

Research Paper**INTELLIGENT RENEWABLE ENERGY POWERED EV CHARGING STATION WITH ADVANCED ADAPTIVE
FILTERING AND VOLTAGE CONTROL****VELPULA CHANDANA¹, DR.R.DEVASARAN²**¹Mtech Student, Dept of EEE, Holy Mary Institute of Technology & Science, Keesara, Bogaram, Telangana,
India.²Professor, Dept of EEE, Holy Mary Institute of Technology & Science, Keesara, Bogaram, Telangana, India.
Mailid: rdsaran@hmg.ac.in**ABSTRACT**

As Electric Vehicles (EVs) rapidly grow and the demand for clean energy sources continues to rise, the need for high-tech charging infrastructure using renewable energy has increased. This project introduces an Advanced Solar PV-based Smart Electric Vehicle Charging System with Enhanced Power Quality and Grid Stability. The suggested system comprises a Solar Photovoltaic (PV) array, Battery Energy Storage System (BESS), bidirectional DC-DC converter, Voltage Source Converter (VSC), and the utility grid, which are all crucial for the efficient charging and discharging of the energy storage system. The primary goal is to increase charging efficiency, utilize renewable energy, enhance power quality, and boost overall system reliability. To utilize the PV array maximum power under the different sun irradiance conditions, a Maximum Power Point Tracking (MPPT) technique is used. In order to keep the DC-link voltage stable and to assure the smooth power transference, Second Order Sliding Mode Cascaded Controller (SOSMCC) is used. Moreover, a Linear Extended State Disturbance Observer (LESDO) is employed to estimate and compensate system disturbances for better transient response and less voltage variation. For improving the power quality, a Sparse-Aware Bias-Compensated Adaptive Filtering (SABCAF) algorithm is implemented for harmonic suppression and accurate current estimation. The proposed system is simulated and modeled using MATLAB/Simulink for various operating scenarios such as variations in solar irradiance, load disturbances and transitions from charging mode. The simulation results show that the proposed method provides better voltage regulation, lower harmonic distortion, better dynamic responses, and better charging performance than the conventional ones. The proposed system could be used in future smart-grid integrated applications for charging EVs and could be considered as a reliable and efficient system that is environmentally friendly as well.

Keywords: Solar PV, Electric Vehicle, Smart Charging, MPPT, Smart Grid, Renewable Energy, SOSMCC, LESDO, SABCAF, Power Quality.

I. INTRODUCTION

Electric Vehicles (EV) have been gaining traction globally because of the demand for sustainable modes of transport and clean energy sources. The traditional modes of transport are mainly based on fossil fuels that add a major share to greenhouse gas emissions, environmental pollution, and natural resource depletion. In response to these challenges, renewable energy sources, like Solar Photovoltaic (PV) systems, have proven to be effective alternatives to power EVs charging infrastructures. The advantages of solar PV technology include the fact that it's readily available, low maintenance cost and environmentally friendly energy creation. The combination of solar PV and EV charging stations can help decrease reliance on traditional grid power while promoting sustainable transportation. But, solar energy is intermittent, with fluctuating charging requirements, which can pose issues with voltage regulation, power quality, and energy management. Thus, there is a need for advanced control and energy management strategies to guarantee reliable and efficient charging operations under dynamic environmental and load conditions. Nowadays, it has been found that renewable-energy based EV charging system plays a significant role in the path of energy sustainability and reduction of carbon emission [1] [2].

The use of modern smart-grid technologies has made it possible to develop intelligent EV charging systems that facilitate both the Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. These systems can allow EVs to not only consume energy, but also serve as distributed energy storage devices that can provide energy back to the grid during peak demand times. Combining battery energy storage systems, bidirectional converters, and advanced control algorithms enhance system flexibility and the stability of the electrical grid. However, due to variations in solar irradiance, load and grid disturbances, it is still difficult to maintain a stable DC-link voltage and smooth power transfer. The conventional control methods usually have slow dynamic response and poor disturbance rejection ability. To address these constraints, new techniques like Second Order Sliding Mode Cascaded Control (SOSMCC) [3] and Linear Extended State Disturbance Observer (LESDO) [4] are used for better voltage regulation, transient performance, and system robustness.

