

Enhanced EV Battery Charging Using Solar PV and SOSMCC Disturbance Observer for Smooth Grid Integration with SABCAF Control

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Abstract - The proposed study proposes an intelligent control based state-of-the-art solar PV electric vehicle (EV) charging system that will help to improve the grid stability, power quality and renewable energy utilization. The system is designed to enable the efficient Grid to Vehicle (G2V) and Vehicle to Grid (V2G) operations in various load and environmental conditions. It includes a solar PV array, a battery energy storage unit, a bidirectional DC-DC converter, and a grid interface. A Second Order Sliding Mode Cascaded Control (SOSMCC) method is implemented to ensure the stability of the DC-link voltage and the smooth operation of the charging and discharging of electric vehicle batteries in case of sudden changes and fluctuations in solar radiation.

Dynamic performance is further improved by the incorporation of a Linear Extended State Disturbance Observer (LESDO) to minimize settling time, overshoot and undershoot in transient operating conditions. Moreover, in order to remove harmonics and extract the fundamental current component accurately under IEEE 519 standards to improve the power quality, Sparse-Aware Bias-Compensated Adaptive Filtering (SABCAF) method is applied for harmonic suppression. The system stability, energy management capabilities and charging efficiency are evaluated by employing MATLAB/Simulink models and whole system analysis. The simulation results demonstrate faster convergence, lower mean square error, higher harmonic rejection, and better ability to reject disturbances when compared with more conventional methods. For future smart electric vehicle charging infrastructures that include renewable energy sources, the suggested method offers a dependable, efficient, and ecologically friendly alternative.

Key Words: Battery energy storage system, charging discharging control, electric vehicle, SABCAF, solar PV system, SOSMCC.

1.INTRODUCTION

With the increasing requirement for environmentally friendly transportation and renewable energy, electric vehicle (EV) technologies have developed at a quick pace. The rapid urbanization, industrialization and extensive use of fossil fuel transportation systems have resulted in extreme pollution, emissions of greenhouse

gases and depletion of traditional energy sources. Renewable energy integration and electrified transportation systems have been the centers of attention of governments and academics due to these environmental issues. Solar photovoltaic (PV) technology is one of the most promising and widely adopted technologies in the large variety of renewable energy technologies as a result of its abundant availability, low cost of operation and its environmentally friendly nature. The promise of solar PV installations combined with EV charging infrastructure is a sustainable and effective solution to improve clean mobility and to remove fossil fuels from the transport system. PV-assisted EV charging is highly desirable for the utility grid and the environment because of its potential to directly harness solar energy to power EVs. The fluctuating power quality of Electric Vehicle charging load combined with the intermittent nature of solar irradiation creates power quality, voltage control, energy management and system stability issues. For successful and reliable operation of combined solar PV and EV charging in various scenarios and load conditions, advanced control algorithms and intelligent power management techniques are required.

Modern power systems have new potential and technical problems brought about by the development of grid-connected solar EV charging stations. The traditional approach to charging electric vehicle batteries is to rely on the utility electricity grid, thus increasing the peak demand and distribution network instability when a large fleet of EVs is plugged in simultaneously. Photovoltaic systems, smart grid technologies, bidirectional converters, and battery energy storage systems (BESS) are all components of renewable-energy-based charging designs that academics have suggested as solutions to these problems. It is now possible for electric cars to do double duty as energy consumers and generators thanks to these integrated technologies that enable G2V and V2G operations. This two-way flow of energy enhances grid adaptability, efficiency, and load balancing. Still, it's not easy to keep the DC-link voltage steady and the power transfer smooth even when the load changes suddenly, the mode changes, or the solar power output fluctuates. When working in an unpredictable environment, traditional control approaches seldom provide the promised quick dynamic reaction and effective disturbance rejection.

Harmonic distortion, low power factor, and voltage fluctuations are all caused by increased use of power electronic converters in EV charging systems, and all have a significant impact on the quality and reliability of the electrical power delivered to customers. Therefore, the proper operation of the charging system in various climatic and grid conditions as well as under better power quality conditions with lower harmonics requires advanced charging control methods. The problems have pushed researchers to introduce adaptive filtering algorithms, disturbance observers and Second Order Sliding Mode Cascaded Control (SOSMCC) in the recently developed EV charging systems using renewable energy sources. The outstanding robustness, rapid convergence, and great disturbance rejection capacity of SOSMCC have made it a popular choice among these approaches.

