. We wrap up our study by outlining our expectations for this topic going forward as well as the remaining research directions that the scientific and industrial community need to follow [5].

Additionally, the dearth of charging stations, particularly in developing nations, impedes the quick adoption of EVs as a more economical form of transportation. As a result, EV owners use their home connection to recharge their batteries. As a result, there is a significant loss to the power system and the profitability index drops. Due to their non-linear design, many EV chargers can cause power quality issues for the distribution grid, including harmonics, voltage fluctuations, and power loss. The reason of the power quality issues in the energy distribution network is fragmented and ineffective EV charging schemes. You may employ energy management techniques, enhance converter topologies, integrate renewable resources, and rethink charging patterns to get around these. Technology, economics, and ecology all agree that the wisest course of action is to make use of the available renewable resources. Additionally, it enhances power quality by lessening the load on the electrical infrastructure [6]. The increasing popularity of battery-powered cars has led to a new emphasis on the techno-economic analysis and optimal scheduling of electric vehicles, taking many factors into account. Therefore, while planning and managing renewable energy networks, it is fundamental to take EV integration into account. Techno-economic benefits including lower generating costs, voltage stability, less power loss, lower greenhouse gas emissions, and guaranteed power system trustworthiness might be obtained with the right design solution and EV integration. Furthermore, modern power networks frequently include renewable energy sources with EV charging. Recent technological developments have led to the evolution of conventional grid systems into EV and intermittent integrated grid systems; nevertheless, integrating renewable sources and dynamically charging EVs poses design and operational challenges. Therefore, modeling the grid-tied renewable energy-based EV system and optimizing EV charging are essential to achieving optimal outcomes.

B. CHARGING STATION

Electric cars and trucks (EVs) have garnered a lot of interest recently due to their usage of sustainable energy. But the issue is that if EVs grow more common, there will be an excessive demand for charging, adding to the grid's burden. This research introduces a revolutionary DC charging system that provides a continuous power supply for loads by utilizing renewable energy sources including solar, wind, and battery-powered energy storage systems (BESS).

There have been multiple detrimental effects on the environment as a result of the rising demand for conventional energy sources. Greenhouse gases are a contributing factor to adverse global warming, which is caused by resource depletion and excessive carbon dioxide emissions. The temperature of the earth was managed and CO2 emissions were decreased as a result of the Paris Agreement. Resources for clean energy and related technologies have been created in order to lessen these issues. Even while improvements in technology have greatly reduced these emissions, the transportation sector is still responsible for around 25% of greenhouse gas emissions. Transportation will increase by 77% by 2055 as a result of both population growth and the movement of freight. The adoption of electric cars and trucks (EVs) and their research are crucial because of the previously listed issues. Electric cars produce relatively little noise and very little, if any, exhaust emissions, which significantly reduces traffic congestion and improves the quality of the surrounding air. This shift is driving the car industry to convert to zero-emission automobiles. In 2019, the global fleet of battery electric cars (BEVs) saw the addition of about 1.5 million new vehicles, bringing the total number of BEVs in function to around 4.8 million [7].

Defining electric grid dependability

Our concept of grid dependability is based on three metrics: resilience, invulnerability, and reliability. The definitions of these metrics in the currently previously published studies vary and often overlap. Below, we clarify their respective meanings:

- **Reliability**: A dependable grid has few outages. The North American Electric Reliability Corporation defines reliability as the capacity to reliably supply electricity to meet demand. On an unstable system, outages happen too frequently to be accepted.

- **Resilience**: A robust grid recovers quickly from shocks. The ability to recover from adversity and change is resilience. An unresilient grid has continuous outages because it recovers from perturbations slowly.

Invulnerability: An invulnerable grid generates fewer interruptions overall. On the other hand, a vulnerable grid is vulnerable to major difficulties, with outages possibly affecting significant portions of the network[8].

Diesel engines are becoming more and more popular in the automobile industry on account of their higher durability and thermal efficiency; yet, the environment and public health are greatly endangered by the exhaust pollutants they produce. The toxicity levels of exhaust emissions can be minimized by using pretreatment and posttreatment techniques. It is believed that switching to electric vehicles is the greatest way to reduce vehicle pollution. The adoption of electric cars in society is largely determined by the necessity for infrastructure for their charging. In countries where fossil fuels are the primary source of electricity, the introduction of electric cars will just shift the pollution risk from the vehicle operating phase to the renewable energy generating phase[9]. Both an experimental inference-based study of the transformation efficiency of platinum-based diesel oxidation catalysis systems and a comprehensive review of post-treatment emission control methods for diesel engines are presented in this paper. Fossil fuels provide more than 70% of the power generated in India. Additionally, a feasibility study on the construction of solar-powered electric vehicle charging stations atop petrol stations that are presently in operation has been conducted in Dehradun, India. The study's conclusions show that the planned solar power system at 26 gas stations has a 1.9 GWh overall energy generating potential. This suggests that installing solar-powered charging stations will be a useful strategy for raising the societal acceptance of battery-electric cars and increasing the proportion of renewable energy[10].

C. Electric Vehicle Charging Stations

The advancement in the economy and society of this nation is mostly attributable to its modern transportation system. At the moment, this market is dominated by automobiles with internal combustion engines (ICEs). Their exhaust and tailpipe emissions directly contribute to climate change, and the poisons they emit worsen air quality, which is detrimental to human health and the environment. Transport produces around 24 percent of the total CO2 emissions from the combustion of fossil fuels. The carbon dioxide (CO2) emissions sector-specific from fuel burning are shown in Figure 1. In the near future, it is anticipated that these emissions will increase as a result of urbanization, industrialization, and a growth in the number of automobiles. To alleviate the previously mentioned concerns, one alternative to the transportation[11].

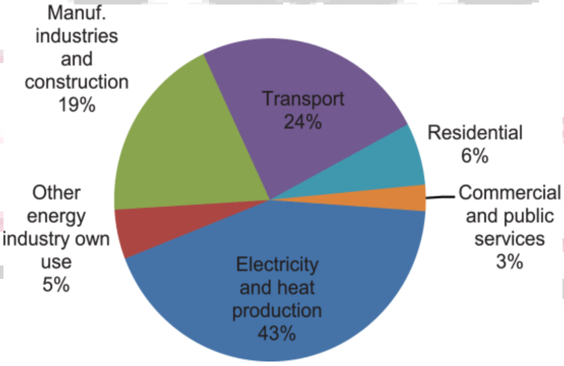


Figure. 1. Sector-wise $C0_2$ emission from fuel combustion [12]

Structural Topologies: The electrification of transportation is a fast-moving target, with pure electric vehicles (EVs) receiving special attention because they produce no emissions. Investigation on improving EV technology has surged in response to the growing interest in expanding the use of EVs that are fueled by renewable and alternative energy sources. Globally, governments are additionally organizing campaigns to encourage the adoption of alternative-energy-powered cars, keeping up with developments in electric vehicle technology.

The advancement of standards and rules related to the utility/customer interface is a major undertaking for a number of governmental agencies as well as business associations, such as IEEE, the Society of Automotive Engineers (SAE), and the Infrastructure Working Council (IWC). These initiatives seek to guarantee compatibility with developing technology breakthroughs and facilitate the integration of EVs into the current infrastructure. In general, the growing popularity of electric vehicles (EVs) and renewable energy sources is propelling important developments in the electrification of transportation. Governments, industry players, and standards organizations are working together to create a strong foundation for the broad use of EVs and other energy-powered vehicles.

Further complicating the situation, battery chargers have the potential to generate detrimental harmonic effects into electric utility distribution systems. In consequence of these input line current harmonics, fast-charging stations have a lower power factor, which increases utility current consumption, raises line losses, and shortens distribution transformer lifespans. For the EV charging infrastructure to continue operating as efficiently and sustainably as possible, it is imperative that these harmonic effects are addressed [13].

The growing demand for sophisticated and user-friendly charging infrastructure alternatives is a result of the growing popularity of electric and hybrid vehicles. Furthermore, whole new battery charging protocols will be required for cars that drive and park themselves in the future. Electric cars these days require manual recharging. Stated differently. Computerized car charging systems are covered in this article. An entirely computerized mechanism assists with tethered charging detection. The first part of the painting discusses the benefits of computerized conductive charging structures in relation to various computerized ideas and the necessity of such structures. The second component includes information about the country of origin of the artwork. Its mileage hence functioned as a testament for the already created and announced structures. Subsequently, challenging situations and challenges related to computerized conductive structures are presented. Consequently, the flaws in the character are exposed and analyzed. Finally, a straightforward automated charging station concept is discussed and shown as a possible workaround for charging various kinds of cars at public parking lots [14].

Energy Storage Systems: They examine some of the most popular converters used in DC charging stations with integrated generators during the conversion stages. To this purpose, three isolated dc-dc converters, four active front-end ac-dc converters (unidirectional and bidirectional), and two control schemes are investigated. The primary goal of this comparison is to order the proposed configurations based on supply voltage level, smart grid type, and converter power flow. In addition, the research [15] assesses the trustworthiness, data collecting, and use of the UFCSs while providing a thorough summary of the primary UFCS needs. The purpose of this essay is to establish a connection between the demands of charging station designers and the preferences of the commercial market. These demand management initiatives have the potential to reduce peak demand and save energy firms money, but they may also postpone the development of new power plants and power transmission networks. Studies have shown how EVs may be included into the DR programme to sustain the grid, given the increasing quantity of EVs. In addition to meeting their charging needs, EVs may act as DR agents. In V2G mobile energy networks, the actual mobility of EVs may enhance the effectiveness of DR management and balance the power demand among districts. EVs are used as storage to give the grid additional services in addition to being a regulated load. Power supplies that are both responsive and active are examples of auxiliary services. The conceptualization of the queueing network they used to simulate an EV aggregation allowed the researchers to evaluate the capacities for regulation-up and regulation-down separately. The revolutionary idea behind V2G technology To control EV charging in the CS, a central aggregator is needed. Rather than depending just on EVs, whose tenure in the CS may be limited and hence prohibit them from delivering V2G services, the CS demands other parties to complete the grid request at all costs. the development of hybrid energy systems for smart grid applications that combine solar (PV) with energy storage (ESS). The literature contains in-depth evaluations of several approaches to combining PV, EVs, and ESS in a CS. The vast majority of them are typically impracticable since they rely on PV and ESS for vehicle charging. To make their ideas work, they need to raise money. Analyzing the subsidies necessary to build the PV system in an economically feasible position near to an ESS and an electric vehicle (EV) charging station is essential, given the present high cost of both PV and ESS. The simultaneous use of PV, ESS, and EV as suggested by them is not practical since there are now inadequate global subsidies to replace self-installed energy sources with electric vehicles [16]. Alternatively, you may swap something with the grid.

Grid Impacts: The trend toward decarbonization and interest in environmentally friendly technologies are accelerating due to growing concerns about climate change. EVs fueled by renewable electricity can replace internal combustion engine cars (ICEVs) and cut down on greenhouse gas emissions and petroleum use. Additionally, new technologies on their powertrain—like wide-band gap component-based motor drives that increase battery-to-wheel efficiency—are making EVs more competitive in the energy-saving market. An electric vehicle's adoption and use are significantly influenced by how simple it is to recharge one. In general, charging power levels may be divided into two categories: FC and slow charging. The former generally refers to distributed charging using energy rated lower than the maximum domestic power (22 kW in the EU and 19 kW in the US, for example), both at home and in public places. Conversely, fast chargers often come in FCSs and have a higher power rating. The charging modes are defined by SAE J1772 and IEC 61 851-2 according to the power level and type of input current (DC or AC). IEC 61 851-2 establishes four charging modes, the DC charging mode being Mode 4 and Modes 1, 2, and 3 are the AC charging modes. Moreover, the FC is supported merely by Modes 3 and 4. Three levels of EV charging are defined by SAE J1772, with Level 3 being FC using a DC off-board charger and Levels 1 and 2 being sluggish charging using AC on-board chargers (OBCs).

Considering the AC OBC is heavy and requires up a lot of space, its maximum power rating is limited (43 kW for Mode 3 in IEC 61 851-2). As a result, the DC off-board charger, which may provide greater charging power, is the common FC. When FC is described in this study, it is referred to as the DC FC for simplicity's sake [17].

D. TRENDS OF FAST CHARGING

The majority of EVs only drive short distances and mostly rely on home charging, according to a 2017 poll [18]. As shown in Fig. 2, the study also indicates a favorable link between the number of FC incidents and the daily driving distance of EVs. When the scope is per week, the same result holds true. Given the strong association, EV drivers must have FC while traveling long distances. EV manufacturers (like Tesla) and energy suppliers (like Shell) have established several FC facilities in recent years to allay consumers' range anxiety and encourage them to utilize EVs for long-distance adventures.

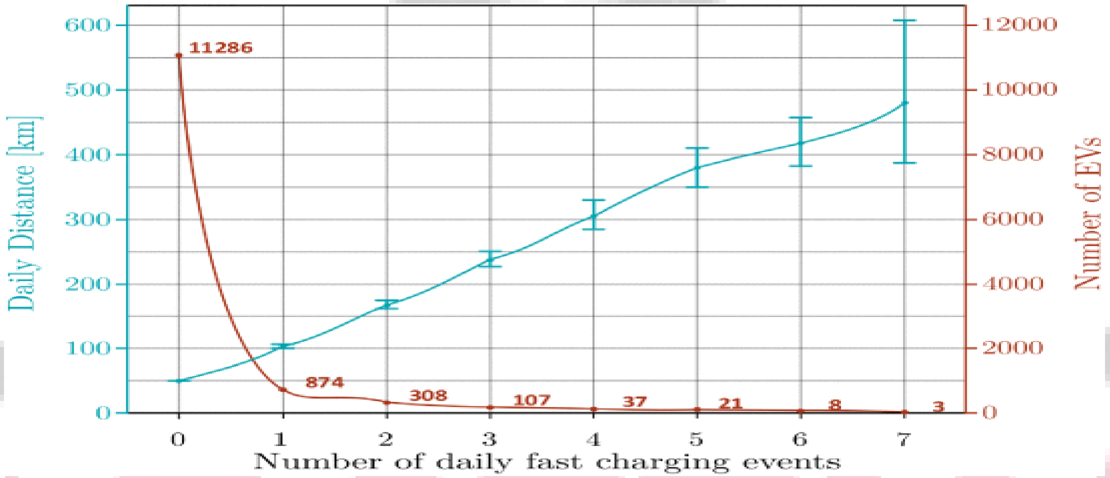
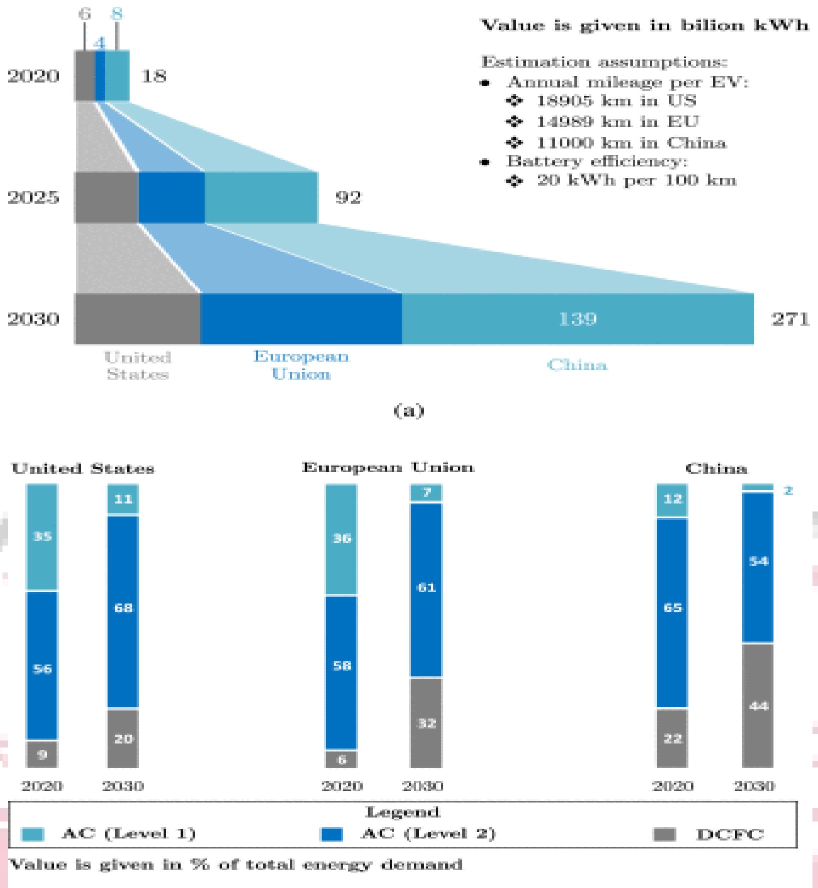


Figure 2. The relation between the daily distance travelled and the number of the FC events [18]

Ultra-Fast Charging

The overall energy consumption for EVs is anticipated to increase tremendously when EVs are rolled out. Fig. 3(a) [19] displays the trend of EV energy demand in the three main markets. More precisely, as can be shown, DCFC penetration will rise substantially even while sluggish ac charging will maintain its leading position through 2030 in Fig. 3(b).



(a)

(b)

Figure 3. The energy demand for EVs: (a) Total energy demand (b) Energy demand by charging mode [19]

The DC fast charger (DCFC), which is moving toward ultra-rapid charging, currently rates at 50 kW [20]. The market's mainstream EVs have an average battery capacity of 60.1 kWh, or an average range of 317 kilometers [21]. In contrast to overnight sluggish charging, most drivers consider a 15-minute charge period to be the maximum when going [22]. Table 1 lists the necessary power for different EV models [21] available on the market in order to charge EVs in fifteen minutes. As can be seen, the long-range EV can require up to 228 kW of charging power. As the battery capacity increases, the charging power can also rise. To satisfy the need in the near future, 350 kW DCFC has apparently already been created [23].

Architecture of Ultra-Fast Charging Station

It is anticipated that the majority of FCSs would be built beside freeways in order to provide FC service for lengthy journeys. An FCS typically consists of 10–12 150 kW DCFCs, with a total electric power of 1.5–1.8 MW, per the design of Tesla's FCSs [24]. To prevent overloading the low-voltage (LV) grid, a direct link to the medium-voltage (MV) distribution network is recommended for such an FCS. Various methods are suggested in [25]. for FCS's direct connection to the MV grid. As seen in Fig. 4, the LV distribution network within the FCS may be either AC or DC. The majority of modern FCSs have embraced the AC distribution network, which is more developed than its DC equivalent [26]. However, there are benefits to the DC network design on fewer conversion stages and simpler integration of chargers. Additionally, because the rectifier is centralized, a solid-state transformer (SST) may replace it along with the MV/LV line frequency transformer. This can drastically lower the space, power losses, and cost of FCSs when compared to AC-coupled stations [27]. An SST-based FCS is already being developed by a company as a promising idea [28]. Despite this, the AC-coupled FCS will be the major topic of this study as it is still the accepted approach for the next few decades.

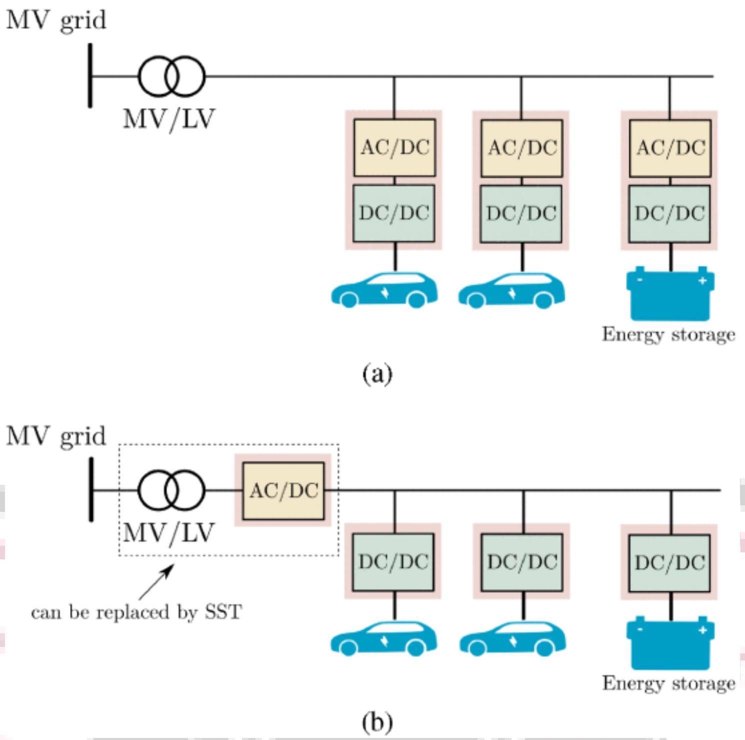


Figure 4. The structure of UFC station: (a) with AC distribution network (b) with DC distribution network where SST can be used alternatively [29]

II. LITERATURE REVIEW

The sun is an infinite energy source that can provide all of the human race's energy demands. Solar energy may be used directly and converted into electrical power. solar cells, often known as PV cells, are a direct way to use solar energy to generate electricity. Concentrated solar power (CSP) technology is another way to use solar energy indirectly. With multi-junction PV cells, the efficiency of photovoltaic solar cells has increased and is now at 34.1%. Technologies that use concentrated solar power, or CSP in particular, have a promising future in the production of energy because of their high capacity, effectiveness while and capability to store energy. Furthermore, agriculture directly uses solar energy, mostly for water treatment and irrigation. Solar energy is used to power the automobiles, which are used for home uses like space exploration. The most promising potential applications of solar energy are found in satellite power plants, which employ microwave waves to transfer electrical energy from solar panels in orbit to Earth. The projected future of solar energy is bright because of technical breakthroughs and its environmentally conscious nature. The main barrier to the future of solar energy, however, is not just its high initial cost but also the year-round unavailability of PV cell components. These challenges can be met by developing PV solar cells that are numerous, inexpensive, and efficient in addition to an efficient energy storage system.