Another important concern in EV charging infrastructures is power quality. Power electronic converter usage is widespread and can result in harmonics, reactive power demand and current distortions which negatively affect the performance of the utility grid. High levels of harmonic distortion can lower the efficiency of the system, cause higher losses and affect electrical equipment. These are overcome by using advanced filtering technique like Sparse-Aware Bias-Compensated Adaptive Filtering (SABCAF) for harmonic suppression and extraction of accurate fundamental current component. In order to improve charging efficiency, power quality and utilization of renewable energy, a novel Solar PV-Based Smart EV Charging System is proposed that combines MPPT, SOSMCC, LESDO and SABCAF techniques. The performance of the proposed approach is evaluated using MATLAB/Simulink simulation and shown to be effective in maintaining the voltage stability, minimizing Total Harmonic Distortion (THD), and ensuring reliable charging under different operating conditions. The proposed system can be considered as a sustainable and intelligent solution for future EV charging applications integrated with smart grid [5] [6].

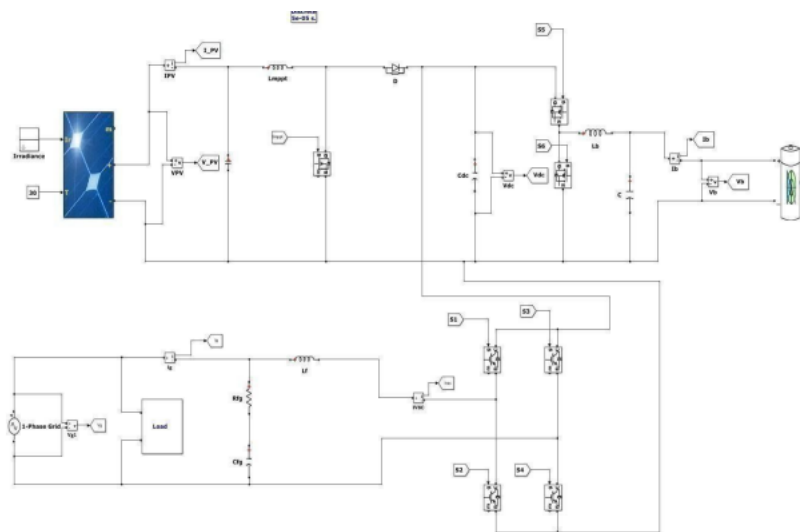


Fig. MATLAB/SIMULINK circuit of the proposed single-phase ac-dc-ac SB-3LGUPQC converter

II SURVEY OF RESEARCH

1. N. Senapati et al. have proposed a renewable energy based DC micro-grid system with solar PV and battery energy storage system for charging EVs. They were primarily focused on improving the voltage stability, energy management and power sharing capacity of their system for various operating conditions. The proposed coordinated control strategy has been successfully tested to control the power flow from PV power sources to battery storage and charging loads while keeping the DC bus voltage stable. For better system efficiency and lesser power losses advanced converter topologies and intelligent switching mechanism have been implemented. The simulation results revealed that the system improved the dynamic response, reliability and utilization of renewable energy resources, compared to the conventional charging system. The study emphasized the importance of integrating

energy storage solutions with renewable energy sources to ensure uninterrupted charging processes, even during fluctuations in solar energy supply levels. Moreover, the authors highlighted the environmental benefits of renewable energy charging systems, such as the reduction of greenhouse gas emissions and fossil fuel consumption. Their work is a significant step towards sustainable and smart EV charging systems in smart-grid applications.