This management approach is capable of maintaining a stable voltage of the DC-link even under changes in solar irradiation and load, and can stabilize the charging/discharging operations of EVs. Disturbance observers are used in most of the cases to estimate and compensate for the system uncertainties, overshoot, undershoot and external disturbances which affect the system's stability. Under conditions of continually varying operating conditions, the Linear Extended State Disturbance Observer (LESDO) can significantly enhance the transient response features and reduce the settling time. The other issue is how to maintain good power quality in PV based EV charging systems. It is possible that harmonics generated by non-linear loads and switching devices can affect the distribution networks, so that they can be subject to electromagnetic interference, reduction of efficiency and enhancement of loss.

To overcome these problems, higher-order harmonic components are suppressed and the fundamental component of the load current is extracted properly using Sparse-Aware Bias-Compensated Adaptive Filtering (SABCAF) and other advanced adaptive filtering methods. In general, the application of the SABCAF algorithm enhances the power system's performance and reliability by reducing mean square error (MSE), Total Harmonic Distortion (THD) to be below IEEE 519 standard limits and increasing the convergence speed. A sustainable and efficient charging infrastructure for future smart grids is planned to be built using solar technology. This system is a combination of renewable energy generation, smart energy management and advanced control methods. The photovoltaic (PV) array plays a dominant role in the generation of renewable energy in the system, and the energy storage battery will be used to ensure the system can continue to operate even when the sun is not available. In order to get the most out of the PV system regardless of the weather or amount of sunlight, Maximum Power Point Tracking (MPPT) methods are used. The regulated

charging and draining of electric vehicle batteries is made possible by bidirectional DC-DC converters, which also allow for a smooth transition between G2V and V2G modes. In order to improve power quality and decrease reactive power consumption, the Voltage Source Converter (VSC) and its related control circuits keep in sync with the utility grid. The performance of the system can be analysed through modelling and simulation using MATLAB/Simulink, considering different scenarios such as variations in solar irradiation, load changes, and grid disturbances. Results from simulations show that charging efficiency, voltage stability, harmonic distortion reduction, and system dynamics are all much improved when SOSMCC, LESDO, and SABCAF are integrated. In addition to enhancing the usage of renewable energy, the suggested strategy promotes clean energy transportation systems and reduces greenhouse gas emissions, all of which contribute to sustainable development objectives.

Finally, PVs for the charging of electric vehicles hold the promise of environmentally friendly and economically viable transportation. By integrating renewable energy, intelligent power management, and advanced converter technologies with robust control algorithms, many of the challenges associated with existing EV charging applications can be effectively solved. Solar power charging for electric cars has various benefits such as reduced pollution and cost of operation, and a great reduction in fossil fuel dependency.

Increase the stability, power quality, disturbance rejection capability and harmonic control capability of your system under dynamic operating conditions with the help of advanced control strategies like SOSMCC, LESDO, and SABCAF. Further, the capability of bidirectional charging makes efficient energy transfer between the utility grid and EVs for smart grid applications and increases the flexibility of energy management. Although the present study is mostly based on simulation analysis with MATLAB/Simulink, the suggested approach provides a good basis for future smart charging infrastructure development as well as real time hardware implementation. The future of transportation is clean, reliable, and environmentally responsible, and solar PV charging systems for electric vehicles will be a key component of this. This is because PV technology, battery storage and advanced control methods are continually developing.

2. proposed system

In the proposed system, by combining intelligent control techniques with an advanced photovoltaic based electric vehicle (EV) charging infrastructure, efficient energy management, steady power flow and improved power quality can be provided under dynamic operating conditions. This system consists of a solar photovoltaic (PV) array, a battery energy storage system (BESS), a

bidirectional DC-DC converter, a voltage source converter (VSC), and an interface with the utility grid, and can be used to enable charging operations between vehicles and the grid as well as charging operations between vehicles and the grid. The main goal of the suggested strategy is to reduce reliance on traditional electrical power sources that are based on fossil fuels as much as possible while making efficient use of renewable solar energy for charging electric vehicles. The proposed method is an improvement of existing charging systems which rely mainly on grid power.

It ingeniously optimises the energy distribution between the electric vehicle battery, the solar PV system and the utility grid based on the load demand and the solar energy generation. State of the art control techniques ensure a stable DC-link voltage, proper charging, reduced harmonic distortion and seamless mode changes. The proposed design reduces greenhouse gas emissions, improves the reliability of smart-grid and promotes eco-friendly mobility. The entire system has been modelled in MATLAB/Simulink and the system dynamics is analysed for various charging conditions, load disturbances, and varying solar irradiation levels.