MB Hayat **et al. (2019) [33]** includes a comprehensive examination of the direct and indirect ways to generate electricity from solar energy, as well as the direct applications of solar energy, and covers every facet of the solar energy system. An overview of the state-of-the-art techniques for characterizing and evaluating PV performance has been given. Possible answers to the issues with economics, technology, the environment, and storage are also investigated. Furthermore, a comprehensive list of potential topics for future research on solar energy-based direct and indirect power generation should be considered.

As a result of the requirement for DSSCs with greater power conversion energy and more inexpensive, lower-cost manufacturing, many educational organizations have been searching for better ways to optimize individual components of the cell to boost its efficiency. The present investigation thus examines several approaches to the synthesis and fabrication of an enhanced DSSC for the production of power from renewable sources.

JE Ikpesu **et al. (2020) [34]** examines the different methods that FTO is fabricated for DSSCs and how graphene is added for DSSC optimization. For an efficient light harvesting, the optimization of DSSC employing FTO was studied with the different manufacturing processes (CVD, sputtering, spray pyrolysis, and hydrothermal procedures). Next, we talked about the use of graphene-based materials in the counter electrode and transparent conducting electrode, as well as in the semiconductor layer and dye molecules, which make up the photo anode. As previously mentioned, adding graphene to the photo anode can increase the cell's efficiency because of its distinctive characteristics, which include higher dye absorption, enhanced charged separation, and good electrical conductivity. Lastly, a prediction for future developments in DSSC optimization

A Mohammadnia **et al. (2020) [35]** explored the relationship between increased cell temperature and decreased conversion efficiency in consolidated photovoltaic (CPV) modules due to long wavelength solar radiation that is not absorbed by the cell's band gap. The long wavelength solar spectrum needs to be isolated from solar irradiation in order to be used effectively. This is due to the possibility that various energy harvesting methods may convert part of the long wavelength heat energy that would otherwise be wasted into beneficial power. In order to increase overall solar energy harvesting, this study looks at a unique hybrid system that separates solar radiation and consists of solar thermoelectric generators (STEGs), a cavity, a Stirling engine, a beam splitter, a solar concentrator, and CPV. Moreover, the cavity's STEGs prevent the Stirling engine from overheating. In order to predict and evaluate the hybrid system's daily performance, including its electrical power and conversion efficiency, coupled governing equations are built. The governing equations are solved and the model is evaluated using the Software for Engineering Equation Solver (EES) application. Additionally, an estimate of the energy harvesting components of the hybrid system's cost performance is provided. The location of the model's examination was decided upon as Aalborg, Denmark. The conclusions of the analytical model for the examined energy harvesting devices are in excellent agreement with findings from earlier research and testing. Results indicate a total electrical power output of 45.4 kW and a system conversion efficiency of 21.8%. While the CPV and STEG offer better cost performance, the STEG may be used as one of the energy harvesters that has been studied for the hybrid power generating system. Moreover, the findings indicate that there is a considerable probability that the hybrid system under investigation will develop into a highly efficient hybrid energy harvester and contribute significantly to the progress of future renewable technologies

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Kumar, K. R et al. (2021) [36] demonstrates how, with an expected 1.2% annual increase, the industrial sector produces about 54% of the energy generated globally. For thermal energy, most industrial sectors now rely on fossil fuels, but solar energy in particular has the potential to displace these sources. This article offers a thorough analysis of several solar thermal energy systems and their industrial uses. Power generation, oil and gas, paper and textile, food processing and beverage, pharmaceutical, leather, motor vehicles, and metal are among the industries covered. The required heat amount and quality are determined for each application. While all applications require heat in the form of steam or hot water, power plants and enhanced oil recovery present a significant opportunity for solar steam augmentation. Similar to this, the milling of rice, the production of pulp and paper, and the refining of petroleum all require large amounts of steam or hot water. Process heat requirements are lower in the textile, food & beverage, pharmaceutical, leather, and car manufacturing sectors. The amount of solar radiation in the area, the accessibility of land, the cost of conventional fuel, the required steam quality, and the system's flexibility in terms of integration with the current process are the main factors influencing the integration of solar thermal energy systems with industrial processes. Along with the financial considerations, the challenges of integrating solar thermal energy systems with the process heat sectors are examined. It has been suggested that future work solve the inadequacies of the integration.

Roy, P et al. (2022) [37] it conducting research on hybrid renewable energy sources (HRES), which are energy sources that combine two or more renewable energy sources (such as wind turbines and solar panels) to increase system efficiency and, to some extent, improve the reliability of the energy supply. The purpose of this work is to give a comprehensive examination of power architectures, power electronic converter topologies, design optimization methods, and mathematical representation in relation to wind-solar HRES. This research presents many hybrid energy storage system coupling techniques and outlines their main advantages and disadvantages since the addition of an energy storage system can further reduce the uncertainty of HRES. Sophisticated HRES power conversion technologies and control architectures have been shown and examined. In order to give academics, engineers, and policymakers a comprehensive reference on this topic, this study reviews the many energy source combinations, modeling, power converter topologies, sizing, and optimization techniques used in the present HRES. This article also discusses the implications of future research and development on HRES as well as the technological obstacles associated with HRES.

Javed, M. S et al. (2020) [38] It's developing more and more obvious that energy storage is going to be crucial for next-generation renewable energy (RE) systems. The use of energy storages to achieve high RE penetration has received more attention in recent study. This study offers a thorough examination of hybrid solar-wind power supply systems based on pumped hydro storage (PHS). The article also discusses upcoming research, PHS's present use, its overall installed capacity, and the technological challenges associated with utilizing this storage in the context of RE-based systems. This review research looks at the technical, economical, and environmental aspects of solar-wind-PHS systems that have been discussed in papers during the last 10 years. Research is further divided into groups according to the purpose, location, primary results, and methodology. PHS technology has once again shown to be a technologically and financially feasible choice, as evidenced by the literature. Reversible pump turbine machines have improved PHS performance, flexibility, and reaction time; nevertheless, hybridizing PHS with other storages can increase overall system reliability and expand the spectrum of services, especially in off-grid RE systems. This review will be useful to researchers who are interested in modeling and techno-economic optimization of RE-based PHS systems. Hybrid storage, like PHS batteries, is a novel technique to compensate for each other's inadequacies and is anticipated to be a productive field of research in the future.

Afshar, S. et al. (2021) [39] rated based on The market for electric cars (EVs) is expanding, but because there isn't enough infrastructure for charging them, EV adoption is increasing at a rate that has never been witnessed before. Currently, the low ratio of electrically powered cars to combustion engine cars makes it financially impractical to establish permanent charging stations (FCSs) everywhere. Two significant challenges to the widespread adoption of electric vehicles are range anxiety and total charging time, both of which increase in the absence of FCSs. As a solution, by offering charging services at EV customers' convenient times and locations, mobile charging stations (MCSs) can significantly accelerate the shift toward higher EV adoption. This website will include articles and resources that might help FCSs. technical papers that address MCS, evaluate the challenges, elucidate the benefits, and ultimately recommend possible research topics. MCS is a versatile charging method. The study claims that charging station operators may boost how often their equipment is utilized for charging as well as for the power grid by employing MCS services, which are an inexpensive technology.

Faustino, F. J. et al. (2023) [40] introduces a technique that makes use of the idea of a "charging zone," which is a circular area equipped with technology to meet the needs of nearby electric automobiles for charging. To better meet the needs for electric charging in big urban districts, the Teitz-Bart technique treats the centroids of these zones as a p-median issue. Taking into account six possibilities for the worldwide adoption of electric cars, the suggested technique was used to determine the location of public charging stations in a metropolis of around 3 million people in Brazil. Utilizing commercial geo-processing tools, we additionally examined the centroids' locations within these zones to ascertain the outcome. This comparison demonstrates that 10% more of these zones are distributed geographically according to the recommendation. The power distribution network installations may be used more effectively if there are more zones with this load factor value. Additionally, in areas with a modest flow of electric vehicles, the suggested solution demonstrates an average 319 kW peak demand decrease to match customer demand for charging. For every situation examined, this is accurate. Future connections of charging stations to the power network for distribution with lower financial outlay would be made possible by this peak-demand drop. As a result, by finding public charging locations where the overall number of chargers per station is larger while the charging facilities are operational, the proposed technique can assist the general public and private agents in spreading electric mobility.

Zhang, Y. et al. (2023) [42] Reviewing the installation of electric car charging infrastructure is essential to increasing the range of these vehicles. The Mixed Integer Linear Programming (MILP) approach is often used in studies on the deployment of charging infrastructure in order to achieve a variety of goals. However, the time required for computation and memory requirements of MILP models grow exponentially with the number of integer variables and constraints. Because of this, using MILP models to large-scale optimization issues is not feasible. The Planning of Electric Vehicle Charging Stations (PEVCS) problem is an NP-complete combinatorial optimization problem, as we outline and demonstrate in this study. We also demonstrate the important effect of PEVCS, namely sub modularity. Additionally, we suggest two effective techniques that leverage submodularity to enhance the traditional PEVCS methodology. Moreover, we offer a verifiable assurance on the efficacy of our suggested techniques. The outcomes show the effectiveness and effectiveness of these techniques are for both small- and large-scale datasets, particularly in practical large-scale scenarios. Government subsidies and the California electric vehicle (EV) law, which mandates the phase-out of new gasoline-powered vehicles by 2035, are significant milestones toward the widespread adoption of EVs. Even though EV charging infrastructure is continually being installed across the US, the biggest barrier to mainstream EV adoption is still its unequal distribution and lack of infrastructure.

Loni, A et al. (2023) [43] explores social equity access, the amount of EV charging demand satisfied, and site development costs (installation, building, and operation) to offer an innovative, data-driven solution for San Francisco's charging station placement and size. San Francisco is home to the first 200 potential EV charging stations, making it a member of an early generation. The demands of EV charge demand, social equity access, and site development costs are balanced before determining the optimal locations, sizes, and types of charging stations. The Non-dominated Sorting Genetic Algorithm-II (NSGA-II) addresses a variety of multi-objective optimization (MOO) problems, including the kind, size, and positioning of EV charging stations. To extract the best answer from the Pareto-optimal front, the Technique for Order of Preference by Similarity to the Ideal response (TOPSIS) is ultimately employed. The northwest, west, and center areas of San Francisco are viable locations for charging stations for energy service providers and station owners to locate them. After balancing factors including guaranteeing the largest degree of social equality access, optimizing EV demand coverage, and reducing site construction costs, this choice is determined

Shah, T. H et al. (2023) [44] explains how the unanticipated spike in the price of fossil fuels in 2022 seriously jeopardized the cheap transportation sector. The transportation sector is expected to double in size by 2050, which would cause a number of problems such environmental pollutants and the depletion of fossil fuels. As an outcome, there is a global push to produce energy from conventional and carbon-free sources and electrify transportation. Owners of electric cars thus need easy access to the nation's network of charging stations. In order to create grid-connected photovoltaic (GCPV) systems for electric vehicle charging stations (EVCS), this study examines the rooftops of fuel pumps that are currently in place. It also looks at the design and operation of Pakistani cities. A description of the GCPV EVCS mathematical model has been provided. Three Pakistani cities—Islamabad, Lahore, and Multan—have EVCSs. These EVCSs are powered by the electric grid and solar energy. Software called System Advisor Model (SAM) was used to compare each city's techno-economic performance metrics. Sensitivity assessments were carried out in each of the three Pakistani cities that were identified in order to understand how uncertainty affected the GCPV EVCS's functionality. Pakistan will be able to meet the Paris Agreement's emission reduction requirements with the help of this plan

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Bilal, M et al. (2023) [45] By giving customers reliable electricity, research on renewable energy technologies has had a long-lasting effect on the global electrical business. One of the most important research areas in developing countries is the use of renewable energy sources to meet the load needs of electric vehicle charging stations. This study examines the economic and technological viability of renewable energy and grid integration for an environmentally sustainable electric vehicle charging station in three distinct regions of India. The arrangement being presented to satisfy the charging needs of the electric car load is subjected to an economic analysis. The architecture of the system facilitates the flow of electricity between the grid network and other components of the energy system. The locations that are picked are oriented so that the wind and sun face opposing directions. Every station has different operating hours for charging electric vehicles. Using a novel metaheuristic-based optimization algorithm, i.e., modified salp swarm algorithm, the optimal sizing of the system component is carried out to minimize the levelized cost of electricity as well as total net present cost while keeping the probability of power supply failure within acceptable limits. New Delhi has a reduced levelized cost of power of $0.0051/kWh and a lower overall net current cost of $18453.63 because to the projected system's performance. A 325 W wind turbine and 120 solar panels would be the ideal configuration to satisfy the demand for electric vehicles in the New Delhi region. The optimal hybrid system design comprises of 64.5% wind energy, 33.5% solar energy, and 1.94% grid purchase, with an annual power generation of 5,91,117 kWh. Similarly, the best estimates of Ahmedabad's total net present cost and levelized cost of electricity are 222762.80 $ and 0.023 kWh, respectively. The Madurai area has a 37.44% higher total net current cost than the New Delhi region and an 8.17% higher levelized cost of energy. The proposed approach may lessen reliance on the overcrowded grid, particularly in poorer countries.

Meng, W. et al. (2024) [46] The effective management of these quickly growing electric vehicle facilities has become a challenging undertaking because of the great level of uncertainty surrounding electric vehicles, charging station pricing strategies, and the integration of these facilities with distribution networks. To address these problems, this study proposes a two-phase strategy for energy management at charging stations. In the first step, a resource allocation model that considers the profitability of distribution networks, charging stations, and electric vehicle customers is built based on the total possible power areas of charging stations. The data-driven method and Minkowski summation work together to minimize processing burden and preserve the privacy of electric car data while acquiring the aggregate viable region. The second stage of development uses a novel hierarchical pricing approach that includes the retail energy price between charging stations and electric car customers as well as the clearing price between distribution networks and charging stations. Notably, charging stations engage in the aggregate viable power region-based power clearing of dispersed networks, and users of electric vehicles and charging stations agree on a two-phase robust pricing scheme. Lastly, the model is optimized using a distributed organizing technique that has a physically understandable interpretation. The simulation findings show that charging stations using the recommended aggregation technique may make at least 1.76 percent more money overall than they would if they used three other ways. Because of the hierarchical pricing system, charging stations can potentially earn total economic profits 18.60% and 2.94% more than in the centralized dispatch and price-taker modes, respectively. This pricing structure also reduces running expenses for the dispersed network by 24.96% and 25.76%.

Zhao, Z.et al. (2024) [47] The objective is to reduce peak demand and even off the overall load on the power grid by evaluating the challenge of scheduling electric vehicle (EV) charging for public EV charging stations (EVCSs) that can handle a variety of charging needs. A two-level hierarchical charge scheduling strategy, including an online booking system (OBS) and a pricing-based charging control system (PCCS), is offered in contrast to previous research that primarily focuses on a single scheduling approach. In particular, the introduction of OBS can cause bookable chargers' service capacity to decrease, even if PCCS might help move charging demand from peak to off-peak hours. To better simulate the actual charging process, the model additionally accounts for the nonlinear charging profile of the battery. To find the best scheduling choice, a deep reinforcement learning (DRL) based method is created. When deep Q-network (DQN) and deep predefined policy gradient (DDPG) are combined, it becomes possible to handle the hybrid action space, which consists of both discrete and continuous actions. An extensive battery of tests is conducted to evaluate the performance of the developed two-level scheduling method. The findings demonstrate that the suggested technique increases scheduling efficacy by 6.7% to 49.44% when compared to single-strategy alternatives.

Amir, M et al. (2023) [48] analyzed in light of the increasing ubiquity of solar-powered electric vehicle (EV) charging stations and distributed generation (DG) in power system networks. In order to sustain the batteries' state of charge (SoC) throughout the discharge phenomenon, the distribution grid must overcome a variety of obstacles brought about by peak EV demand and intermittent solar irradiation. The paper provides a coordinated control system for photovoltaic (PV)-based EV charging stations based on an intelligent energy management system (IEMS). The suggested IEMS analyzes load demand and real-time weather data to optimize PV generation and grid power utilization for EV charging stations (EVCS). By facilitating the flow of electricity between PV generating, the distribution grid, and EV battery storage, the coordinated activities of the EMS reduce peak power demand by a factor of two. Adaptive neuro-based fuzzy control system also predicts demand for electric vehicle loads and solar energy generation to optimize IEMS according to the Indian power scenario. In order to minimize system losses and minimize peak power consumption as well as the burden that EV charging places on the distribution grid, the suggested IEMS effectively makes use of the buffer battery system. The results are examined and confirmed using a digital simulation model and a real-time hardware-in-loop experimental setup.

Geetha, B. T. et al. (2023) [49] recommends employing a hybrid EOO-QNN approach to distribute capacitors and electric vehicle charging stations (EVCS) throughout distribution networks (DS). Quantum Neural Network (QNN) and Eurasian Oystercatcher Optimiser (EOO) are merged in the suggested hybrid technique. It is hence referred to as an EOO-QNN method. The fundamental goal of the EOO-QNN algorithm is to regulate the capacitors in order to decrease active power loss, raise net gain, and preserve the voltage profile. The QNN is used to predict the optimal control signal for the converter, and the EOO technique is used to generate solutions for power loss issues while enhancing the distribution network's reliability. By then, MATLAB is used for implementing the suggested way and compare it with other already-in-use techniques. The EOO-QNN technique outperforms all other methods, including Scalp Swarm Algorithm (SSA), Wild Horse Optimizer (WHO), and Particle Swarm Optimization (PSO). The results of the simulation demonstrate that the EOO-QNN strategy has a higher voltage than other methods currently in use. According to the simulation study, the suggested approach, which is based on a high voltage of 500 V, is more than other approaches now in use. The outcome demonstrated that the EOO-QNN approach yields a greater voltage than other approaches.

Balu, K et al. (2023) [50] proposes that in order to get more real power from the distribution substation, EV battery swapping stations (EVBSSs) and charging stations (EVCSs) should be included to the radial distribution system (RDS). This work suggests a unique method for figuring out where to best position EVCS and EVBSSs in the RDS. In addition, the EV charger has been modeled as a constant current load. When analyzing the effects of EVCS/EVBSSs demand on the voltage profile, real power loss, total voltage deviation, energy loss cost, and overall operating cost of the RDS, constant power (CP), industrial (IL), residential (RES), and commercial (COM) load models have all been taken into account. To mitigate the effects of the EVCS/EVBSS(s) load and increase the network's stability and self-sufficiency, the integration process of distributed generations (DGs) of the ideal size and at the right location within the RDS is necessary. Additionally, non-dispatchable solar photovoltaic (SPV) and wind turbine (WT) units are converted into dispatchable SPV and WT units (i.e., SPV-BES and WT-BES) by the usage of battery energy storage (BES). This study work offers a unique chaotic student psychology based optimization (SPBO) (CSPBO) method to find the optimal size and position of biomass, WT-BES, and SPV-BES in IEEE 33-bus and actual Brazil 136-bus RDS for CP, IL, RES, and COM load models respectively. This method takes into account not just the average hourly variation in the generating profile but also the The results obtained on benchmark test problems demonstrate that chaotic maps are useful in significantly enhancing the speed of convergence, mobility, and avoidance of local optima of the SPBO algorithm. The results show that it would be possible to achieve the desired level and placement of distributed generation (DGs) in the RDS. The outcomes of the suggested CSPBO approach are contrasted with those of SPBO and Harris Hawk's optimization technique. The results that have been acquired will surely help the electric vehicle and distribution industries improve the efficiency and dependability of the system.

The objective of **Pellegrini, A. et al. (2023) [41]** attempts to comprehend the elements that influence household decisions to set up infrastructure for charging electric vehicles at home. To achieve this, we picked 1,199 residences from throughout the Australian state of New Testament South Wales and issued an online survey to each of them. Every home was obliged to participate in one of two discrete selection experiments (DCEs). The DCEs were created especially for the type of property that the respondents who were recruited lived in: either an apartment inside a complex of buildings or a privately owned house. The data gathered from the two DCEs is analyzed using the Logit Mixed Logit model (Train, 2016), a non-parametric variation of the classic random effects discrete choice model. The empirical findings show that both of the researched groups highly regard the opportunity to install EV home charging stations on their properties, with apartment occupants indicating that they would rather have access to private charging than community charging.

A. Problem Identification

Complementary and sustainable modes of transportation gain appeal over traditional modes of transportation as the need for renewable energy rises. Electric cars, or EVs, are an efficient alternative that manufacturers, researchers, and the government are interested in. An electric vehicle's charging station is comprised of DC/DC power converters and a few storage units with integrated solar energy equipment.

In order to achieve a significant operational change, the controller for these DC/DC converters must be built using optimization algorithms that manage the power flow between the storage units. In order to provide adaptive updating in a continuous mode, the intelligent controller of a converter system must receive the real-time control errors, such as voltage and current faults. The most crucial requirements are therefore those related to algorithm correctness and speed. To lessen reliance on the grid, the research must include more renewable energy sources, such wind power.

III. OBJECTIVES

The objectives associated with the work are as follows:

- To use MATLAB/Simulink to design and simulate a solar energy-based charging station capable of charging multiple electric vehicles (EVs).
- To develop a power flow controller to ensure smooth delivery of power to both the station battery and the EVs, stabilizing the DC common line of the charging station.

- Creating an optimization algorithm for effective power management within the charging station, addressing the challenges posed by variable solar irradiation inputs along with constant input irradiation level.

IV. SIMULATION AND METHODOLOGY

Interest in renewable energy sources and their uses in several industries has grown in recent years. In particular, solar energy has come to light as a viable and environmentally friendly way to power charging stations. In addition to lowering carbon emissions and decreasing reliance on fossil fuels, solar-powered charging stations also provide a dependable and sustainable energy supply.

Developing a solar energy-based charging station involves a complex interplay of various components, including solar panels, batteries, power electronics, and control systems. To design and optimize such a system, engineers and researchers often turn to simulation tools like MATLAB. MATLAB provides a powerful platform for modelling, simulating, and analysing solar energy systems, enabling efficient development and optimization processes.