2. Power control strategies of PV system integrated with smart power grid and EV charging stations were studied in reference [2] by Peng et al. They have learned about issues of energy management, power imbalance and voltage instability caused by the undependable power generation of solar energy. Advanced inverter control and reactive power compensation strategies are proposed to improve the voltage regulation and the ability to support the grid. The developed control framework was utilized to control the active and reactive power in an efficient manner under different environmental condition. The outcomes of the simulation studies demonstrated that the power quality, grid stability and energy efficiency in the utilization of renewable energies can be significantly improved when compared to the conventional techniques. The research also pointed to the need for smart power management systems to power up large-scale solar-powered EV charging stations. Further, the scientists said the use of smart control technology can help to reduce stresses on the utility grid during peak charging times. Their results help to design reliable, sustainable, renewable energy based transportation infrastructures that are able to support future smart-grid operations.

3. The authors in 3. R. B. Bollipo et al., have given a detailed review on Maximum Power Point Tracking (MPPT) techniques in photovoltaic energy systems. Classical MPPT techniques – Perturb and Observe (P&O) and Incremental Conductance (INC), and intelligent methods – fuzzy logic, neural networks, and evolutionary optimization algorithms were tested. These techniques were tested at various solar irradiance levels and temperature and their performance was measured to obtain the maximum available solar power. Based on the results, it was observed that the conventional MPPT methods are simple, economical but have a disadvantage in that they are oscillating in nature and slow to converge around the maximum power point. The intelligent techniques, on the other hand, exhibited superior tracking performance with rapid response and high efficiency of energy harvesting. The study emphasized the significance of MPPT algorithms in enhancing the efficiency of charging and the utilization of renewable energy sources in EV charging systems. In addition, future research of the adaptive/hybrid MPPT techniques was recommended to further improve the renewable energy powered charging infrastructures.

4. S. Chakraborty et al. have come up with a two stage solar photovoltaic (PV) system with seamless operation under the dynamic grid condition. It was proposed that advanced control algorithms were applied to the proposed system to keep the DC-link voltage stable, and provide smooth power transfer between PV and utility grid. The studies were directed towards the improvement of the system reliability, reduction of energy losses and the improvement of power quality. The simulation results revealed that the proposed control scheme not only successfully suppressed the voltage fluctuation but also improved the transient performance in the event of sudden change of load. They said the operating conditions of such applications are often varied, which calls for powerful converter-control technologies for such applications based on renewable energy source. They also emphasized the need for “intelligent” control systems that can optimize the use of renewable resources and ensure the reliability of operation of solar powered infrastructures. The proposed method was shown to have a satisfactory voltage regulation, and good performance compared with traditional methods, which will allow it to be applied to advanced charging applications for EVs with renewable energy resources.

5. Hsu et al. suggested a multi-function charging station for Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H) functions. The study focused on improving the charging efficiency, flexibility of energy management and provision of grid support services through the use of bidirectional power converters and smart battery management systems. The proposed system enabled an electric vehicle to generate energy to the utility grid and load in peak demand period via the distributed energy storage system. To achieve seamless switching between charging and discharging modes, maintain battery safety, and system stability, advanced control algorithms were implemented. The experimental and simulation results showed that the proposed charging infrastructure achieved better power flow control, lower operational expenses, and improved performance of supporting the grid than conventional charging infrastructures. The authors highlighted the need for bidirectional charging in the future smart-grid environment and mentioned bidirectional charging as an important consideration when it comes to renewable energy resources and advanced charging networks for sustainable energy management.

6. Ortega and Milano, the authors of the paper, explored the use of batteries to store energy for renewable energy systems that can be used in a smart-grid and EV application. They considered a number of control strategies in their study to enhance the voltage regulation, power sharing and dynamic performance under various operating conditions. Conventional proportional-integral controllers and advanced adaptive and predictive control algorithms were compared in the study. Experimental results of the simulation revealed that the intelligent methods of control had superior performance with respect to fast response, rejection of the disturbance and energy management performance. It has been remarked by the authors, the need for accurate modelling of the battery and state of charge estimation for reliable charging operations. Additionally, the study highlighted the significance of BESS for mitigating the power intermittency of renewable energy and guaranteeing continuous power supply. The proposed techniques were found to be more efficient, stable and reliable as compared to the traditional techniques. They will use their results to design future renewable energy powered EV charging stations that will be able to help support future smart-grid technologies.