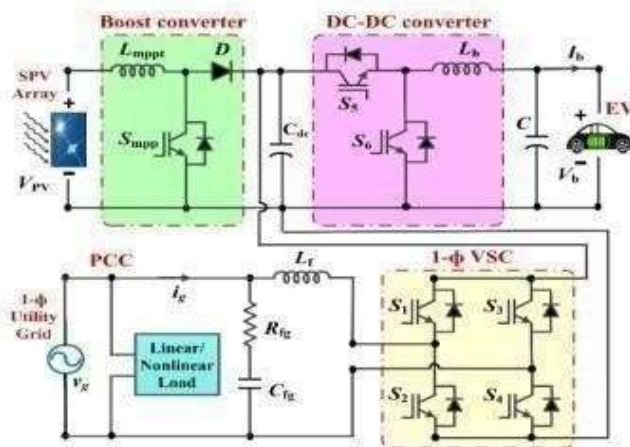


Fig.2. System configuration of PV-GEVBC

For the proposed charging scheme, the solar PV is the main renewable energy source. The PV array is built by series and parallel connections of the PV cells to convert the solar radiation energy directly to electrical energy with suitable voltage and current. The PV system's power generation is continuously changing throughout the day, as solar irradiance and ambient temperature fluctuate. The proposed model uses an efficient Maximum Power Point Tracking (MPPT) technique to extract maximum energy from the PV array under varying atmospheric conditions. The boost converter has a maximum power point tracking (MPPT) controller which continually monitors the maximum power operating point (MPP) of the PV system to ensure that the boost converter is operating at an optimum duty cycle. This makes sure that the solar array can handle variations in temperature and irradiance at its maximum efficiency. The boost converter is connected to the PV

array and boosts the voltage generated by the PV array from the relatively low voltage to the desired voltage (DC-link voltage), which regulates the voltage. The MPPT controller's effective functioning enhances the exploitation of renewable energy sources and decreases energy waste, leading to an overall improvement in the efficiency of the EV charging infrastructure.

For this, a bidirectional DC-DC converter is proposed to facilitate regulated charging and discharging of the EV battery from the DC-link bus. The bidirectional converter plays a crucial role in functionalities like Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G). In the case of an electric vehicle, an electric vehicle charging system uses electricity from a source such as a solar PV system or from the utility grid to charge the battery of an electric vehicle. If the battery requires additional power then it can be discharged back to the grid or to connected loads. The bidirectional converter has a smart control system that maintains a constant charging current to the battery and protects it against deep discharge and overcharging. In order to adapt the charging and discharging process to the battery's operating circumstances and the system's needs, the suggested system constantly checks the battery's State of Charge (SOC). Energy management flexibility, grid stress during peak demand times, and effective usage of renewable energy sources are all enhanced by the use of bidirectional energy transfer capabilities. Battery storage can further help increase system resiliency, providing back-up power during transient network outages or low solar irradiation.

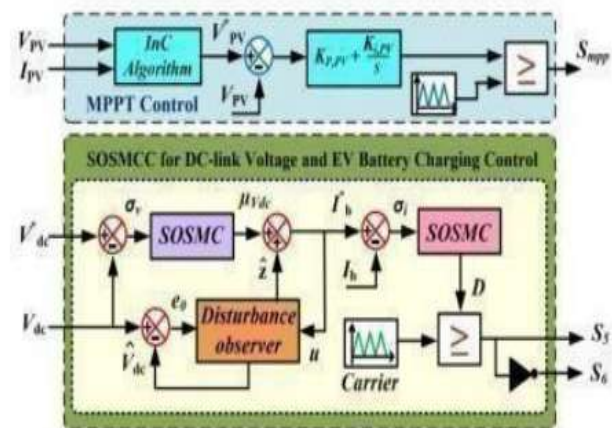


Fig.3. Block representation of MPPT and SOSMCC with observer

The proposed model adopts a Second Order Sliding Mode Cascaded Control (SOSMCC) technique to manage the DC-link voltage and control the power flow in the charging infrastructure, thus improving the dynamic performance and stability of the system. In the case of the intermittent operation, the SOSMCC method is expected to give higher precision of control, fast transient response, and excellent robustness on the

disturbance. Traditional control methods do not work well and are slow to respond when there are sudden changes in solar irradiance or load demand. However, the proposed SOSMCC technique is effective to minimize the DC-link voltage variations, overshoot and undershoot under the transient operating conditions. The cascaded topology of the controller enables the voltage control loop and current control loop to be controlled independently for stability and to decrease steady state error. The second-order sliding mode mechanism can greatly eliminate chattering, whereas more traditional sliding mode control techniques are more prone to chattering. Based on simulation results, it is concluded that the SOSMCC controller is more robust, has a faster settling time and has a smoother charging mode transition compared to the traditional proportional-integral control techniques. So, the solar EV charging system's overall efficiency and reliability are much improved by the suggested controller.