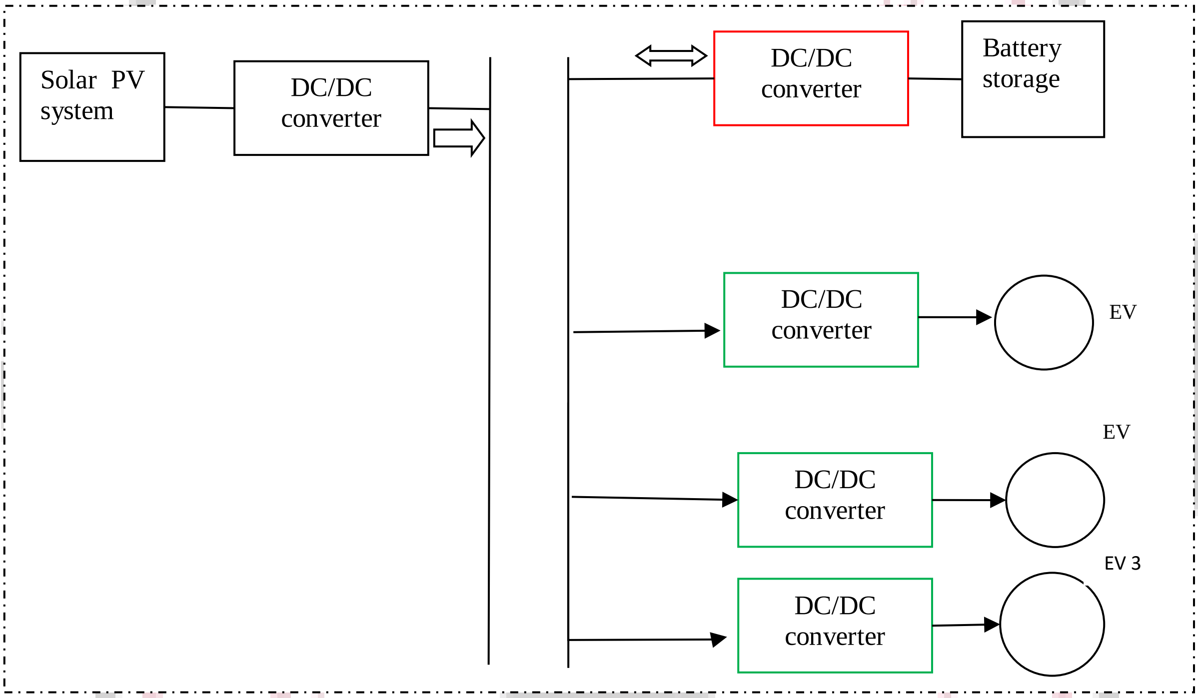

Figure 5 system Architecture designed in MATLAB/SIMULINK

- The term "EV systems" refers to an internet connection of connected local energy hubs with distinct boundaries, control, and management functions. They provide higher-quality operation and a more dependable energy supply to the load centers, enabling bidirectional and autonomous power exchange to prevent power outages. Both onboard and offboard PHEV chargers ought to be fitted in a car.
  • Bi-directional DC-DC converters are DC-DC converters with two quadrants. The input and output current may flow in various directions even when the input signal and output voltage have consistent polarity. The output state of the converter might vary within the dual-quadrant. Both the output and converter input ports on the switch are still able to change the voltage. It is possible for power to go both from input to output and from output to input. It takes quick and accurate control loop computations in addition to complicated PWM drive waveform generation to operate this system in various modes.
  Station Battery Modelling : The most difficult task in creating an appropriate battery model is determining the electrical equivalent representation of a chemical reaction-based battery. A standard battery may be identified by its terminal voltage, which is determined by its state of charge (SOC), and its internal resistance, which is determined by its SOC, temperature, and battery cell age. The internal voltage (voltage source), internal resistance (Rint(s, SOC), and terminal voltage (UDC) are all dependent on the state of charge (SOC) of the battery. One way to describe the terminal voltage is as in

$$U_{DC} = U_{max} * SOC + U_{min} * (1 - SOC) - I_b * R_{int}$$

- where, U_{max} = Fully charged battery voltage
- U_{min} = Fully discharged battery voltage
- I_b = Battery current
- R_{int} = Internal resistance

The Bidirectional DC-DC Converter is a device that modifies the DC voltage on both sides of the converter to the other. The modality depends on a gate signal generator and controller attached to the converter. It functions as a buck converter in the second mode and a boost converter in the first. In the buck mode, it lowers the bus voltage to match the voltage of the battery that needs to be charged, and in the boost mode, it raises the voltage and converts it to the bus. A bidirectional DC-DC converter is helpful for alternating between different types of energy storage, such in electric cars. To manage the battery current during charge and discharge operations, a PI controller is installed, and the reference value of the current is positive for charging operations, and negative value for discharging operations.

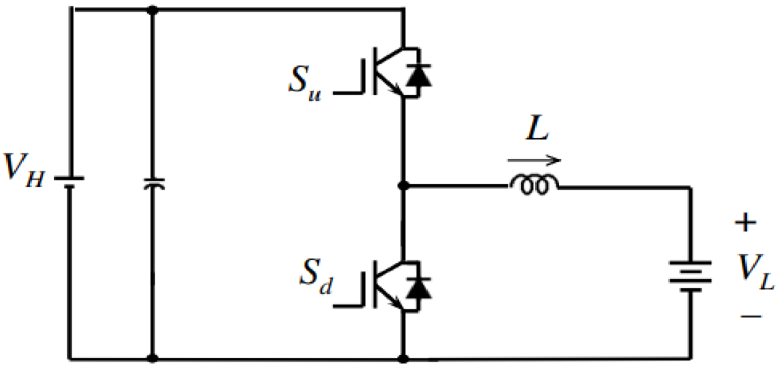

Figure 6 : Bidirectional buck-boost Converter Circuit

The location of the additional energy storage allows bidirectional dc-dc converters to be classified as either boost or buck kinds. Whereas it should be on the low voltage side for the boost type, energy storage for the buck type should be on the high voltage side. Double-sided power flow in bidirectional dc-dc converters is achieved by the switch cell's ability to conduct current in both directions. A unidirectional semiconductor power switch, such as a power MOSFET (Metal Oxide Semiconductor-Field-Effect-Transistor) or IGBT (Insulated Gate Bipolar Transistor), in conjunction with a diode is frequently used to build double-sided current flow power switches since they are not easily accessible. The buc Buck and boost variations are made possible by the exact location of the additional energy storage on bidirectional dc-dc converters to be identified. Energy storage for the buck type should be on the high voltage side,but it should be on the low voltage side for the boost type.

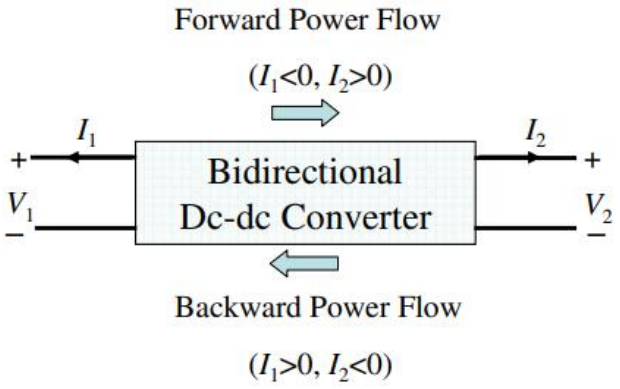

Figure 7: DC-DC converter operational logic block diagram representation

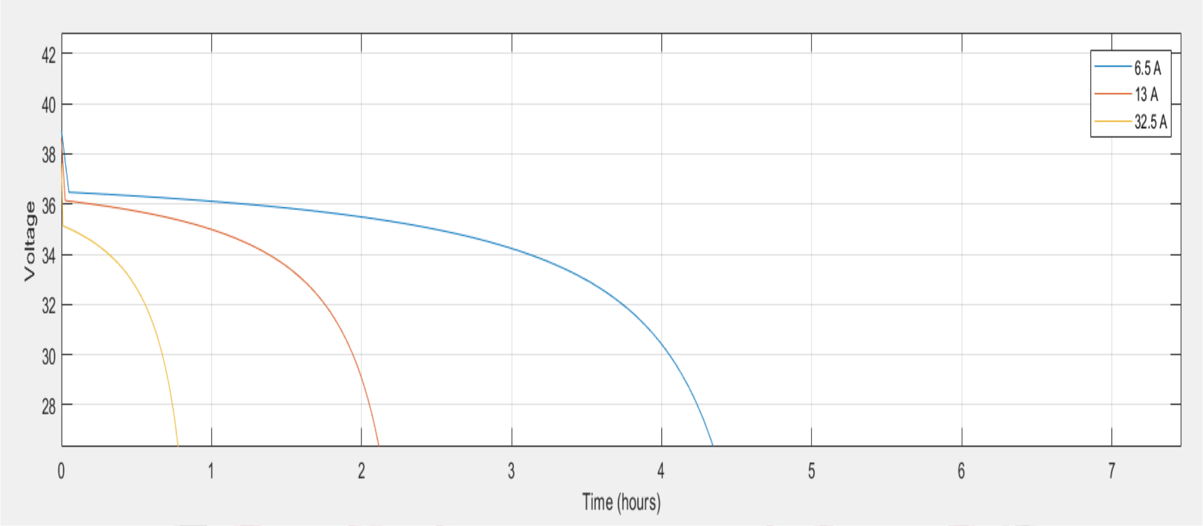

Figure 8: Station battery discharge characteristics for different current values

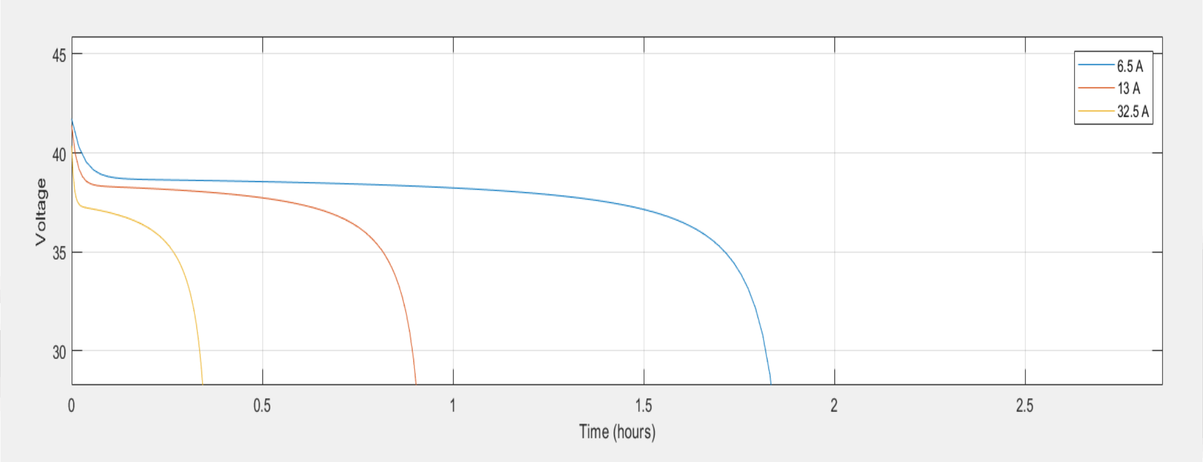

Figure 9: EV battery discharge characteristics for different current values

- **Solar Energy system Modelling in MATLAB**
- 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. A simple equivalent circuit of PV cell is shown in Figure 4.3.
- A cell series resistance (Rs) is connected in series with parallel combination of cell photocurrent (I_{ph}),exponential diode (D), and shunt resistance (R_{sh}) , I pv and Vpv are the cells current and voltage respectively. It can be expressed as:
- $I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$ ..*(4.1)*
- Where:
- I_{ph} - Solar-induced current
- I_S - Diode saturation current
- q - Electron charge (1.6e^{-19}C)
- K - Boltzmann constant (1.38e^{-23}J/K)
- n - Ideality factor (1~2)
- T - Temperature ^{0}K

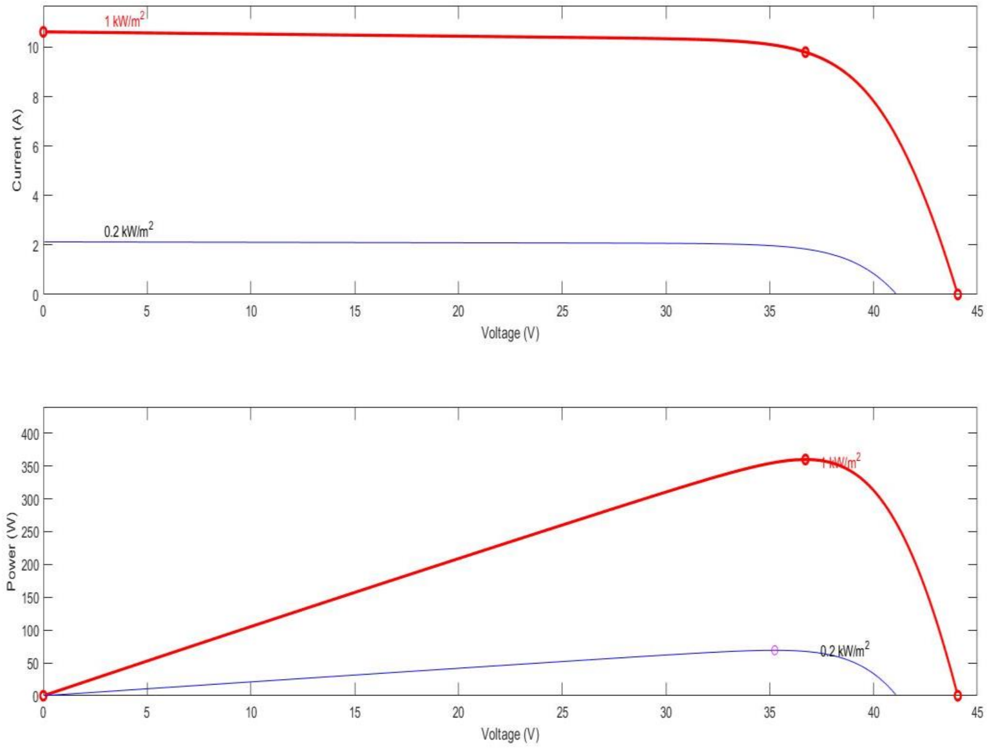

Figure 10: P/V and I/V characteristics of the solar PV array designed in MATLAB

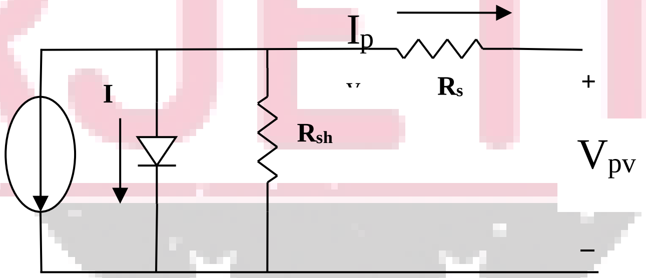

Figure 11 Equivalent circuit of solar pv cell

- The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:
- $I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000}$ ..*(4.2)*
- Where:
- I_{SC} Short-circuit current of cell at STC
- k_i Cell short-circuit current/temperature coefficient (A/K)
- I_r Irradiance in w/m 2
- T_c ,T_r Cell working and reference temperature at STC
- A PV cell has an exponential relationship between current and voltage and the maximum power point (MPP) occur at the knee of the curve as shown in the Figure 12.

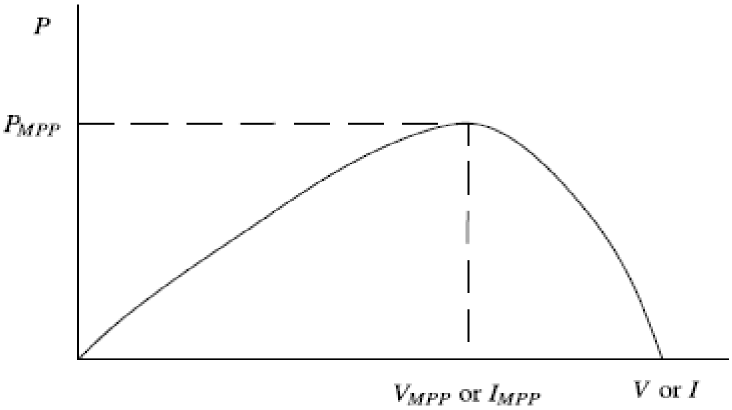

Figure 12 Characteristic PV array power curve

V. RESULTS AND DISCUSSION

With the growing adoption of electric vehicles (EVs), the demand for efficient and sustainable charging infrastructure has surged. One of the most promising solutions to meet this demand is the integration of solar energy systems with EV charging stations. This approach leverages renewable energy, reducing dependence on the grid and minimizing the carbon footprint of EV charging. Solar Panels are the primary source of renewable energy. Solar panels capture sunlight and convert it into electrical energy through photovoltaic cells. The efficiency of these panels is critical to the overall performance of the charging station. The electricity generated by solar panels is in direct current (DC) form. Power converters, such as inverters, are used to convert this DC electricity into alternating current (AC) if needed, as most EVs and grid connections operate on AC. Batteries are used to store excess solar energy. This stored energy can be used to charge EVs when solar generation is insufficient, such as during nighttime or cloudy days. Energy storage ensures a consistent and reliable power supply. Charging Controllers manage the flow of electricity between the solar panels, batteries, and EVs. They ensure that the batteries are charged efficiently and prevent overcharging or deep discharging, which can damage the batteries. EV Charging Points are the actual interfaces where EVs are connected for charging. They come in various types, including standard AC chargers and fast DC chargers, depending on the speed and power requirements. Efficient power conversion and control are crucial for effective utilization of solar energy in charging stations. MATLAB's Power Electronics offers a range of modeling and simulation capabilities for designing power converters, such as DC-DC converters, which are essential for connecting the solar panels, energy storage, and charging infrastructure. Designing and optimization of converters is done in the work these based on various parameters like efficiency, voltage regulation, and power quality. The work has been divided into two cases:

- Case 1: Analysis of the Solar based Charging station (CS) at irradiation input of 1000 W/m^2
- Case 2: Analysis at variable inputs to the Solar based Charging station
- The analysis has been done by designing two systems. The DC-DC converter is driven by constant current P & O Technique in system 1 and the system 2 is the charging station which is being driven by the Modified Cuckoo Search Algorithm with Chaos Theory (MCSA)

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

The power output of solar panels in this case is typically provided at standard test conditions (STC) of irradiance 1000 W/m^2. Considering the given irradiation input of 1000 W/m^2 solar panels that can generate sufficient power to meet the charging station's requirements. There are three Electric Vehicles (EVs) batteries considered with initial SOC % 20%, 50% and 90%. In this case base paper selected has been validated for standard inputs and outputs parameters.

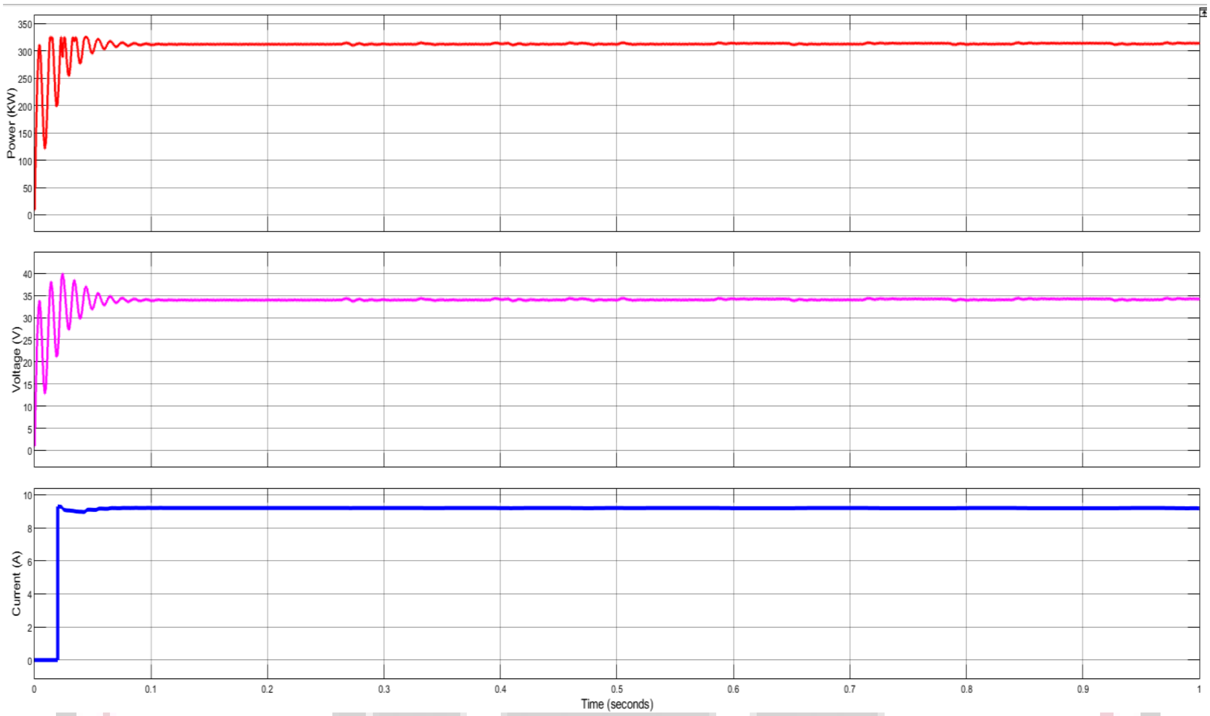

Figure 13 : Solar Power/ Voltage/ Current Output at 1000 W/m^2 in system 1

Figure 13 illustrates the relationship between voltage and current in a solar power system. The graph typically demonstrates how these parameters produce a solar power output of approximately 300 W to 320 W under input conditions of 1000 W/m². This power is effectively distributed across the EV loads and the station battery, charging them via the DC link and ensuring efficient power flow throughout the system.