II. WORKING METHODOLOGY

The proposed Solar PV-Based Enhanced Electric Vehicle Charging System is composed of a maximum power point tracking (MPPT) technique, linear extended state disturbance observer (LESDO) technique, sparse-aware bias-compensated adaptive filtering (SABCAF) technique, second order sliding mode cascaded control (SOSMCC) technique, photovoltaic (PV) array, bidirectional DC-DC converter, voltage source converter (VSC), and battery energy storage system (BESS). The main goal is to maximize the utilization of renewable energy, enhance charging performance, ensure power quality and enable stable Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) services in a changing environment and load profile. Solar PV array is used to transform the solar radiation to electric energy that is the main energy source to charge the electric vehicle battery. Solar irradiance is constantly changing during the day and an MPPT controller is used to extract the maximum power possible from the PV array. The generated DC power is processed, using boost converter, in order to keep the required DC-link voltage. Battery energy storage system supplies backup energy when solar energy generation is low and enables continuous charging operation. The bidirectional converter allows controlled charging and discharging of the EV battery and enables the exchange of energy between the battery and utility grid.

The proposed system uses an efficient MPPT algorithm to find the optimum MPPT of the solar PV system in different climatic conditions. The power output of the PV array is given as:

$$P_{PV} = V_{PV} \times I_{PV}$$

where P_{PV} is the output power, V_{PV} is the PV voltage and I_{PV} is the PV current. The DC-link voltage is controlled by the boost converter based on:

$$V_{DC} = \frac{V_{PV}}{1 - D}$$

Where (D) is the duty cycle of the converter. The SOSMCC controller keeps a stable operation by continuously controlling the DC-link voltage to prevent voltage fluctuation. The voltage control sliding surface is given by:

$$S = e + \lambda \int e dt$$

where e is the voltage error and λ is the controller gain. The Linear Extended State Disturbance Observer can be used to estimate system disturbances and compensate for uncertainties based on:

$$\dot{\hat{x}} = A\hat{x} + Bu + L(y - \hat{y})$$

where ($\hat{x}$) is the estimation of the state variables, (u) is the control input, and (L) is the observer gain matrix. The dynamic behaviour of these advanced control strategies is significantly improved, also settling times are shorter and the rejection capability of disturbances is better.

In order to enhance the power quality and minimize the harmonic distortion, the proposed system includes the SABCAF algorithm which is an adaptive filtering and harmonic suppression algorithm. Grid current Total Harmonic Distortion (THD) is measured by:

$$THD(\%) = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots + I_n^2}}{I_1} \times 100$$

where I_1 is the fundamental current component and ($I_2, I_3, \dots, I_n$) are harmonic components. The Voltage Source Converter synchronises the DC-link with the utility grid and ensures unity power factor operation. The G2V mode of operation involves charging the battery of the EV with energy from the solar PV system and the utility grid. In V2G operation, the battery energy stored is returned to the utility grid during peak demand periods. The whole system is modeled and simulated in MATLAB/Simulink for different solar irradiance, load disturbances and charging conditions. The simulation results show that the proposed charging technology is able to achieve a higher charging efficiency and lower harmonic distortion, better voltage stability, faster convergence, and higher power quality than those of the traditional charging methods of EVs. This methodology offers a reliable, intelligent and sustainable solution for future electric vehicle charging infrastructures integrated with smart-grid technology.