3.Simulation Results

To improve charging efficiency, power quality, and grid stability, the simulation results of the proposed photovoltaic-based electric vehicle (EV) charging system show how effective it is to integrate renewable energy generation, advanced control strategies, and intelligent power management techniques. The system overall was simulated and tested in MATLAB / Simulink in different scenarios including varying solar input, load perturbations, G2V and V2G operations and dynamic mode changes.

The proposed system includes solar panels, a bidirectional DC-DC converter, energy storage batteries, a voltage source converter (VSC), and an interface with the utility grid. The interface is driven by algorithms such as SABCAF, LESDO and Second Order Sliding Mode Cascaded Control. The voltage-regulation capability, disturbance-rejection performance, suppression features and overall stability of the charging system were determined through simulation analysis. Although climatic and electrical circumstances may change quickly, the findings show that the suggested design keeps the DC-link voltage steady and the charging process running smoothly. The proposed system offers improved dynamic responsiveness, reduced harmonic distortion and enhanced use of renewable energy than the conventional EV charging techniques. These results validate the performance and effectiveness of the proposed control architecture, which is essential for ensuring reliable and sustainable EV charging.

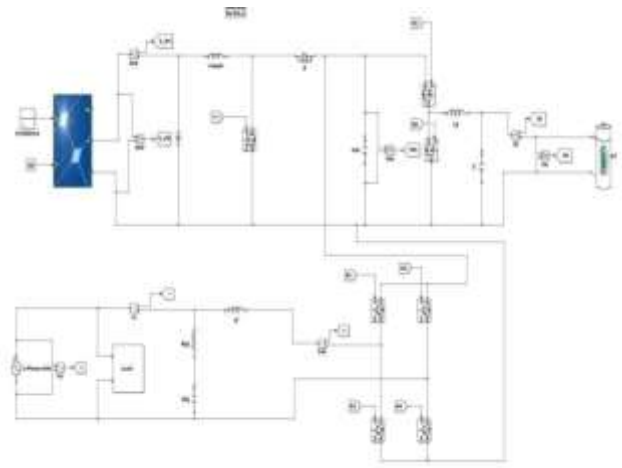


Fig. 4. MATLAB/SIMULINK circuit of the Proposed single-phase ac-dc-ac SB- 3LGUPQC converter

The following point is an important result of the simulations performed using the proposed model; the operation of the PV system under different scenarios of solar radiation. Changes in irradiance may have a major impact on charging efficiency and DC-link voltage stability since the amount of electricity produced by solar panels is directly related to weather conditions like temperature and the amount of sunshine. Maximum Power Point Tracking (MPPT) algorithm is a continuous duty cycle optimization of the boost converter that makes the most out of the PV array. As seen from the waveforms of the simulation, the MPPT controller tracks the maximum power operating point with very little oscillations and is responsive to solar irradiation changes. Under low-irradiance conditions, the controller ensures optimal operation by efficiently utilizing the available solar energy, while during high-irradiance periods, it supplies additional power to the EV charging system.

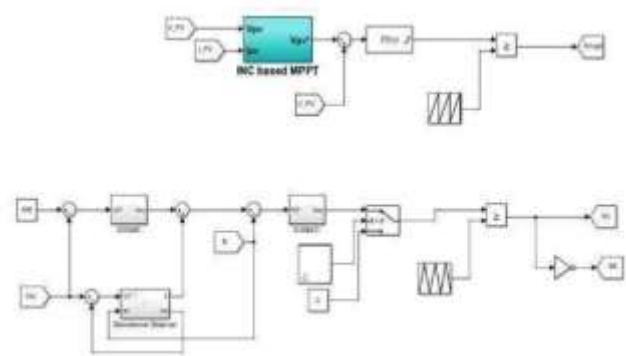


Fig.5.Control system for Boost and DC/DC Converter

According to the simulation results, the proposed charging system is successful in implementing the Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) capabilities, which are related to the bidirectional DC-DC converter operation. During G2V operation the converter carries out a constant voltage and regulated charging current transfer from the utility grid or solar