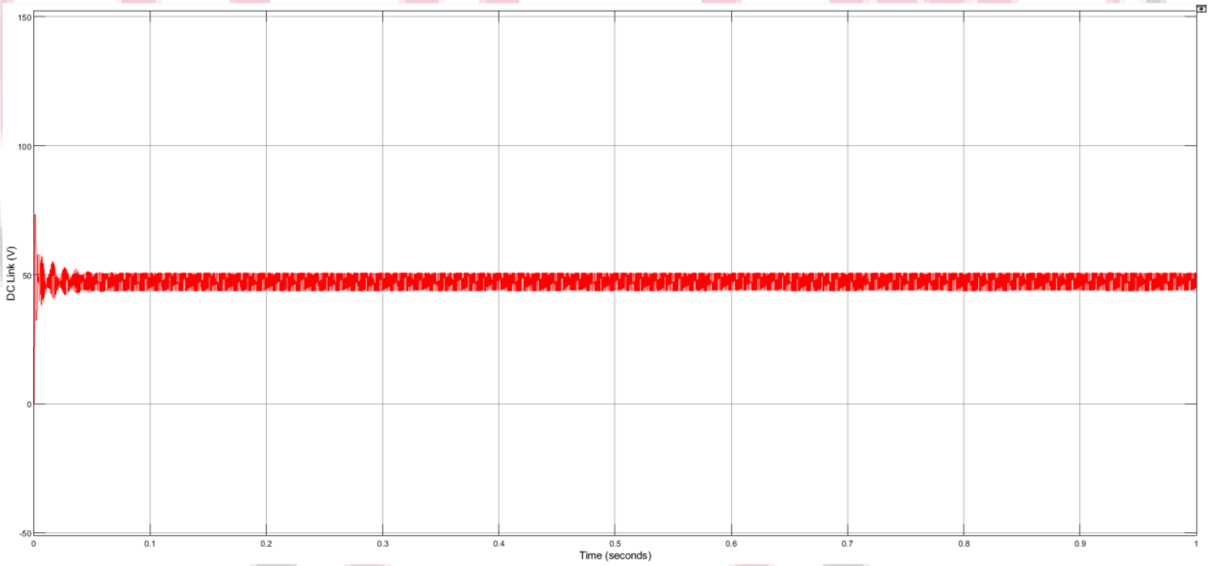

Figure 14 : DC line voltage of the charging station in system 1 when the input irradiation level is 1000 W/m^2

Figure 14 illustrates the variation of the DC link voltage in a charging station over time, given input irradiation levels of 1000 W/m². This voltage is a critical parameter in charging stations, as it determines the voltage available for charging electric vehicles (EVs). In this system, the DC link voltage is maintained at 48V.

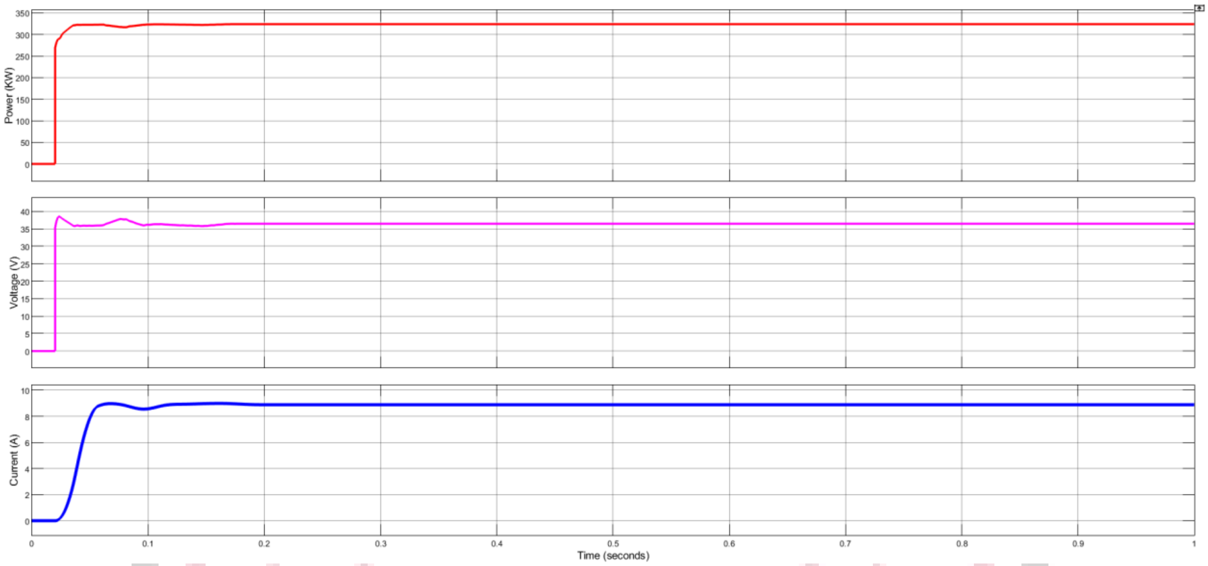

Figure 15 : Solar Power/ Voltage/ Current Output at 1000 W/m^2 in system 1

Figure 15 illustrates the relationship between voltage and current in a solar power system 2. The graph typically demonstrates how these parameters produce a solar power output of approximately 300 W to 320 W under input conditions of 1000 W/m². This power is effectively distributed across the EV loads and the station battery, charging them via the DC link and ensuring efficient power flow throughout the system.

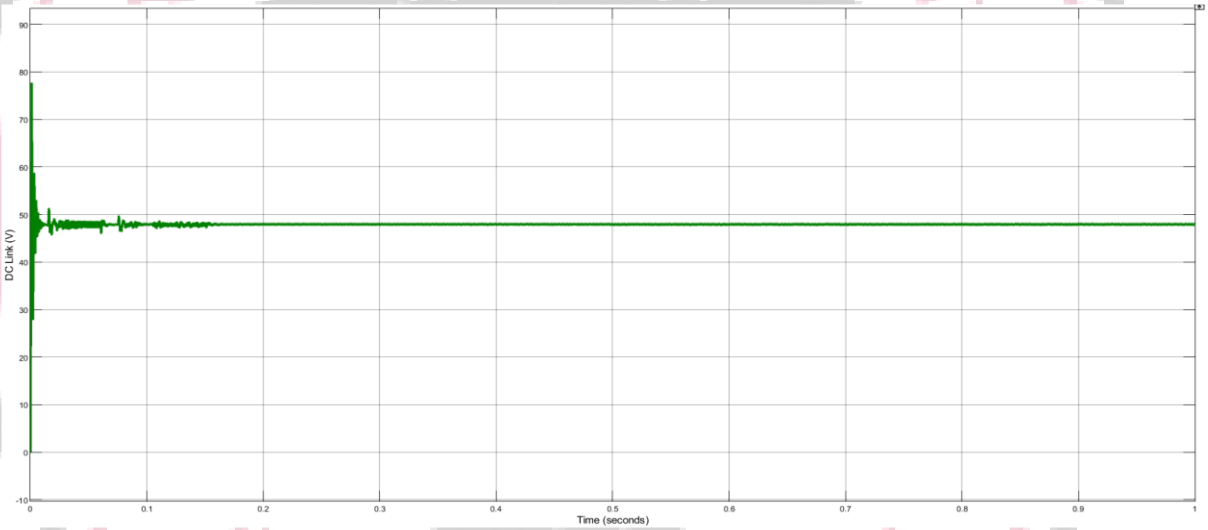

Figure 16: DC line voltage of the charging station in system 1 when the input irradiation level is 1000 W/m^2

Figure 16 illustrates the variation of the DC link voltage in a charging station in system 2 over time, given input irradiation levels of 1000 W/m². This voltage is a critical parameter in charging stations, as it determines the voltage available for charging electric vehicles (EVs). In this system, the DC link voltage is maintained at 48 V and is more stable.

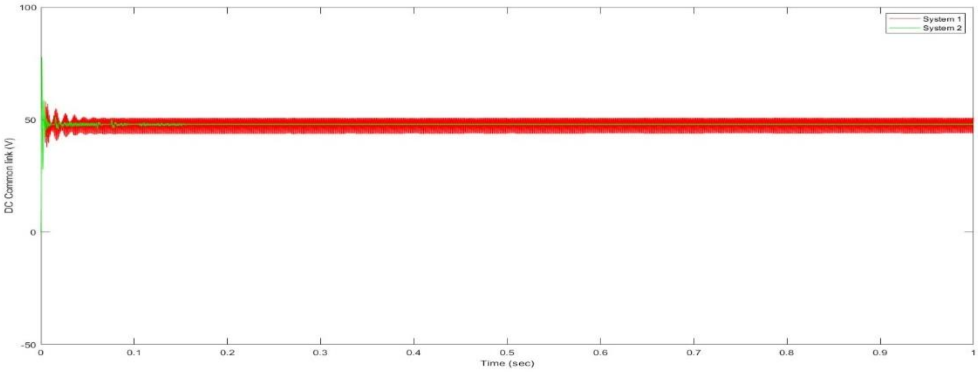

Figure 17: Comparative Analysis of the DC common link voltage in the two systems with constant input irradiation

The figure 17 represents the comparison of voltage output from the CS with controller driven by P&O technique in system 1 and proposed Modified Cuckoo Search Algorithm with Chaos Theory (MCSA) in system 2. The red graphs shows more instability when compared with the green graph representing that the power distribution and voltage line balancing is better achieved by the proposed algorithm.

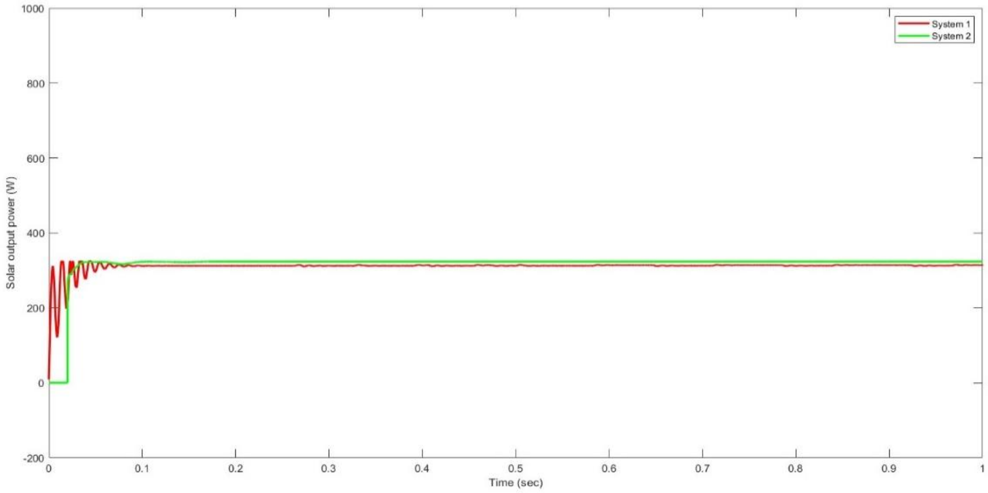

Figure 18: Comparative Analysis of the solar output power in the two systems with constant input irradiation

The figure 18 represents the comparison of solar output from the CS with controller driven by P&O technique in system 1 and proposed Modified Cuckoo Search Algorithm with Chaos Theory (MCSA) in system 2. At the starting point red graphs shows more instability when compared with the green graph which is balanced due the proposed algorithm.

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

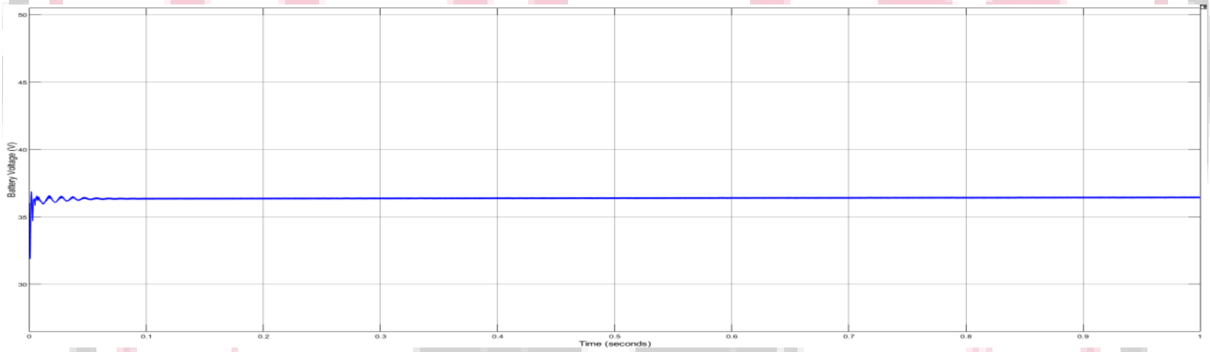

Figure 19: Station Battery voltage in the charging station in system 1 with constant input irradiation

The battery voltage response is a critical parameter indicating the system's ability to store energy efficiently constant irradiation conditions which is presented in figure 19. The performance of the DC-DC converter is driven by P&O algorithm and the overall energy management strategy can be assessed by observing the battery voltage response.

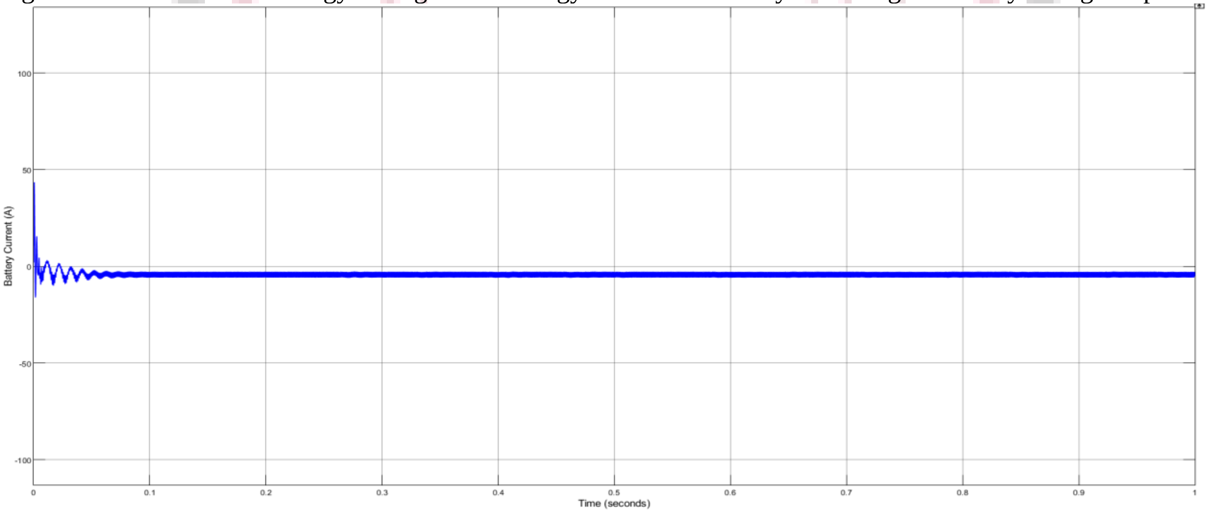

Figure 20: Station Battery current in the charging station in system 1 with constant input irradiation

The current of the station battery is represented by figure 20 for system 1. The battery current is negative representing that the battery is getting charged when the input if 1000 W/m^2 to the solar panels.

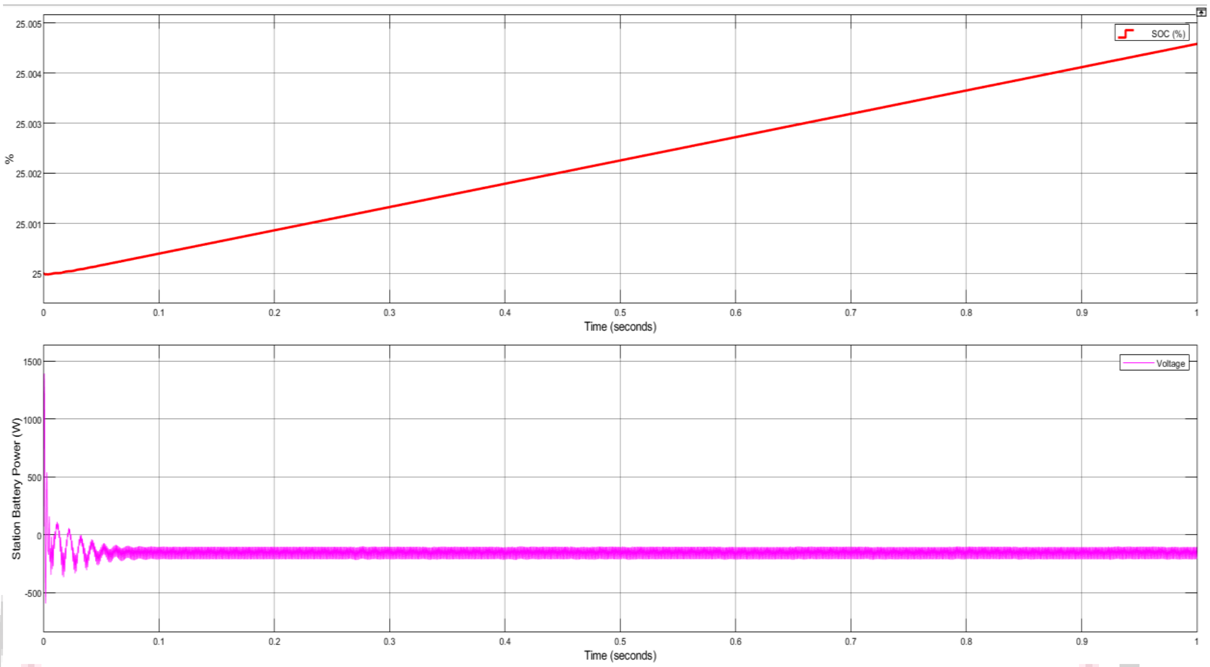

Figure 21: SOC% and Power representation of Station battery in the CS system 1 with constant input irradiation

Figure 21 illustrates the State of Charge (SOC) percentage of the station battery, which increases from 25%, indicating that the battery is being charged by solar power. The corresponding battery power is also indicated which is negative depicting that the battery is getting charged.

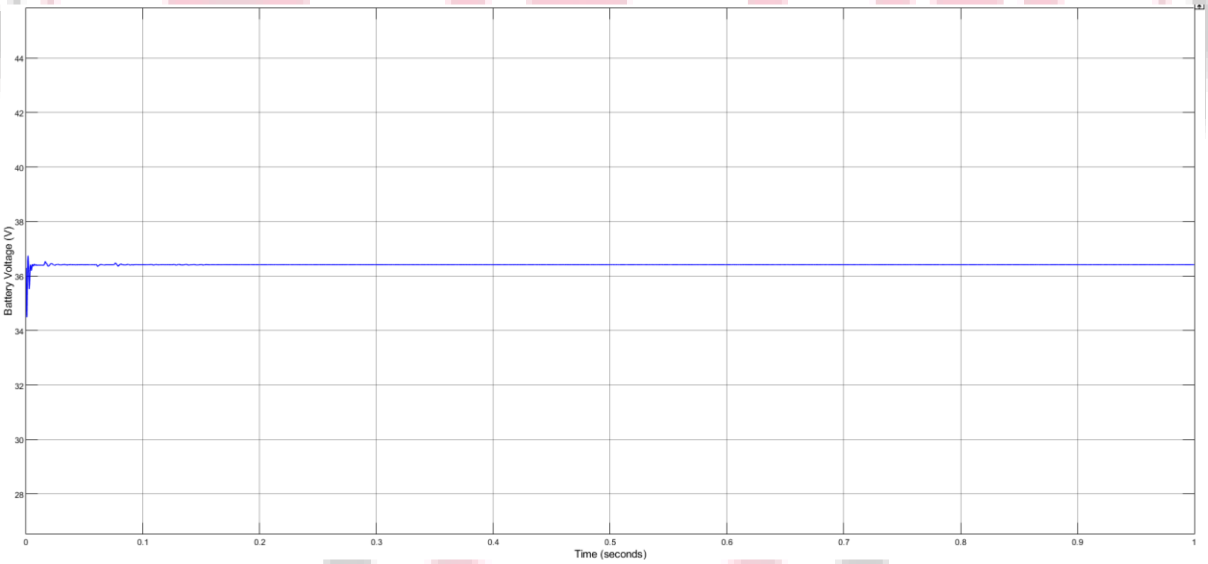

Figure 22 : Station Battery voltage in the charging station in system 2 with constant input irradiation

The battery voltage response is a critical parameter indicating the system's ability to store energy efficiently constant irradiation conditions which is presented in figure 22. The performance of the DC-DC converter is driven by proposed MCSA algorithm and the overall energy management strategy can be assessed by observing the battery voltage response.