IV RESULTS EXPLANATIONS

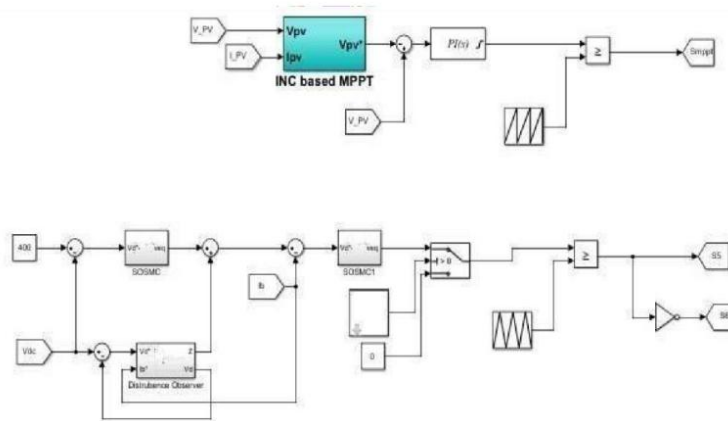


Fig. Control system for Boost and DC/DC Converter

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. In G2V (Grid to Vehicle) mode, the converter performs a continuous, non-perturbed, current regulated and constant voltage switching from the utility grid or solar PV to the battery of the electric vehicle. The charging current curve shows that the charging process is smooth, with no significant current spikes or drops, which helps to extend the lifespan of the battery and improve charging efficiency. V2G can return energy to the loads on the grid and/or to the grid during peak demand. The converter can effectively reverse power flow, while not disturbing or destabilizing the system or the utility network. The simulation results demonstrate that there is only a slight change in the voltage of the DC link bus and no ripple at all when the system is switched from charging to discharging mode and vice versa. Moreover, to prevent overcharging and deep discharging conditions are monitored by the battery's State of Charge (SOC) constantly. It is observed that the bidirectional converter can transfer the energy efficiently, flexibly control the power and improve the grid support capabilities in dynamic operation.

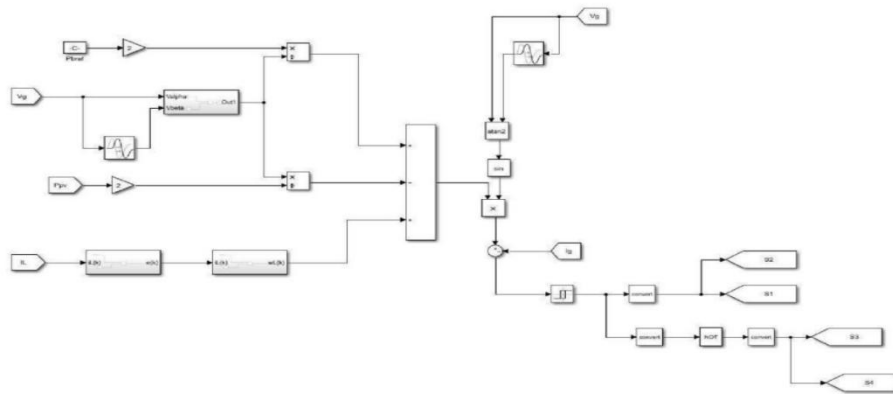


Fig. Control system for VSC

Detailed simulation analysis of the performance of Second Order Sliding Mode Cascaded Control (SOSMCC) strategy was conducted for different transient operating conditions. 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. Traditional controllers in some cases like the load demand change suddenly, may result in a long settling time and can result in a large voltage overrun. The proposed SOSMCC technique can remove these undesirable effects and guarantees quick dynamic response and disturbance rejection. From the simulated voltage waveform on the DC-link, it can be seen that the voltage fluctuation is very small and the DC-link voltage stabilizes rapidly after transient disturbances. It is designed in cascaded configuration to enhance the precision of the current and voltage regulation, besides decreasing the steady state error. The second order sliding mode mechanism also reduces the chattering effects which are common with the conventional sliding mode controller. Under different operating conditions, the transient performance, settling time and the stability performance of the suggested method SOSMCC are superior than that of conventional control. The results demonstrate that the SOSMCC approach is suitable to ensure the power flow of the EV charging network with steady and reliable power supply from RE sources.