PV to the electric vehicle battery. The charging current waveform demonstrates a smooth charging process, minimizing current spikes or droops, which helps preserve the battery's lifespan and enhances charging efficiency. During peak demand periods, V2G can feed energy back into the grid or to the loads connected to the grid. The converter is able to successfully reverse power flow without destabilizing or interfering with the system or the utility network. The results obtained from the simulation show that the voltage on the DC link bus changes very little and there is absolutely no ripple when switching between charging and discharging modes. Moreover, to prevent overcharging and deep discharging conditions are monitored by the battery's State of Charge (SOC) constantly. The bidirectional converter is seen to be able to move the energy efficiently, flexibly control the power, and enhance the grid support capabilities in dynamic operation.

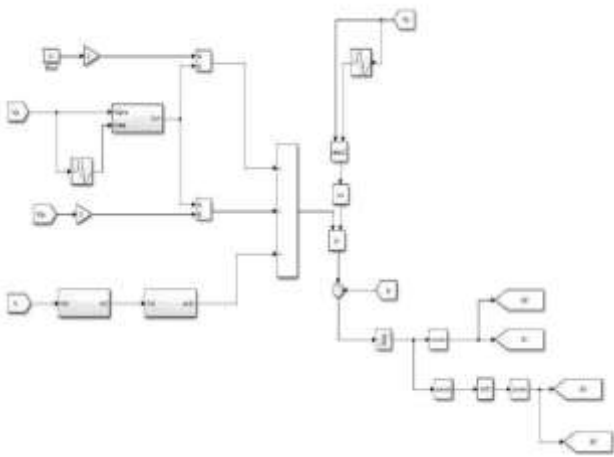


Fig.6. Control system for VSC

The performance of Second Order Sliding Mode Cascaded Control (SOSMCC) strategy was investigated under various transient operating conditions by detailed simulation analysis. Results demonstrate that SOSMCC controller is able to handle DC-link voltage control and maintain a smooth operating of the system even in case of sudden load change between its modes. For some situations, such as a sudden change in the load demand, traditional controllers may cause a long settling time and may cause a large voltage overrun. The proposed SOSMCC method eliminates these unwanted effects and assures fast dynamic response and disturbance rejection capability. The voltage waveform on the DC-link obtained from the simulation shows minimal voltage fluctuation and quick stabilization after transient disturbances. It is designed in the cascaded configuration so as to improve the precision of the current and voltage regulation, while reducing the steady state error. The chattering effects that are typical of conventional sliding mode controllers are also much reduced by the second-order sliding mode mechanism. The suggested method of SOSMCC has better transient

response, settling time and stability performance compared to conventional control under various operating conditions. The results indicate that the SOSMCC approach is effective in maintaining the power flow of the EV charging network with steady and reliable power supply using RE sources.

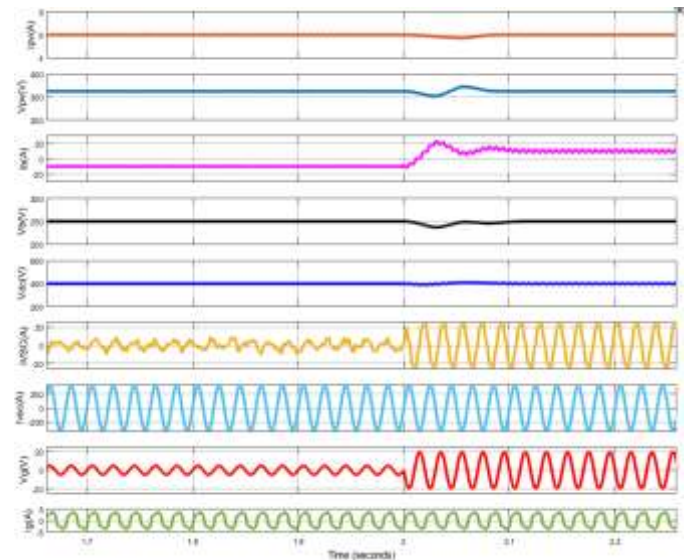


Fig.7. Transitioning performance from G2V to V2G

The Linear Extended State Disturbance Observer (LESDO) integrated into the proposed system showed very good results when it comes to uncertainties and external disturbances of the system. Disturbances like rapid variations in solar irradiation, switching loads or sudden changes between operation modes (G2V / V2G) can have high voltage stability and charging performance impact on DC-links. To keep the charging system as undisturbed as possible by unknown disturbances impacting system dynamics, the LESDO continually creates compensation signals. The simulation demonstrates that the disturbance observer is effective in suppressing voltage overshoot, undershoot and oscillations during transients.