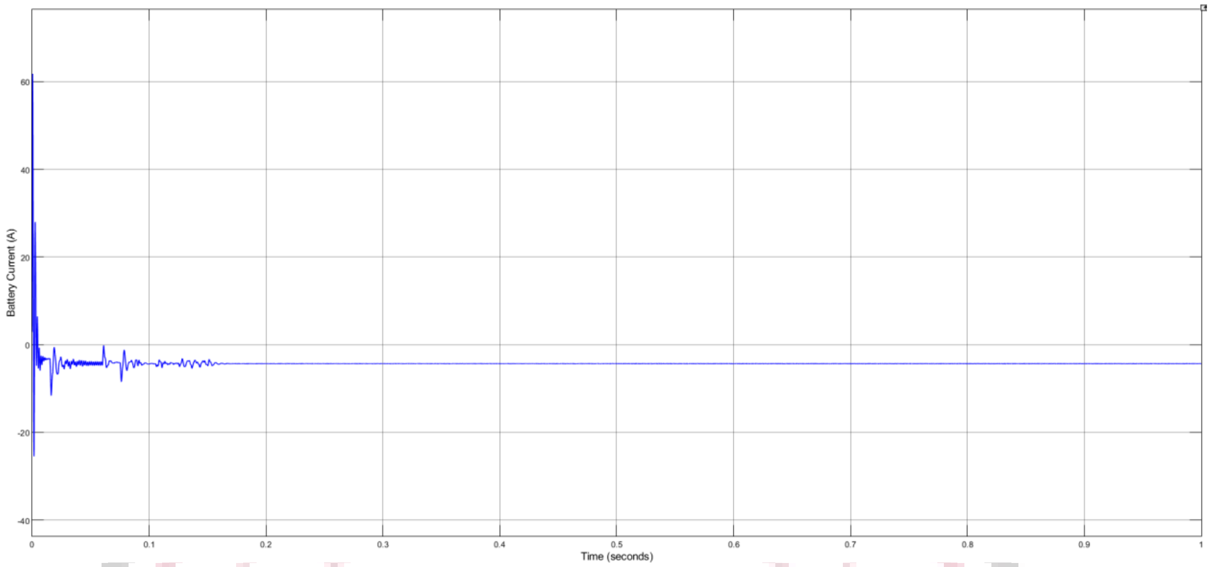

Figure 23: Station Battery current in the charging station in system 2 with constant input irradiation

The current of the station battery is represented by figure 23 for system 2. The battery current is negative representing that the battery is getting charged when the input if 1000 W/m^2 to the solar panels.

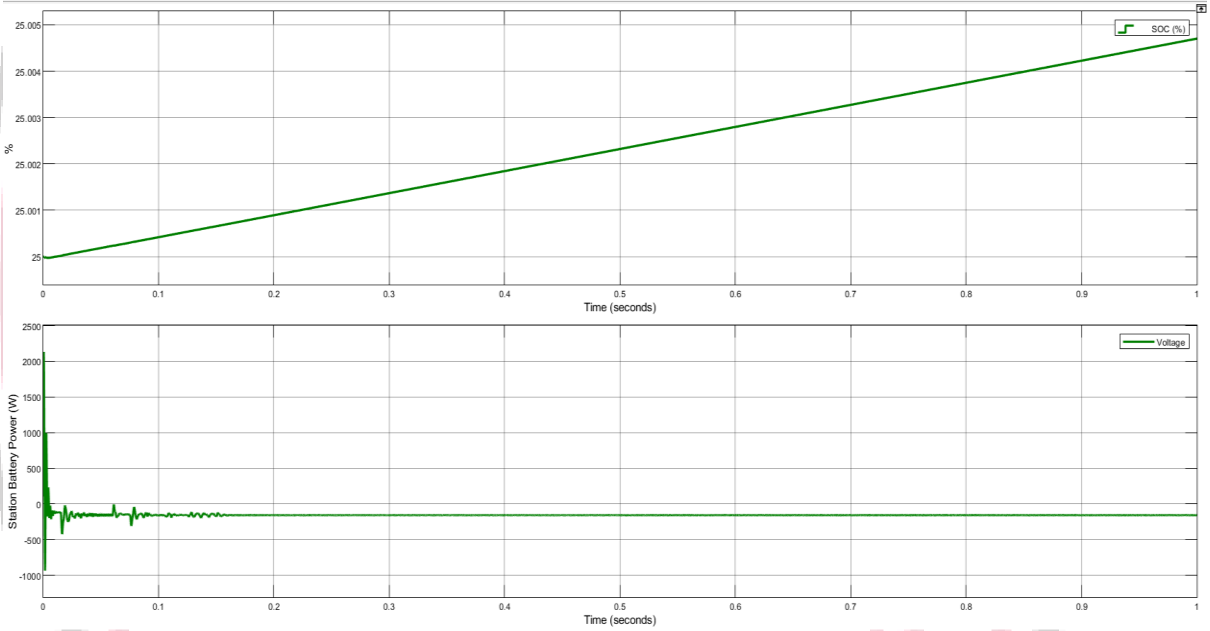

Figure 24 : SOC% and Power representation of Station battery in the CS system 2 with constant input irradiation

Figure 24 illustrates the State of Charge (SOC) percentage of the station battery for system 2, which increases from 25%, indicating that the battery is being charged by solar power. The corresponding battery power is also indicated which is negative depicting that the battery is getting charged.

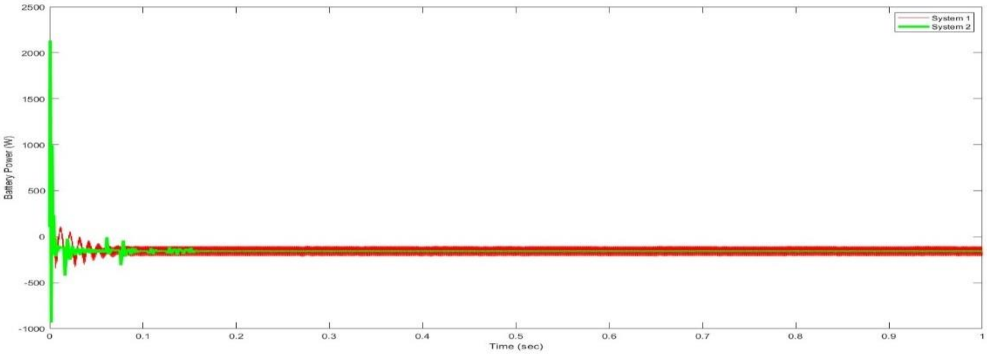

Figure 25 : Comparative Power representation of Station battery in two systems with irradiation input 1000 W/m^2

The figure 25 represents the comparison of power of the station battery with controller driven by P&O technique in system 1 and proposed Modified Cuckoo Search Algorithm with Chaos Theory (MCSA) in system 2. The red graphs shows more instability when compared with the green graph which is balanced due the proposed algorithm

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

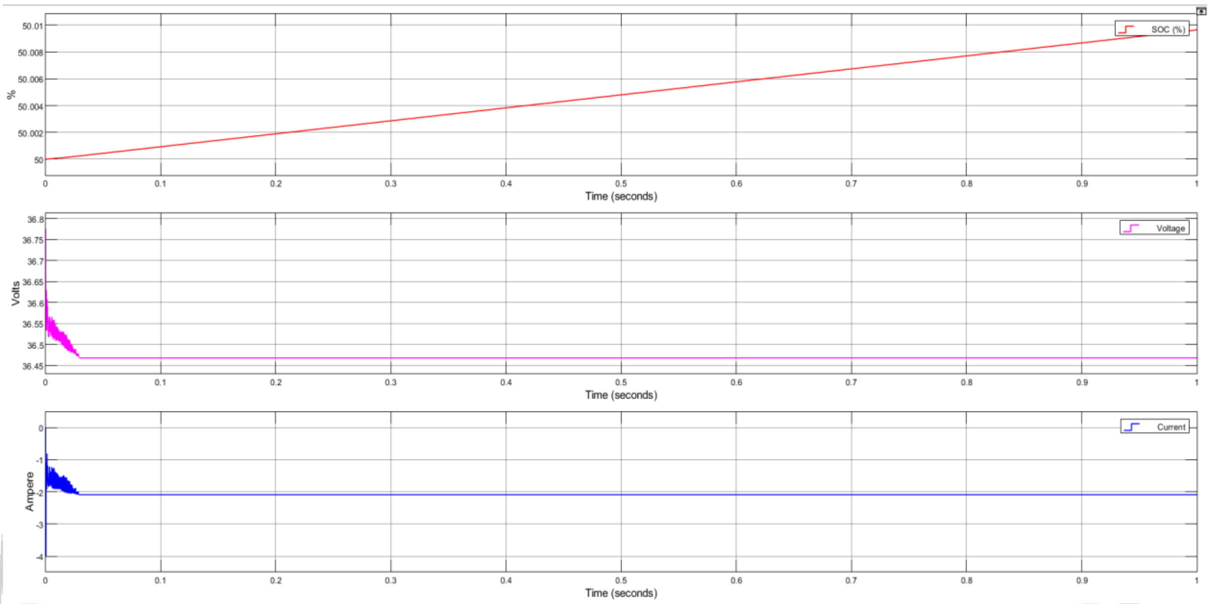

Figure 26: SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 50% in system 1

The figure 26 represents the battery state of charge, voltage and current. SOC is rising showing that the load battery is getting charged in the system 1 rising its SOC from the 50% in the CS with constant maximum input irradiation levels.

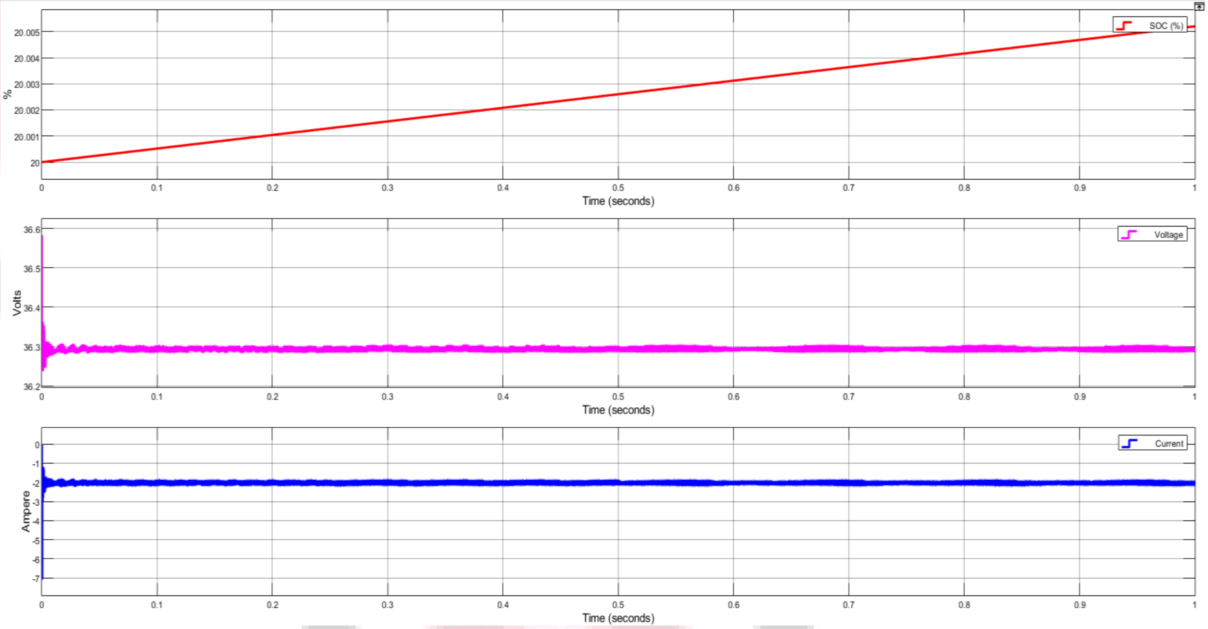

Figure 27: SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 20% in system 1

The figure 27 represents the battery state of charge, voltage and current. SOC is rising showing that the load battery is getting charged in the system 1 rising its SOC from the 20% in the CS with maximum input irradiation levels.

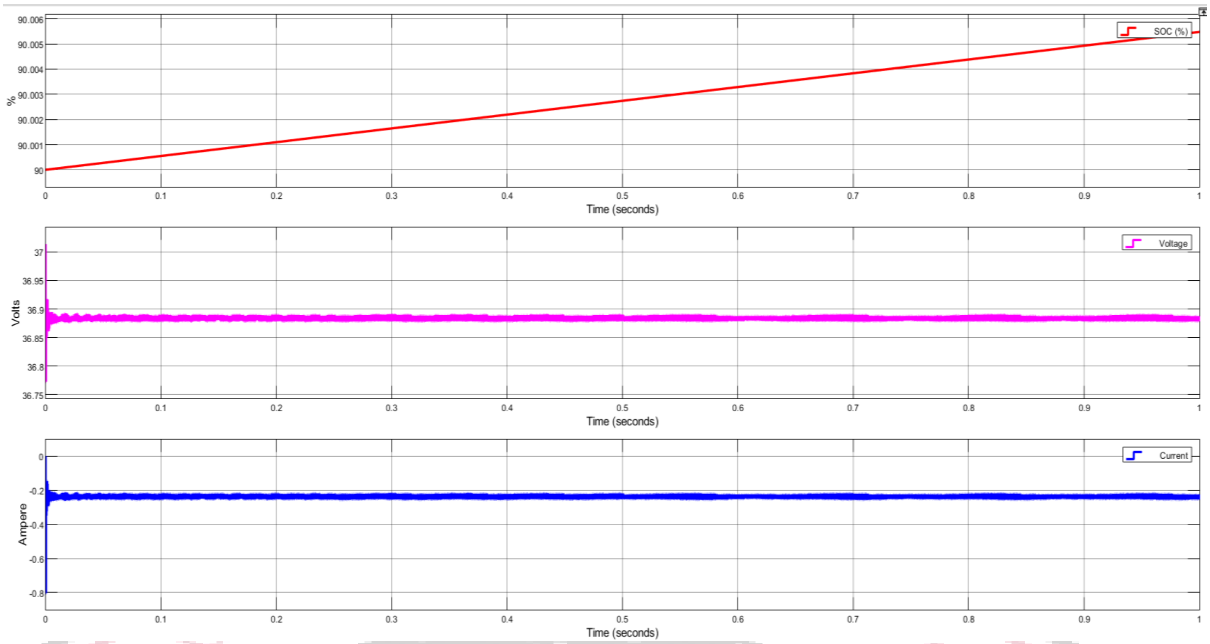

Figure 28: SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 90% in system 1

The figure 28 represents the battery state of charge voltage and current in system 1. SOC is rising showing that the load battery is getting charged rising its SOC from the 90% in the CS with maximum input irradiation levels.

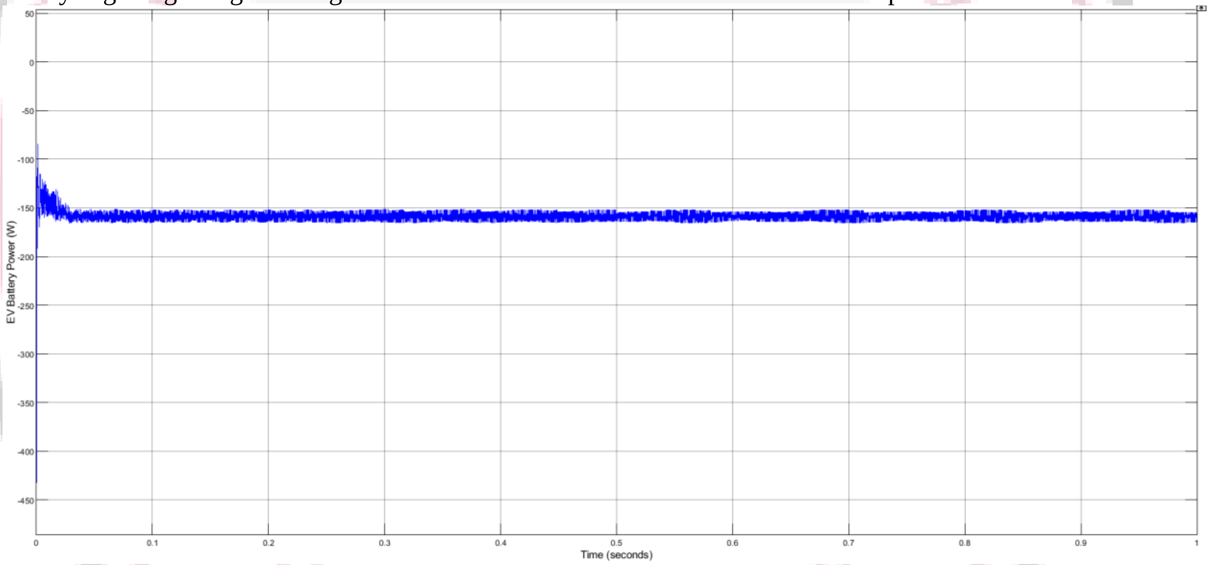

Figure 29: Total load side power of EV battery with initial SOC of different values in the system 1 with 1000 W/m^2

The figure 29 shows the total power required at the load side of the charging station system 1. The total power required by the three EV is approximately 160W which is supplied by the solar energy system.

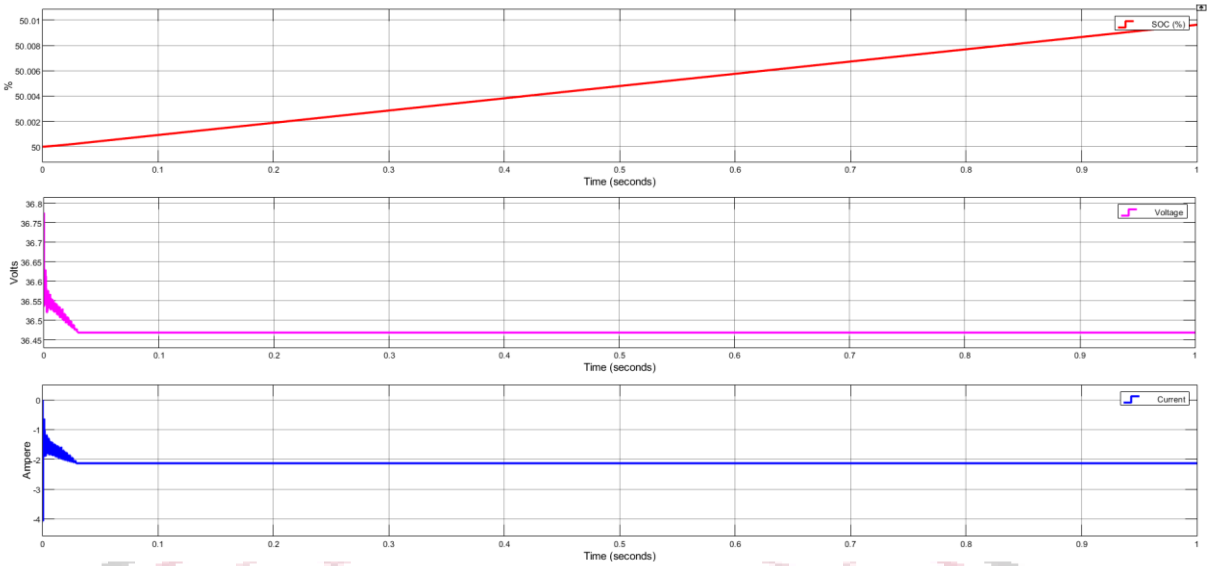

Figure 30 : SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 50% in system 2

The figure 30 represents the battery state of charge, voltage and current. SOC is rising showing that the load battery is getting charged in the system 2 rising its SOC from the 50% in the CS with constant maximum input irradiation levels.

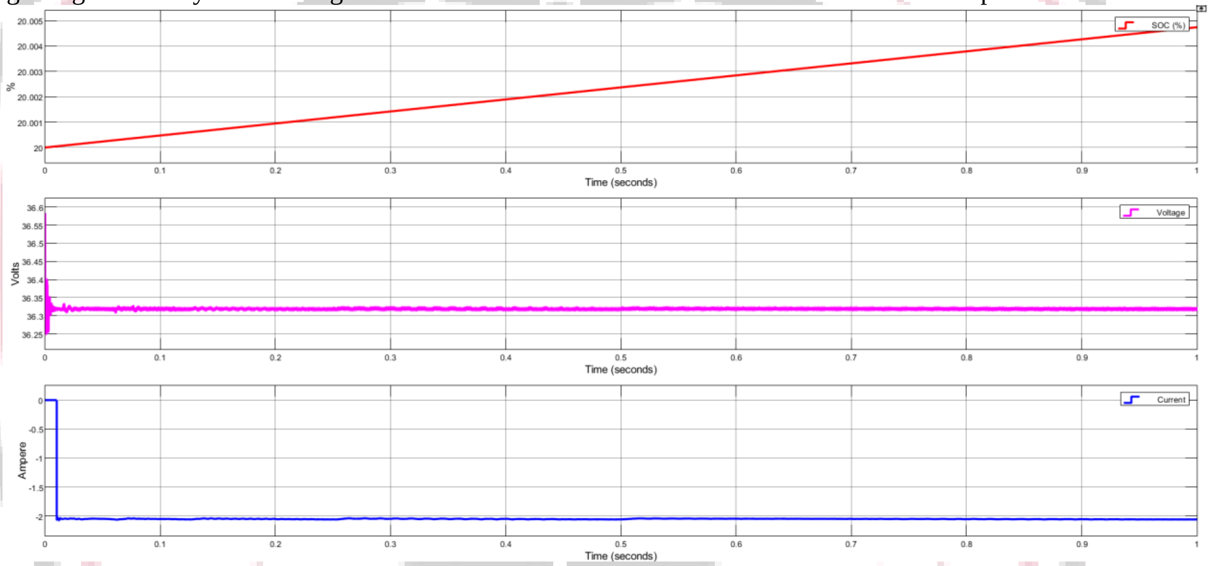

Figure 31 : SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 20% in system 2

The figure 31 represents the battery state of charge, voltage and current. SOC is rising showing that the load battery is getting charged in the system 2 rising its SOC from the 20% in the CS with maximum input irradiation levels.