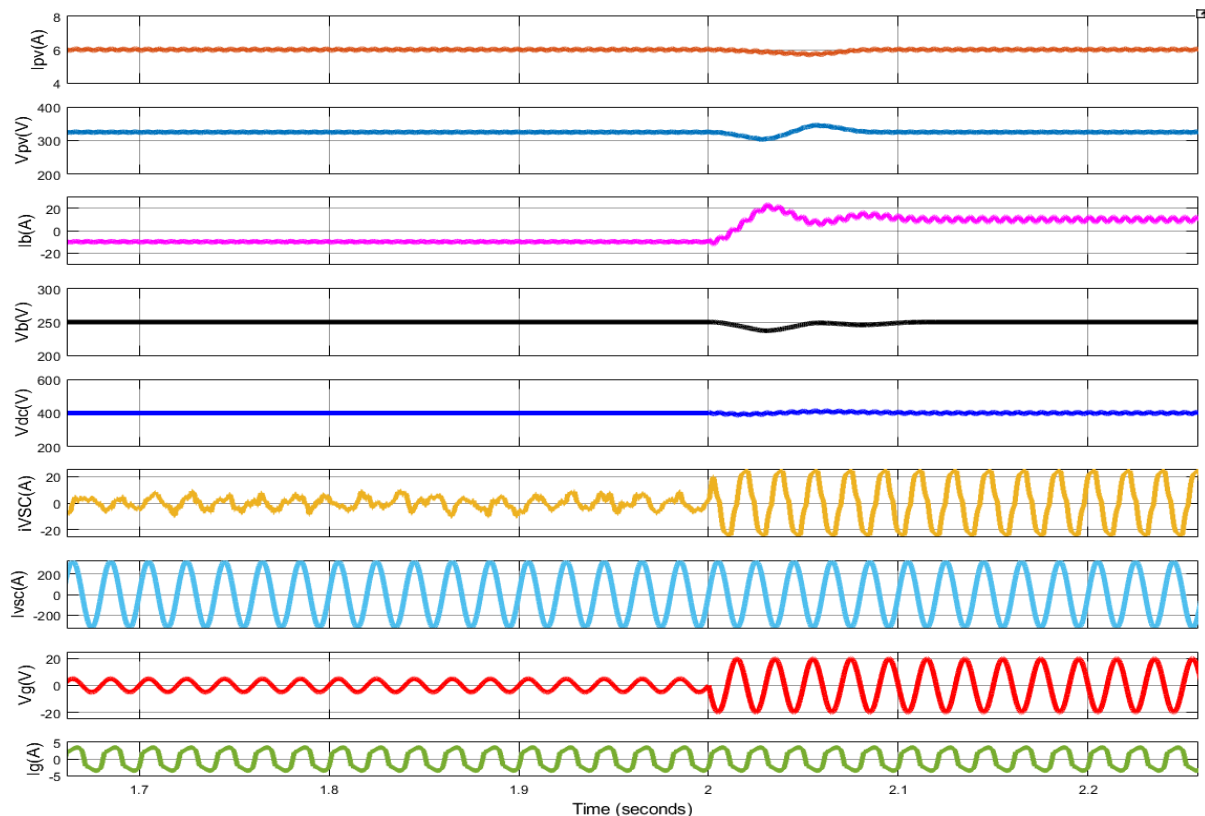


Fig. 8. Transitioning performance from G2V to V2G

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. Rapid changes in solar irradiation, switching loads or a sudden change in operation modes (G2V / V2G) are examples of disturbances that can have a 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 shows effectiveness of the disturbance observer in suppressing voltage overshoot, undershoot and oscillations during transients. The transient response of the LESDO was better, and the settling time was significantly faster than that of the existing disturbance observer systems. The results show that the proposed observer will improve the system resilience and the system will still be able to charge even when facing fast electrical and climatic changes. The combination of the SOSMCC controller and the LESDO allows for power flow management, very stable control of the DC-link voltage. The findings confirm the ability of the proposed disturbance compensation mechanism for improving the stability of the operation and the reliability of the entire charging system in practical EV charging systems using renewable energy.

A simulation study of the proposed system to improve the quality of power supply has also been done. Harmonics can be generated by power electronic converters and/or nonlinear loads and this can lead to reduced system efficiency and impact on grid performance. To overcome this problem, proposed charging method is to condition the current signal and to reduce the harmonics by the use of SABCAF algorithm. The simulation results show that the SABCAF controller is able to separate the fundamental part of the load current and eliminate higher order harmonic components from the load current. After filtering, the grid current waveform becomes almost sinusoidal, which means that there is a significant decrease in harmonics and the current quality is enhanced. Adaptive filtering has the advantage of faster convergence speed and smaller Mean Square Error (MSE) than traditional filtering methods to dynamically adjust the filter coefficient according to the operating conditions of the system. In simulation Total Harmonic Distortion (THD) values are calculated and it is seen that the proposed solution keeps the THD

values within the IEEE 519 standard limit of 5%. Reducing harmonic distortion will significantly enhance power quality, power losses and system efficiency. Based on the results of the simulations, it can be concluded that the SABCAF algorithm can deliver better results in terms of harmonic mitigation which is suitable for the new charging infrastructure of EVs powered by renewable energy.