The LESDO improved transient response and achieved a much faster settling time than the current disturbance observer systems. The results indicate that the suggested observer can enhance the system resilience, ensuring the system remains able to charge even under rapid electrical and climatic changes. The coordinated operation of the SOSMCC controller and LESDO provides power flow management as well as very steady regulation of the DC-link voltage. These results validate the suggested disturbance compensation mechanism's capacity to enhance operational stability and overall charging system dependability in real-world EV charging systems that combine renewable energy.

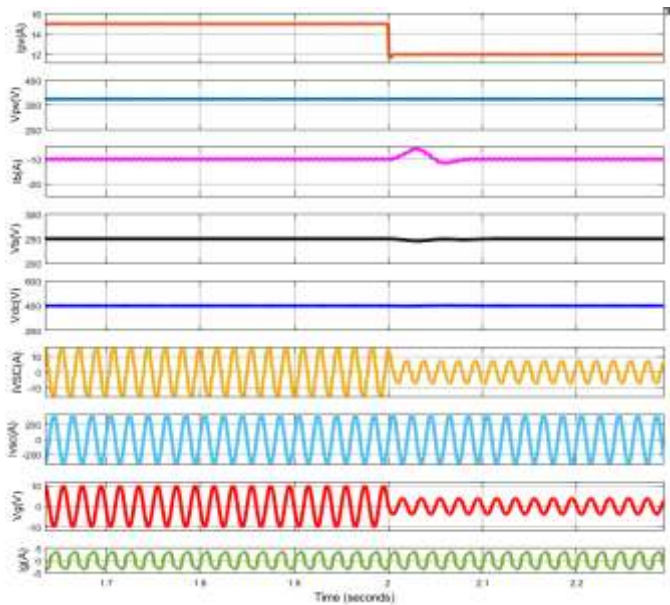


Fig.8 Performance during the change of solar irradiance

Another key result of the simulation study is the efficiency of the switching between the G2V and V2G modes of operation in the system. For the smart grid to support reliable charging infrastructure for electric vehicles, charging and discharging must seamlessly follow each other. According to simulation experiments, the suggested control system can control the mode switching without causing instability, large voltage jumps, or current surges. The bidirectional converter keeps the DC-link voltage and battery current at all times while power can flow in either direction during the transition between G2V and V2G modes. Charging the battery continues uninterrupted and without transitory oscillation when the system switches from V2G to G2V mode. The SOSMCC controller and LESDO observer work together to suppress mode switching disturbances for seamless energy transfer between the battery, PV system and the grid. The results show that the proposed solution is able to meet the requirements for bidirectional charging for future distributed energy storage and smart-grids.

4. CONCLUSIONS

Lastly, the proposed solar photovoltaic (PV) electric vehicle (EV) charging system will be reliable, efficient, and environmentally friendly for transportation and energy management in the future. One way to lessen our reliance on traditional energy sources that rely on fossil fuels and the pollutants they produce is to charge electric vehicles using sustainable solar electricity. The proposed system integrates a solar array, a bidirectional DC-DC converter, a battery energy storage system, a Voltage Source Converter (VSC), and advanced charging control algorithms to ensure reliable and efficient operation during different load and weather conditions. Maximum Power Point Tracking (MPPT) ensures maximum power extraction from PV systems, and Second Order Sliding Mode Cascaded Control (SOSMCC) provides good

control of DC-link voltage and enhances system stability. Additionally, the capacity to reject disturbances and minimize transient oscillations in the dynamic operating circumstances is enhanced by the Linear Extended State Disturbance Observer (LESDO). To enhance the power quality further, the Sparse-Aware Bias-Compensated Adaptive Filtering (SABCAF) method greatly reduces the harmonic distortion, thus keeping the Total Harmonic Distortion (THD) within the limits specified in IEEE 519 standard. The simulations were performed in MATLAB/Simulink and verified the efficiency of charging process, proper voltage control, reduction of harmonics, and smooth G2V and V2G operations. To conclude, the proposed design is a feasible, intelligent, and energy-efficient charging infrastructure for EVs supporting smart grid applications with renewable energy, which can play a crucial role in sustainable development and clean transportation.

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