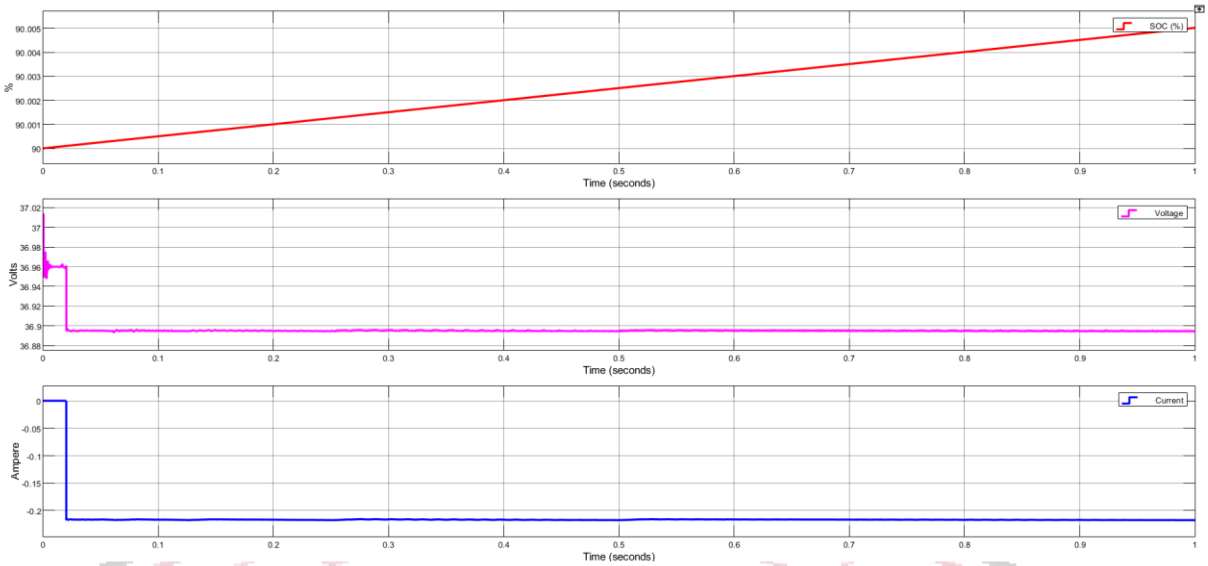

Figure 32 : SOC%/ Voltage/ Current Representation of EV battery with initial SOC of 90% in system 2

The figure 33 represents the battery state of charge voltage and current in system 2. SOC is rising showing that the load battery is getting charged rising its SOC from the 90% in the CS with maximum input irradiation levels.

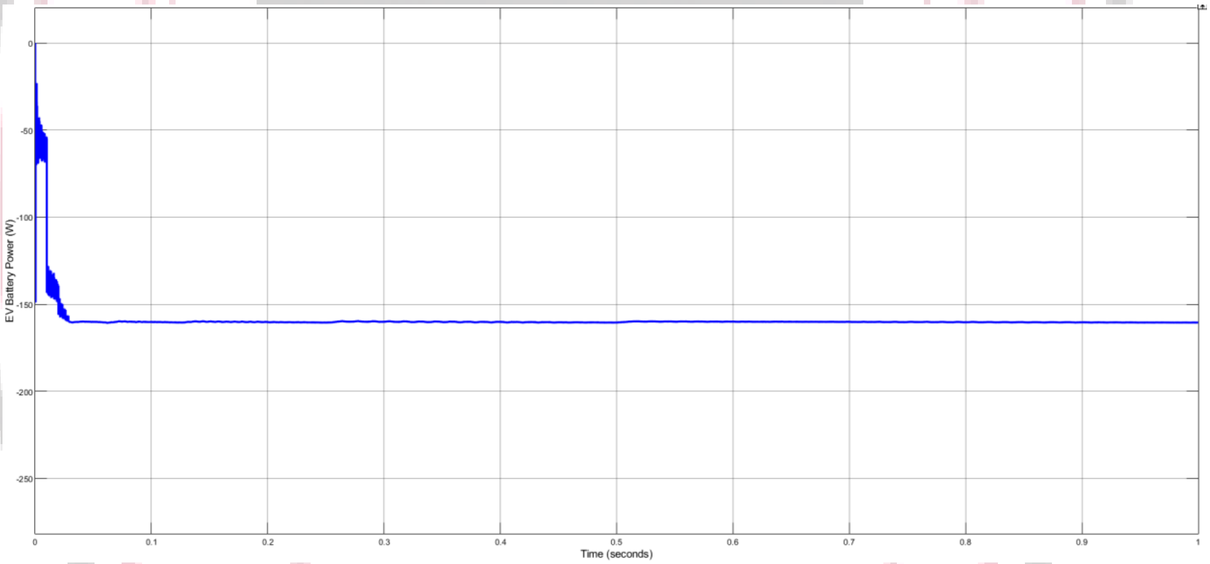

Figure 33 : Total load side power of EV battery with initial SOC of different values in the system 2 with 1000 W/m^2

The figure 33 shows the total power required at the load side of the charging station system 2. The total power required by the three EV is approximately 160W which is supplied by the solar energy system.

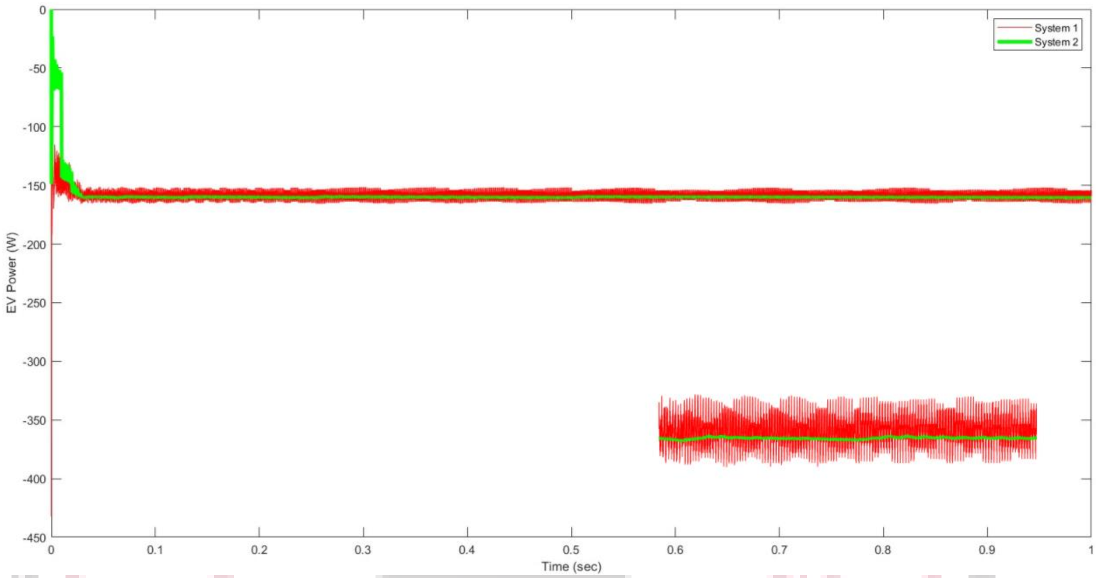

Figure 34 : Comparative Load Power representation of Station battery in two systems with irradiation input 1000 W/m^2

The figure 34 represents the comparison of power of load end with controller driven by P&O technique in system 1 and proposed Modified Cuckoo Search Algorithm with Chaos Theory (MCSA) in system 2. The red graphs shows more instability when compared with the green graph which is balanced due the proposed algorithm depicting that power quality delivered to the load is improved.

B. Variable inputs to the Solar based Charging station

A solar energy-based charging station with an irradiation level of 200 W/m² utilizes solar panels to generate electricity from the available solar radiation, resulting in a power output of approximately 6 W. The direct current (DC) electricity produced by the solar panels needs to be converted and regulated for effective use. This is achieved through power electronics components, such as DC-DC converters. These converters not only transform the DC electricity but also incorporate control functionalities to manage the power flow, ensuring optimal utilization of solar energy. An algorithm is designed to drive these converters, effectively managing the power flow across the charging station.

There are two systems which are being used for controlling the power flow across the charging station. The DC-DC converter is driven by constant current P & O Technique in system 1 and the system 2 is the charging station which is being driven by the Modified Cuckoo Search Algorithm with Chaos Theory (MCSA)

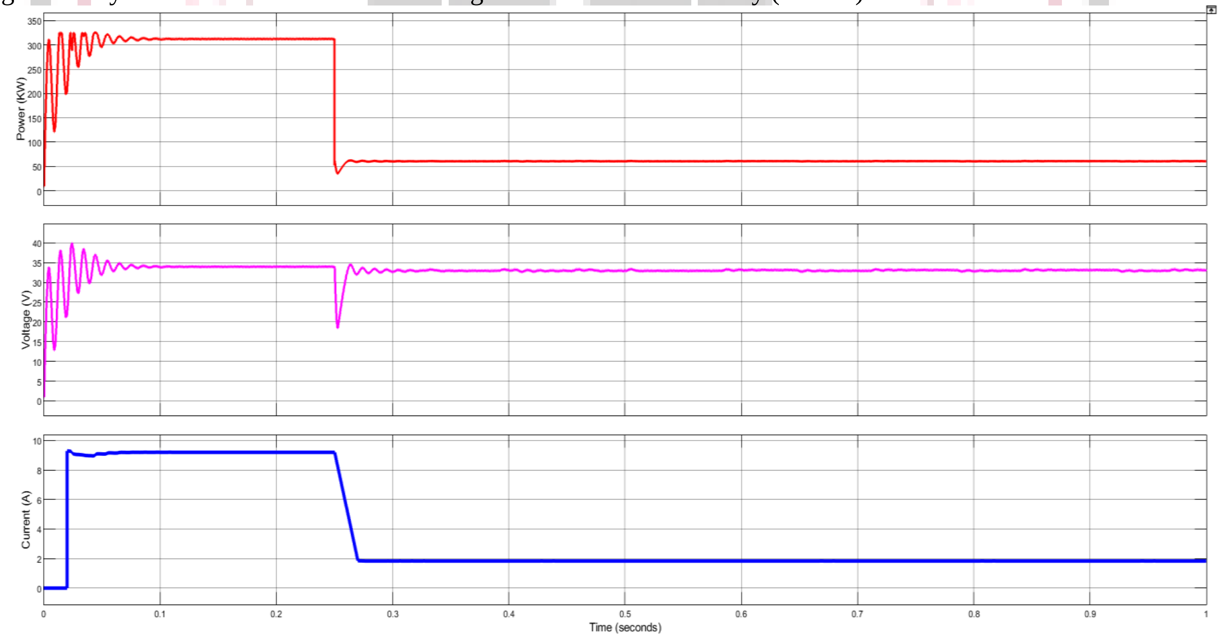

Figure 35: Solar output in the CS in system 1

The figure 35 describe the output from the solar energy system when the irradiation levels are changes from 1000 W/m^2 to 200 W/^{2}. The figures explain the solar output power, voltage and current to the CS where the control of the DC-DC converter is done by P&O algorithm

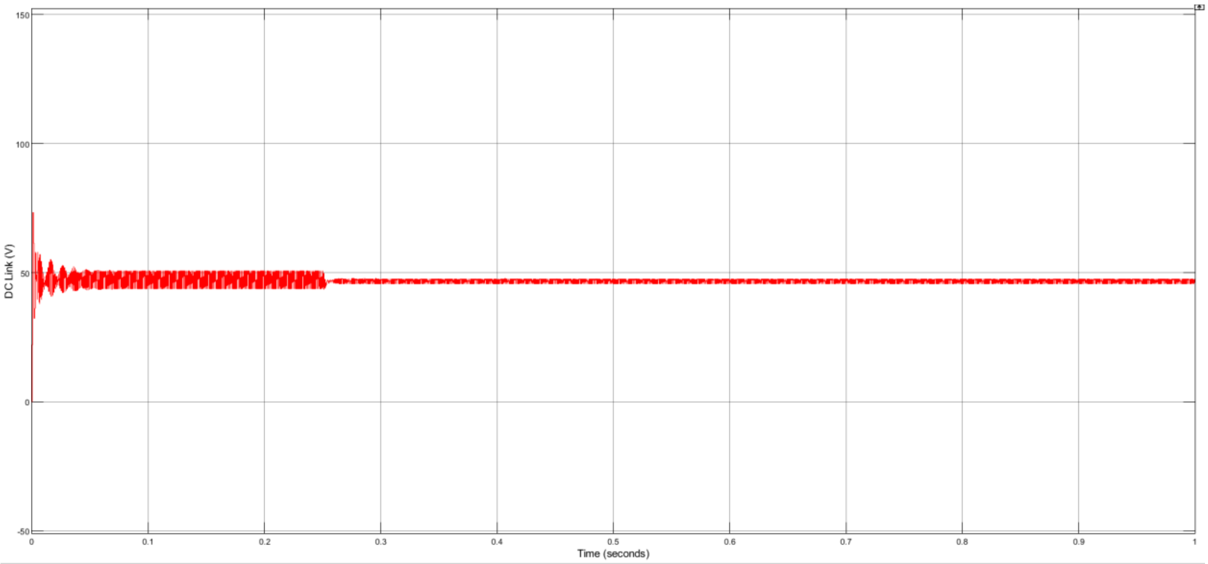

Figure 36 : Common DC link of the CS in system 1

The DC link of the CS feeding power to the loads where the EV are connected in system 1 is represented in the figure 36 . At 0.25 The irradiation levels are reduced showing a change in the line voltage as well. The balancing in this case is done by P&O algorithm

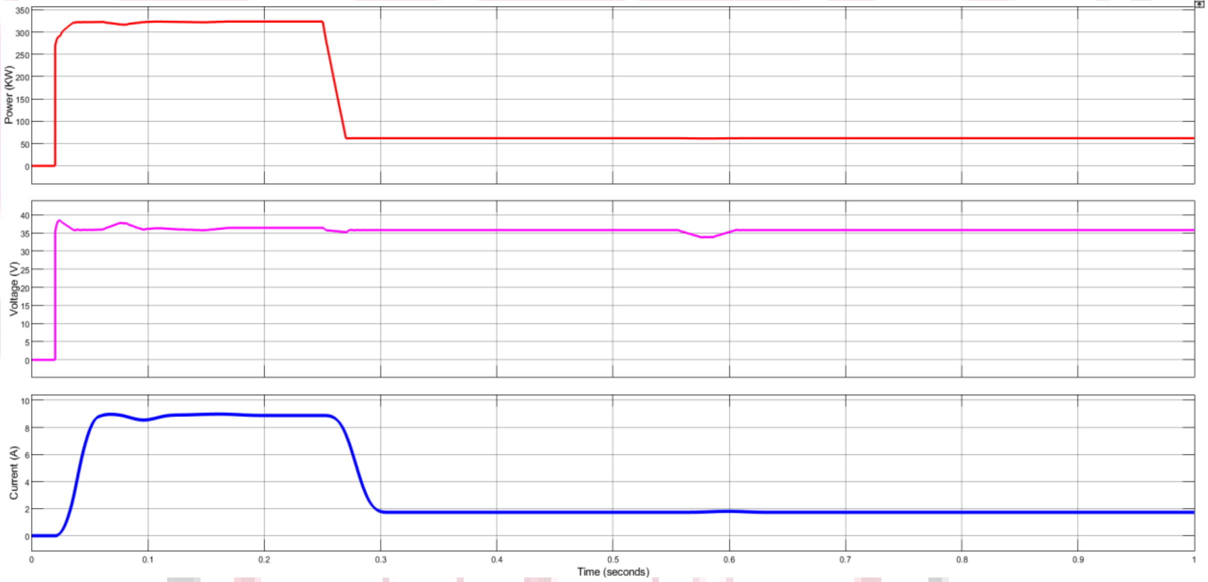

Figure 37: Solar output in the CS in system 2

The figures 37 describe the output from the solar energy system when the irradiation levels are changes from 1000 W/m^2 to 200 W/^{2}. The figures explain the solar output power, voltage and current to the CS where the control of the DC-DC converter is done by proposed AI based Modified Cuckoo Search Algorithm with Chaos Theory (MCSA)

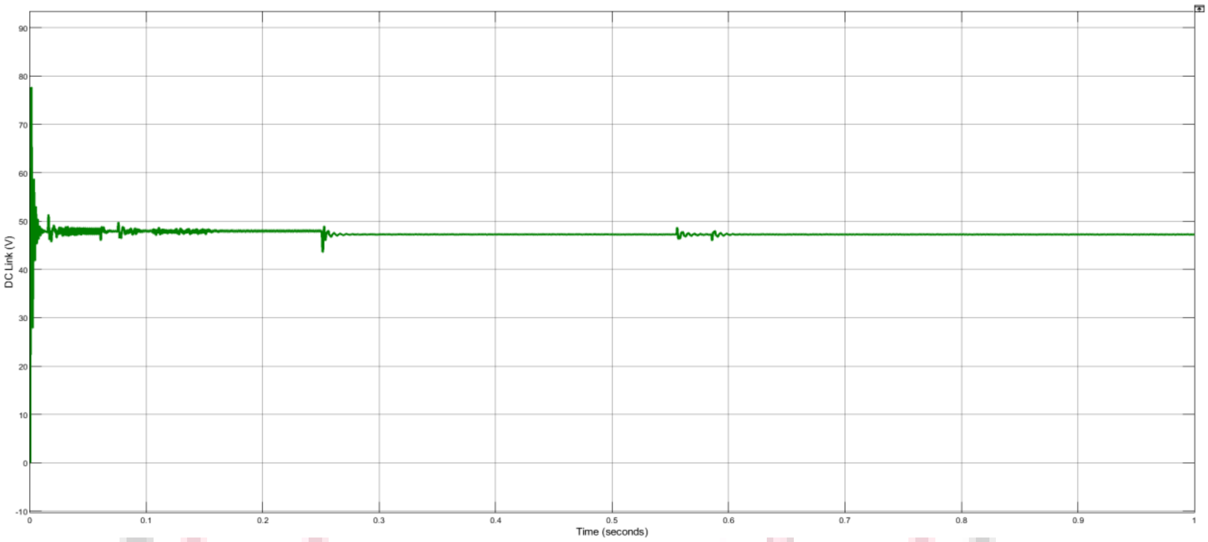

Figure 38: Common DC link of the CS in system 2

The DC link of the CS feeding power to the loads where the EV are connected in system 2 is represented in the figure 38. At 0.25 The irradiation levels are reduced showing a change in the line voltage as well. The balancing in this is done by proposed AI based Modified Cuckoo Search Algorithm with Chaos Theory (MCSA)

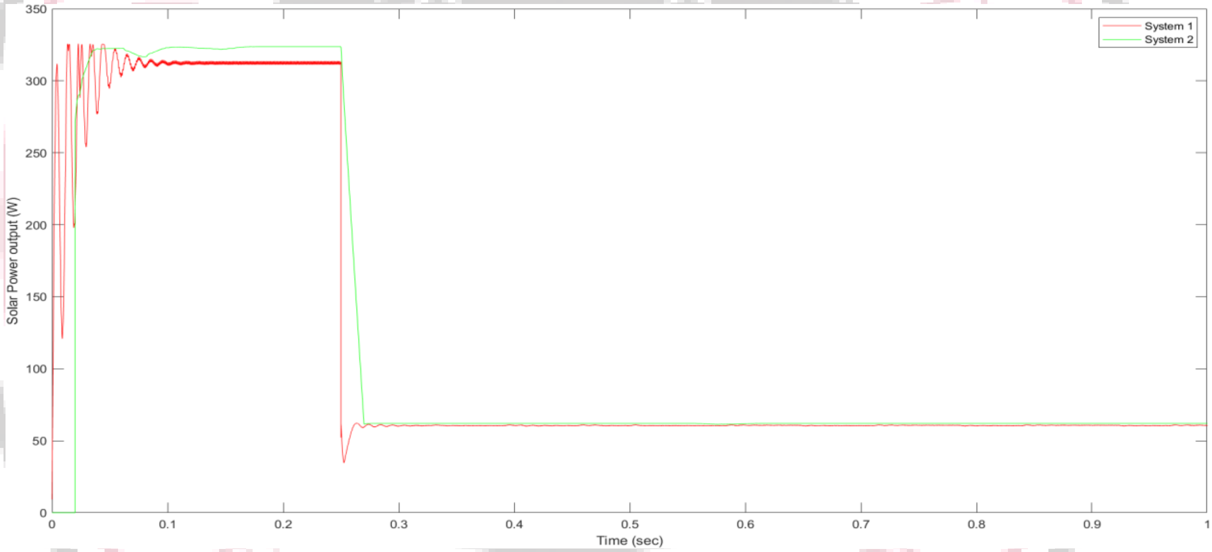

Figure 39: Comparative Analysis of Power outputs from solar CS using Two algorithms with variable inputs

The red graph in figure 39 represents the solar power output profile in system 1 and P&O algorithm is employed in the charging station. The green graph showcases the power output profile with the application of proposed AI based Modified Cuckoo Search Algorithm with Chaos Theory (MCSA) . The green graph displays a more stable and continuous line or curve that connects data points, with each point corresponding to the power output at a specific time.

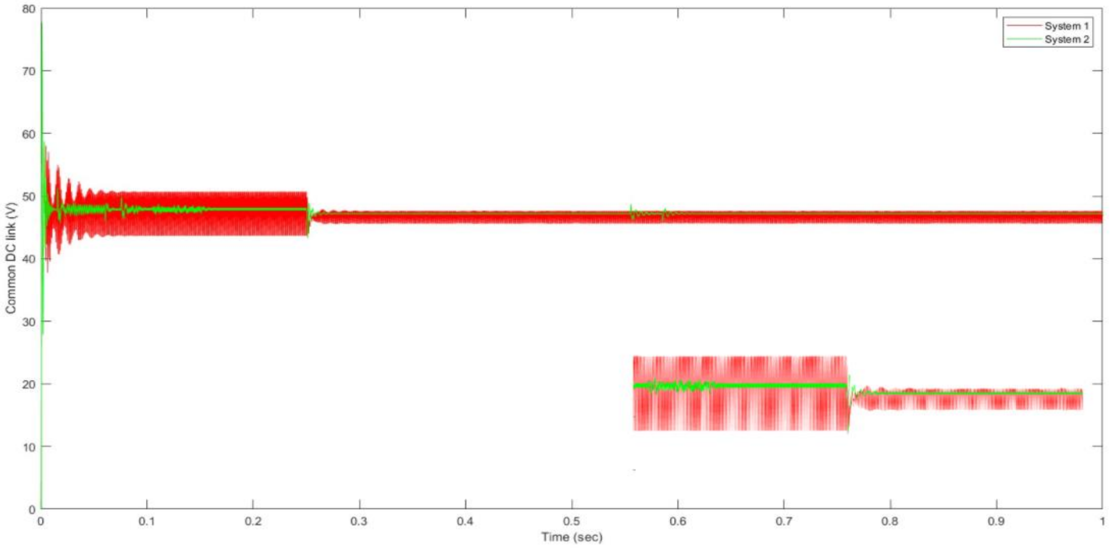

Figure 40 : Comparative Analysis of DC link in solar CS using Two algorithms with variable inputs

To compare the performance of two algorithms for DC link voltage control and balancing, a comparative graphs is being represented by figure 5.28 that illustrate how the DC link voltage varies over time under the influence of each algorithm. The red graph represents the DC line voltage of system and green graph represents the CS where there is MCSA is used for balancing and distribution control. It can be concluded that the proposed algorithm has better performance and more stable than the red graph.