The Voltage Source Converter's (VSC) ability to keep the DC-link bus and utility grid in sync is shown by the results of the accompanying simulations. The VSC transforms the regulated DC power into high quality AC voltage so that it is “grid-integrated”, “load-supply-ready”. Improved converter efficiency and reduced switching losses were achieved by the use of intelligent pulse-width modulation (PWM) switching methods. The simulation waveforms demonstrate steady voltage profiles with a range of loads and low distortion, even grid currents. The converter is able to keep the PF very near unity and compensate the reactive power requirements of the nonlinear loads. The role of the VSC is to manage power flow adaptively in order to maintain voltage stability and continuous charging operation in the event of a transient like an unforeseen addition of load or a grid event. The converter output convergence with the utility grid during the entire simulation was virtually the same. The results showed the need for VSC based power quality improvement, reactive power compensation and an integration of renewable energy resources without any issues in the power grid.

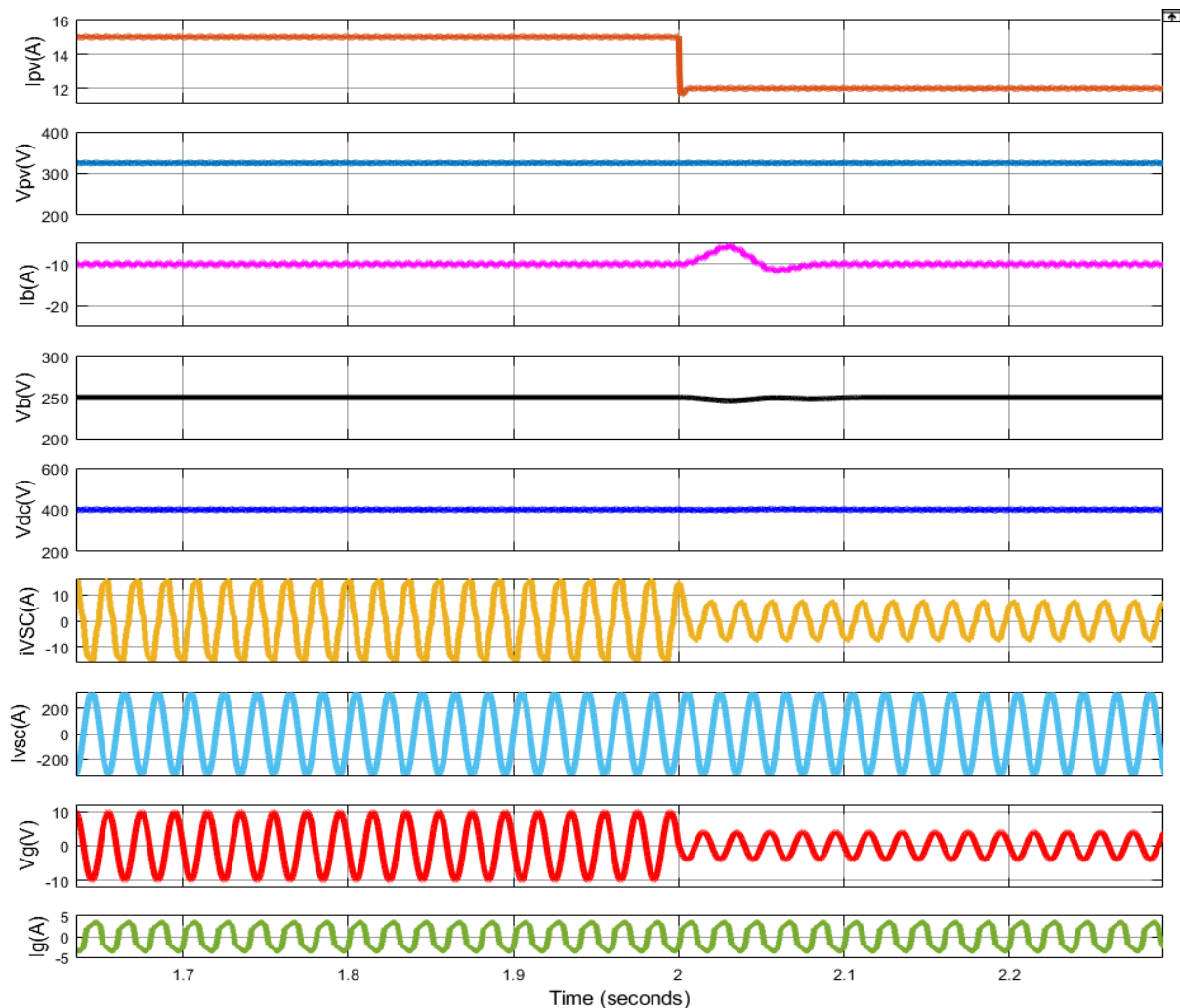


Fig. Performance during the change of solar irradiance

One important finding from the simulation study is the efficiency of the switching between the two modes of operation of the system, the G2V and the V2G. If the smart grid is to enable reliable charging infrastructure for EV, charging and

discharging should follow each other in a seamless manner. The proposed control scheme is capable of controlling the mode switching while ensuring no instability, large voltage jumps or current surges as verified by simulation experiments. The bidirectional converter maintains the DC-link voltage and battery current at all times and the power can be either transferred from G to V or V to G during the transition between G2V and V2G modes. The charging process of the battery can go on without transitory oscillation when the system switches from V2G to G2V. In collaboration with the LESDO observer, the SOSMCC controller is able to suppress any mode switching disturbances to ensure seamless energy transfer from 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. The comparative study performed in simulation also gives a further indication as to the potential advantages of the proposed control techniques as compared to conventional techniques. In dynamic conditions, the reaction