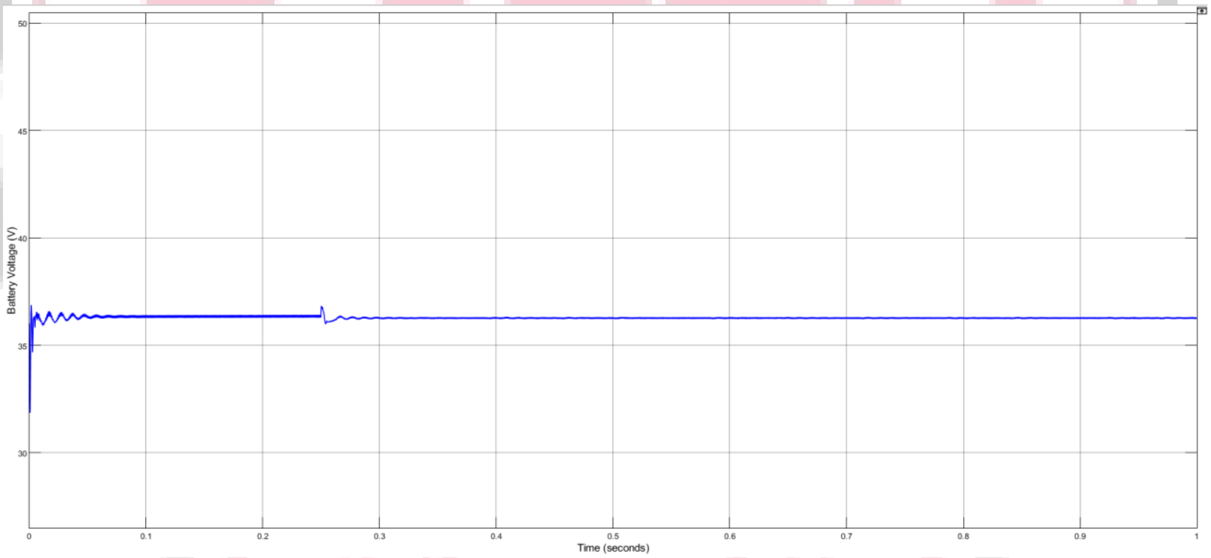

Figure 41 : Station Battery Voltage response in the system 1 with variable irradiation levels

The battery voltage response is a critical parameter indicating the system's ability to store energy efficiently under varying sunlight conditions which is presented in figure 41 The performance of the DC-DC converter is driven by P&O algorithm and the overall energy management strategy can be assessed by observing the battery voltage response.

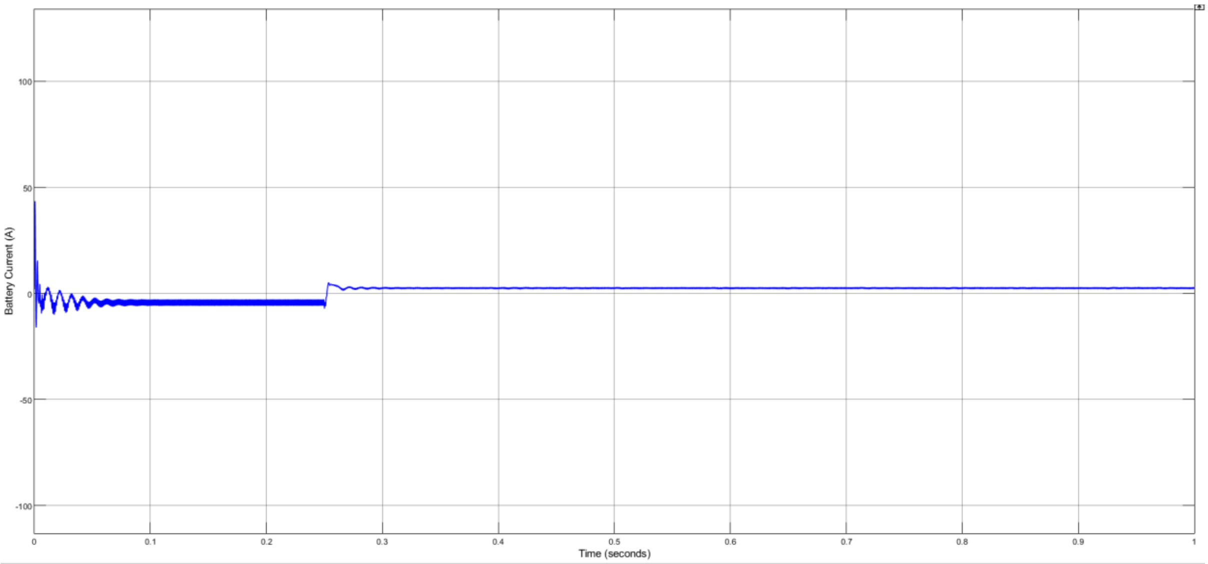

Figure 41 : Station Battery Current response in the system 1 with variable irradiation levels

The current of the station battery is represented by figure 41 for system 1. There are changes in the battery current output values from negative to positive showing that battery is getting charged and discharged respectively

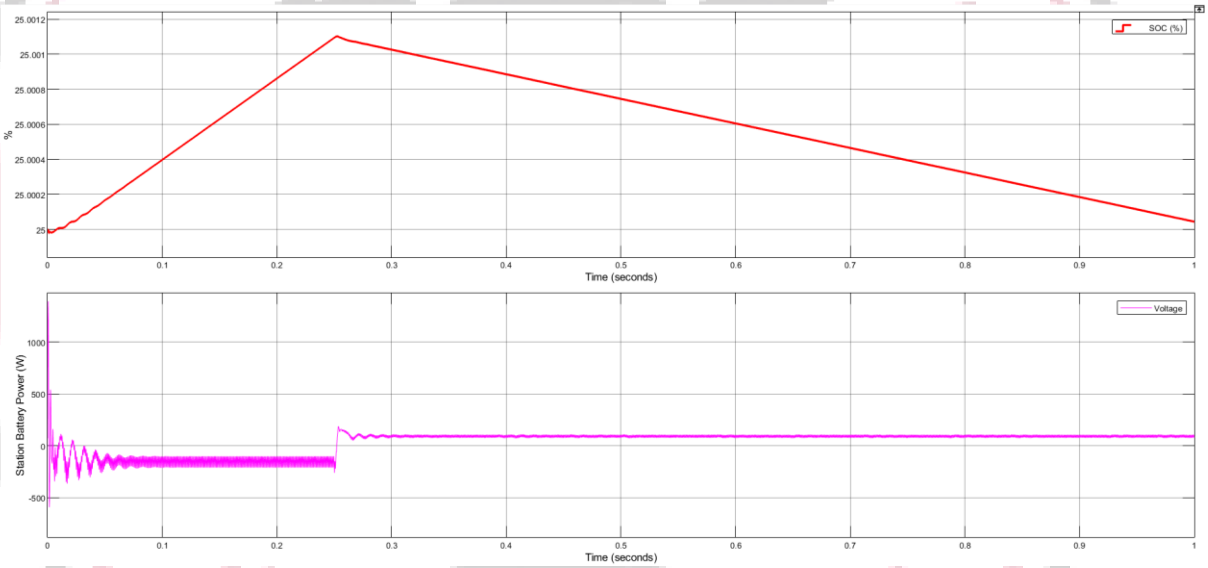

Figure 42 : Station Battery SOC and Power response in the system 1 with variable irradiation levels

The SOC and power of the station battery is represented by figure 42 for system 1. There are changes in the battery power output values from negative to positive showing that battery is getting charged and discharged respectively The SOC levels are increasing for the irradiation input level 1000W/m^2 and it getting reduced when the irradiation levels are reduces depicting that battery is being used to charge the EV in the charging station. The quality of the power fed is determined by the P&O algorithm which is used in system 1 for driving the DC-DC converter.

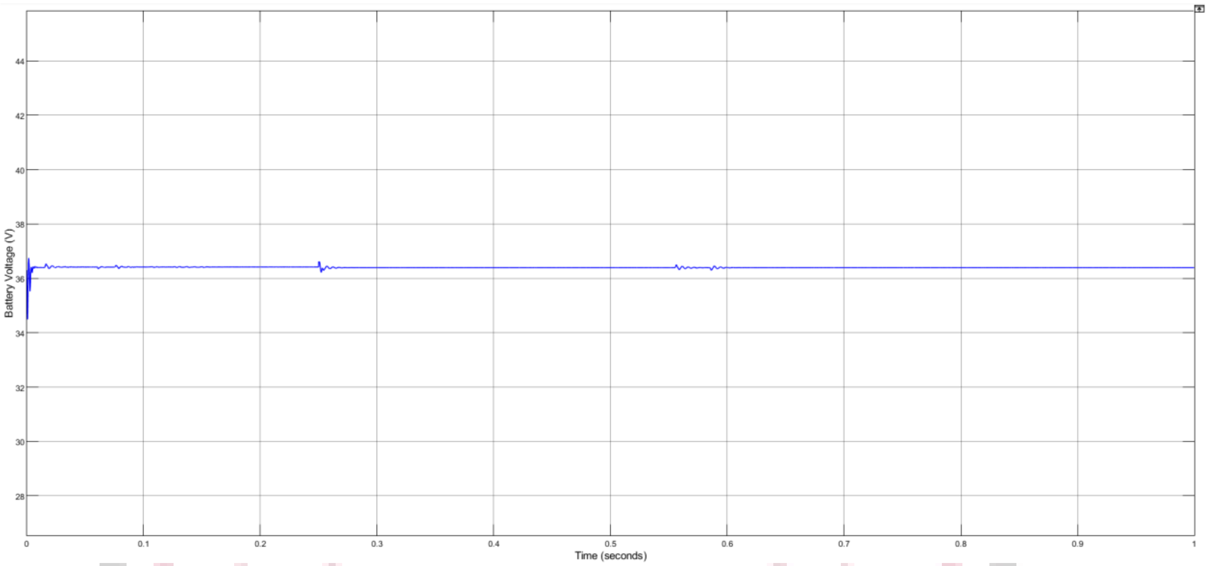

Figure 43 : Station Battery Voltage response in the system 2 with variable irradiation levels

The battery voltage response is a critical parameter indicating the system's ability to store energy efficiently under varying sunlight conditions which is presented in figure 43 . The performance of the DC-DC converter is driven by proposed MCSA algorithm and the overall energy management strategy can be assessed by observing the battery voltage response.

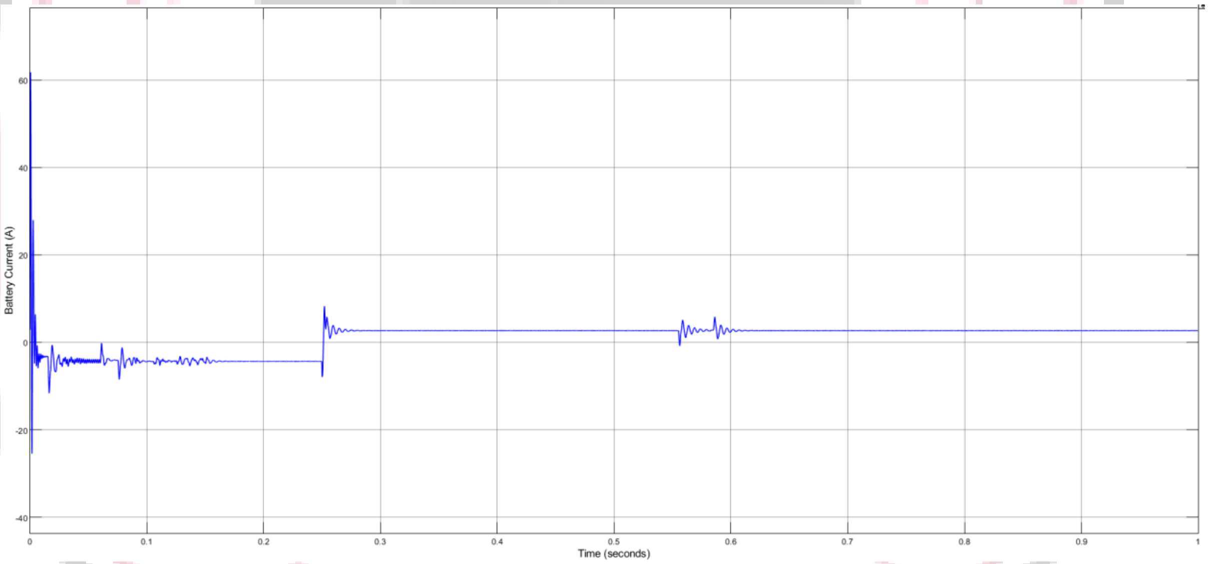

Figure 44 : Station Battery Current response in the system 2 with variable irradiation levels

The current of the station battery is represented by figure 44 for system 2. There are changes in the battery current output values from negative to positive showing that battery is getting charged and discharged respectively

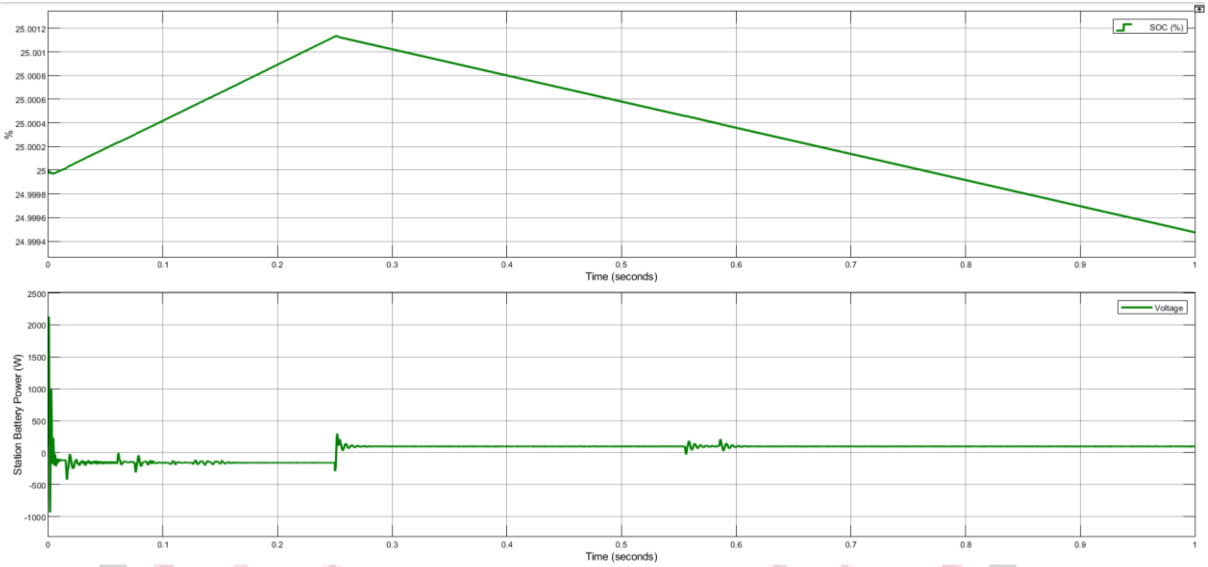

Figure 45: Station Battery SOC and Power response in the system 2 with variable irradiation levels

The SOC and power of the station battery is represented by figure 45 system 1. There are changes in the battery power output values from negative to positive showing that battery is getting charged and discharged respectively The SOC levels are increasing for the irradiation input level 1000W/m^2 and it getting reduced when the irradiation levels are reduces depicting that battery is being used to charge the EV in the charging station. The quality of the power fed is determined by the P&O algorithm which is used in system 1 for driving the DC-DC converter.

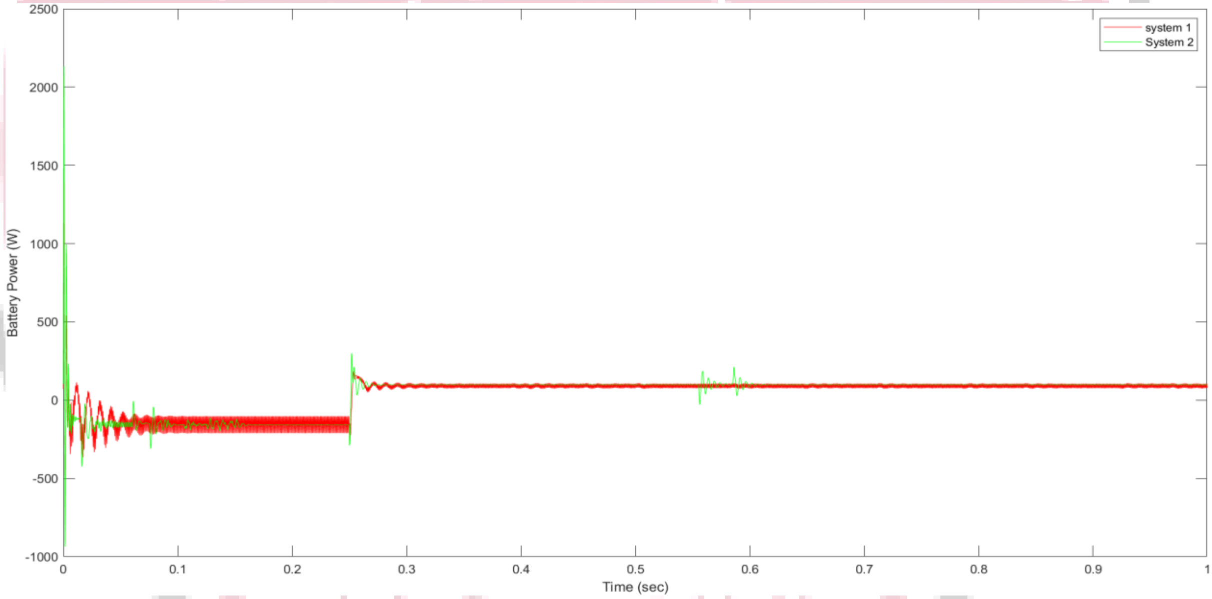

Figure 46 : Comparative Response of Station Battery Power in system 1 and 2 with variable input conditions

The figure 46 highlights the dynamic response of two different systems to varying conditions affecting the station battery power. System 2 demonstrates quicker stabilization and less initial fluctuation, making it potentially more efficient in handling sudden changes

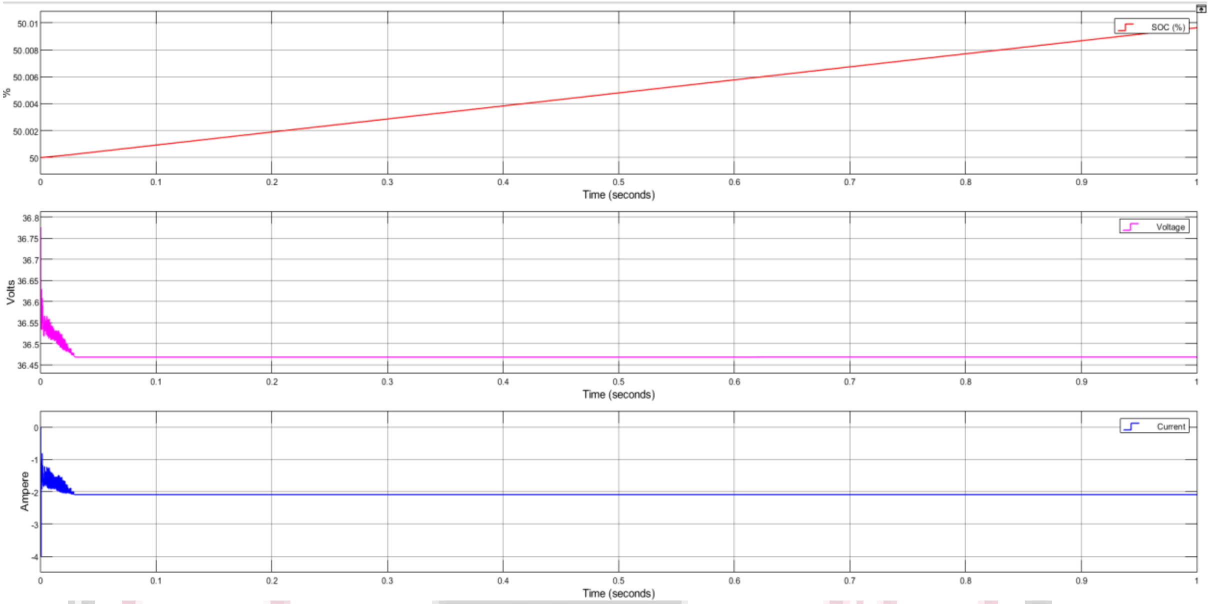

Figure 47 : EV 1 with initial SOC (50%) response in the system 1 with variable irradiation levels

The EV are connected to the solar based charging station whose voltage, current and SOC are represented by the figure 47. The SOC of battery is increasing with the help of power fed from the P&O algorithm in this system whose initial SOC was 50%

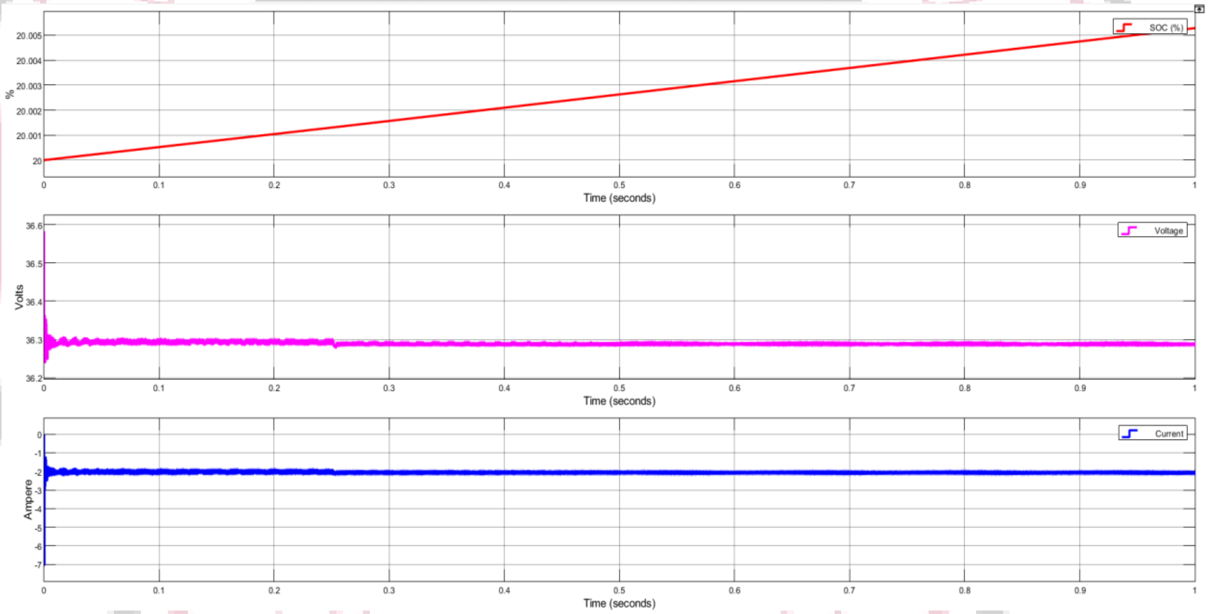

Figure 48 : EV 2 with initial SOC (20%) response in the system 1 with variable irradiation levels

The EV are connected to the solar based charging station whose voltage, current and SOC are represented by the figure 49 he SOC of battery is increasing with the help of power fed from the P&O algorithm in this system whose initial SOC was 20%

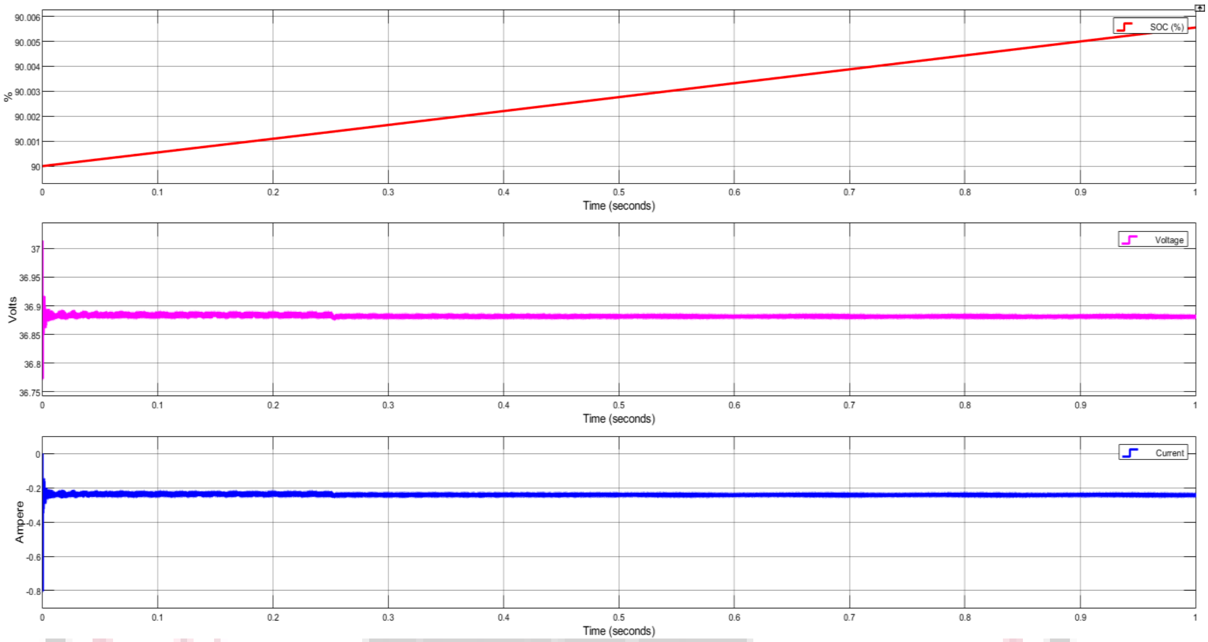

Figure 50: EV 3 with initial SOC (90%) response in the system 1 with variable irradiation levels

The EV are connected to the solar based charging station whose voltage, current and SOC are represented by the figure 50. The SOC of battery is increasing with the help of power fed from the P&O algorithm in this system whose initial SOC was 90%

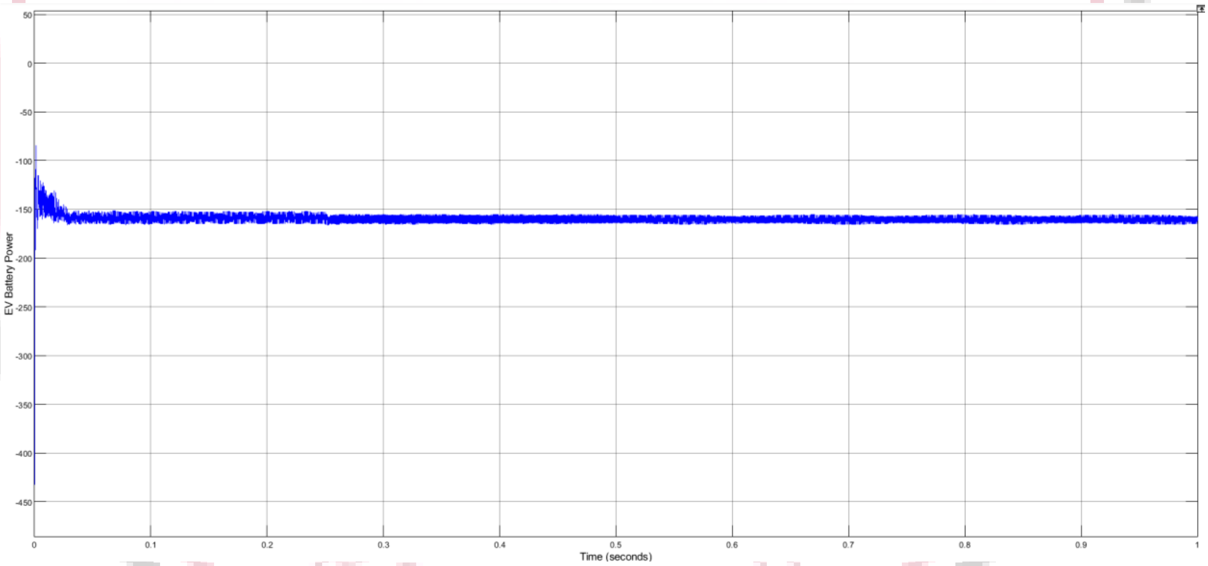

Figure 51: Total Power fed to the EV in the system 1 with variable irradiation levels

The total power fed to the EV in System 1 under variable irradiation levels is a result of the coordinated operation of the solar panels, DC-DC converter fed with P&O algorithm, and battery storage which is represented in figure 51. The system aims to maximize power delivery to the EV by adapting to changing solar conditions, ensuring efficient energy transfer, and maintaining a stable power output.

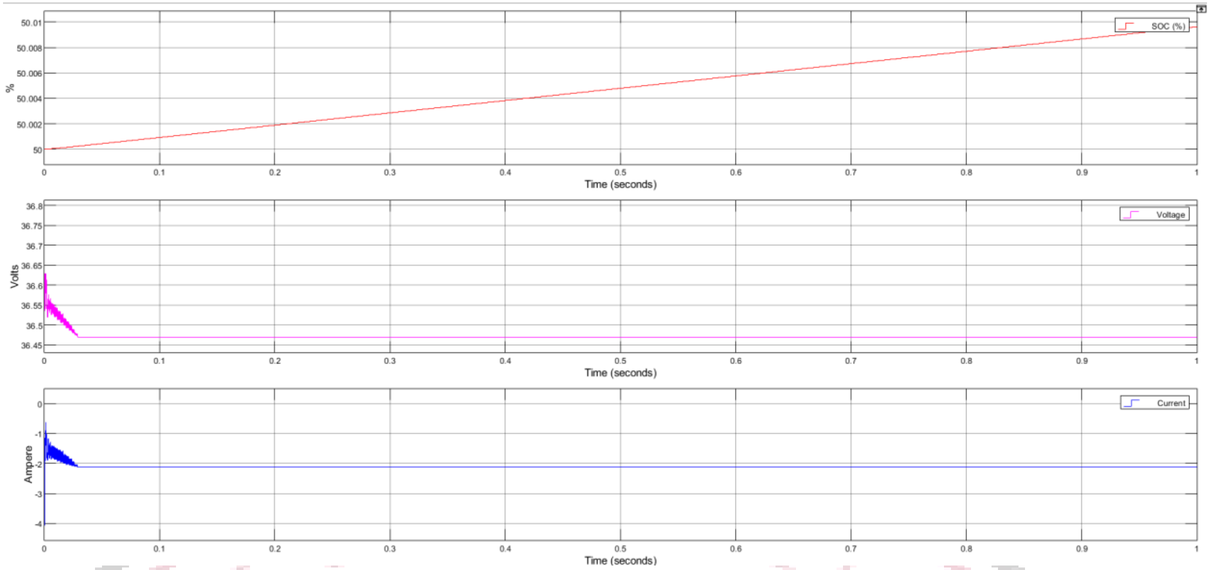

Figure 52 : EV 1 with initial SOC (50%) response in the system 1 with variable irradiation levels

The EV are connected to the solar based charging station whose voltage, current and SOC are represented by the figure 52. The SOC of battery is increasing with the help of power fed from the proposed MCSA algorithm in this system whose initial SOC was 50%

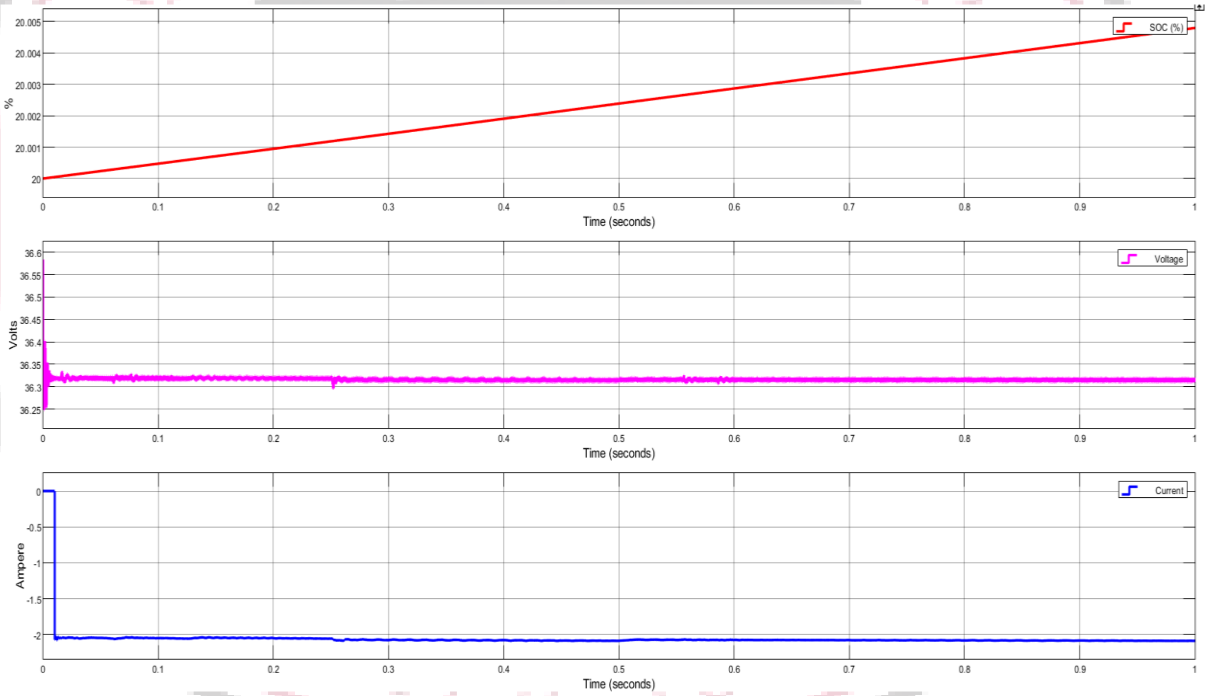

Figure 53: EV 2 with initial SOC (20%) response in the system 1 with variable irradiation levels

The EV are connected to the solar based charging station whose voltage, current and SOC are represented by the figure 53. The SOC of battery is increasing with the help of power fed from the proposed MCSA algorithm in this system whose initial SOC was 20%

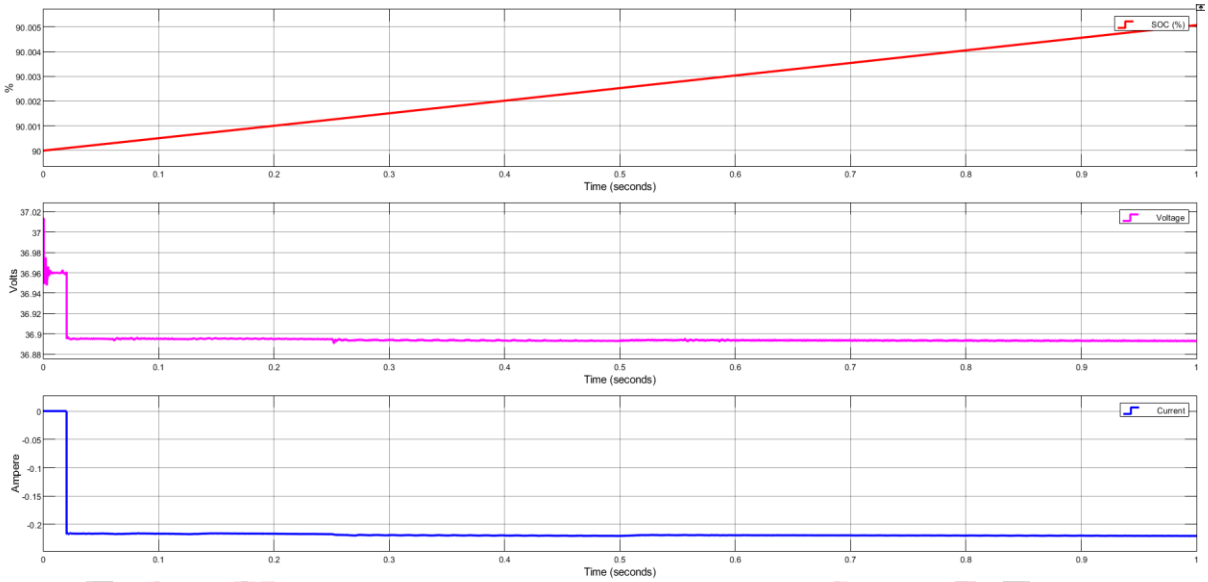

Figure 54 EV 3 with initial SOC (90%) response in the system 1 with variable irradiation levels

The EV are connected to the solar based charging station whose voltage, current and SOC are represented by the figure. The SOC of battery is increasing with the help of power fed from the proposed MCSA algorithm in this system whose initial SOC was 90%

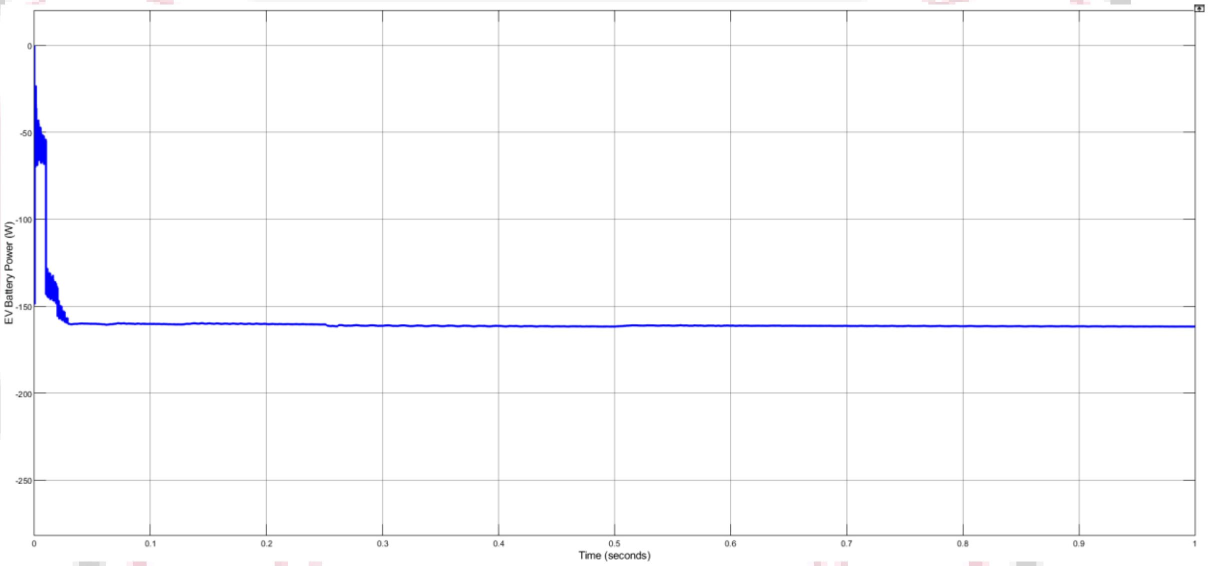

Figure 55 : Total Power fed to the EV in the system 1 with variable irradiation levels

- The total power fed to the EV in System 2 under variable irradiation levels is a result of the coordinated operation of the solar panels, DC-DC converter fed with proposed MCSA, and battery storage which is represented in figure 55 . The system aims to maximize power delivery to the EV by adapting to changing solar conditions, ensuring efficient energy transfer, and maintaining a stable power output.

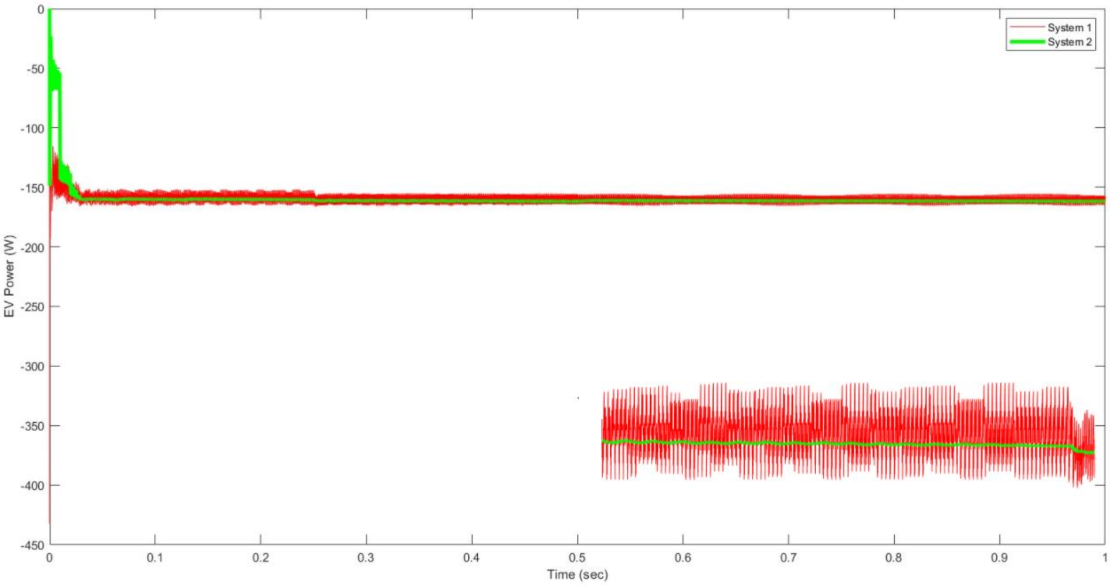

Figure 56: Comparative analysis of total output power fed to the EV in the two systems

The figure 56 highlights the dynamic power response of two systems delivering power to an EV under variable conditions. System 2 demonstrates quicker stabilization and more consistent power delivery, suggesting it is better optimized for managing power fluctuations using the proposed algorithm MCSA.

VI. CONCLUSION AND FUTURE SCOPE

A. 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 1000W/m^2 and varying irradiation level from 1000 W/m^2 to 200 W/m^2 by employing the power management strategy based on Modified Cuckoo Search Algorithm with Chaos Theory (MCSA) directed towards driving DC-DC converters in the Charging station. The following key conclusions were drawn from the work: mhnt6,kn m

- The proposed algorithm based on MCSA approach has better stabilization 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 MCSA algorithm delivered more stabilized power to them.
- Station battery power quality was also improved by proposed algorithm when compared with that driven by P&O approach for the converter.

The MCSA 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 (station battery) 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.

B. Future Scope

The system has been studied with the proposed algorithm in stand alone mode which can be further extended to integrating the system with grid. As the use of multiple renewable energy sources, such as wind, hydro, and biomass, becomes more prevalent, there is scope to extend the MCSA algorithm's capabilities to optimize power allocation among these sources. This would allow for a more comprehensive and efficient utilization of diverse renewable energy resources in charging stations and other energy systems.

The MCSA algorithm can be applied to optimize power allocation in more complex systems, such as multi-building energy systems, industrial microgrids, or smart cities. By considering diverse energy sources, loads, and storage options, the algorithm can provide efficient solutions for meeting energy demands and reducing overall energy costs.

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