time, harmonic distortion and disturbance rejection ability of the conventional proportional-integral controller and simple filtering methods are generally slower. The combination of the suggested SOSMCC, LESDO and SABCAF algorithm, however, significantly improves the voltage control, harmonic suppression and dynamic responsiveness. The simulation results show that, the simulation not only does not overshoot or undershoot but also can converge faster than the conventional method, and its settling time is also shorter and the Mean Square Errors (MSEs) are also smaller. It is also shown that the proposed control architecture is good for adaptation to variations in the environmental conditions such as solar irradiation and load demand. It is shown that high-level adaptive control and disturbance compensation strategies can be effective in improving the performance and reliability of the solar EV charging system. The proposed technology possesses better performance features that is suitable for its future application for transportation in conjunction with renewable energy.

V.CONCLUSION

Finally, the solar photovoltaic (PV) electric vehicle (EV) charging system will be reliable, efficient and environmentally friendly for future transportation and energy management. 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 consists of solar array, bidirectional DC-DC converter, battery energy storage system, Voltage Source Converter (VSC) and advanced charging control algorithms to ensure reliable and efficient operation under varying load and weather conditions. Maximum Power Point Tracking (MPPT) guarantees the extraction of maximum power from PV system and Second Order Sliding Mode Cascaded Control (SOSMCC) ensures good control of DC-link voltage and improves the system stability. In addition, Linear Extended State Disturbance Observer (LESDO) is used to improve the ability to reject disturbances and to minimize transient oscillations in the dynamic operating circumstances. 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 carried out using MATLAB/Simulink and confirmed the efficiency of charging process, proper voltage control, reduction of harmonics, and smooth G2V and V2G operations. Finally, the recommended design is a feasible, intelligent and energy efficient charging infrastructure for EVs in smart grid application for renewable energy that could be important in sustainable development and clean transportation.

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