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Multifunctional Bidirectional Charging System for EVs and Grid with Improved Power Quality Using a Sparse Proportionate NLMF Based Method

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Abstract –

Electric vehicles are one of the most fascinating and essential fields to emerge in recent years. Therefore, this paper addresses the multifunctional charging system integrated with the grid, EV battery and household utilities. It presents an improved idea about the charging system with grid connection and its connection to the varying local nonlinear load. It consists of a voltage source converter (VSC) tied to the grid and bidirectional converter, which charges/discharges the battery and also regulates the constant voltage across the DC bus, where all the vehicles are connected for charging. It also shows the operations of charging/discharging the battery of EVs and the voltage and current profile across the battery as per the state of charge (SOC) limits. Moreover, the sparse constrained proportionate normalized least mean fourth (SCP-NLMF) based method is used to control the charging system by estimating the active component of load current. The derived mean square error (MSE) of load current is improved due to low convergence rates in later periods. The adaptation process becomes more accurate by mitigating the MSE error of load current to converge faster and the dynamic response is further improved. The simulated results validate the accuracy and efficacy of the SCPNLMF technique and charging system.

***Keywords* –** Multifunctional charging power quality, SCPNLMF, voltage source converter.

I. INTRODUCTION

Due to significant societal advancements, rapid urbanization, and coal-fired electricity generation, air pollution has become a critical environmental hazard to human health. A 2019 study by the World Health Organization (WHO) identified air pollution as a significant ecological hazard to health, with the combined impact of ambient (outdoor) and household (indoor) air pollution linked to approximately 6.7 million premature deaths annually. Climate change, increasing worry over energy prices, and the depletion of conventional energy resources have caused endeavors to mitigate it in many ways, such as through government policies focusing on significant areas of industry, transportation, urbanization, power generation, and municipal and agricultural waste. According to the International Energy Agency (IEA), India is ranked third largest in the global emission of greenhouse gases, including CO_2, NO_2, SO_2, etc. The country is responsible for around 2.5 billion metric tons of CO_2, or precisely 7% of worldwide CO_2 emissions. In short, air pollution is controlled by using green energy in the power sector. The transportation sector is a significant source of urban air pollution.

The charge/discharge and energy management are discussed carried out the review on the charging infrastructure and various charging levels for the plug-in-EVs. Moreover, these multifunctional charging systems are operated in four non-identical configurations with respect to future smart grids: (1) The EV battery pack being charged by the grid from the G2EV mode; (2) The EV battery pack can inject stored energy back into the electrical power grid through the electric vehicle-to-grid (EV2G) mode; (3) The charging system is operated in the vehicle to home mode (EV2H) mode; (4) a multifunctional vehicle to vehicle (V2V) charging system is also the requirement for the current era. Here proposed a coordinated control to help the penetration of EVs into the grid and support the grid frequency control during the fast EV's charging rates. In researchers have focused on the performance of the bidirectional battery chargers (BBCs). More specifically, they consider a designed BBC for the charging of a particular EV and subsequently it is sized to match the specifications of that particular EV's battery. In a voltage based scheme is discussed, which does not require any communication between EVs and the grid. However, the impact on grids with integration of EVs and power quality issues are not included in it. The quality of power during the EV2G and G2EV operating modes is also one of the major concerns during the grid interaction.

The increase of consumer nonlinear loads, for example, electric furnaces, power converter based power supplies and LEDs, etc., at the point of common coupling (PCC), is the main cause in disturbing the quality of voltage and current in the distribution grid. In a power quality control is proposed for the battery storage and PV array based system. It enables the only active, only reactive, and simultaneous active and reactive power exchanges with the grid. This system is able to maintain the grid current THD below 5% in all operating modes. The optimal planning of Electric Vehicle charging stations into the grid/distribution feeder has become very important as it plays a significant role in quality management. It presented an integrated traction machine and converter topology that enables the bidirectional power flow between EV and DC/AC supply and/or the grid. The traction motor has also an adequate value of inductances, which are used for the bidirectional converter operations, reducing the need for extra inductors for the charger and EV2G converter operations. The electric power train system size and weight are minimized with this presented approach. There are various control methods, which are used to control the grid interactive converter for bidirectional power flow and to address the power quality concerns.

In this paper, a sparse constrained proportionate normalized least mean fourth (SCP-NLMF) based method is used for EV2G and G2EV and battery operations, along with power quality improvements. It reduces the harmonics, corrects the power factor and also retrieves the peak power generation. Moreover, proposed an efficient battery charging system, in which low cost battery charging is imposed and at the same time degradation time of the Lithium- ion battery is also improved. Therefore, battery energy storage technology is the core of the multifunctional charging system for EVs, which comprises a bi-directional converter and VSC tied to the grid. It plays the important role in monitoring the charging/discharging of the EV battery and battery swapping techniques, which are achieved by finite state machine (FSM) based logic. In the above model, different types of control methods are used to control the load current, DC link voltage and grid currents. Therefore, the adaptive controls are the key to controlling the charging system with improved transient response analysis. In sparse constraint NLMF adaptive techniques are presented to estimate the sparsity of the system. It improves steady state and transient performances of the system. Moreover, these adaptive filters enhance the fundamental load current tracking ability, as they consist of a zero attracting term as well as the variable step size. The step size of the technique is updated under adaptively disturbances and noise. Therefore, these controllers are playing a crucial role as the charging system is subjected to dynamic conditions, charge/discharge and sudden load changes. In this paper, a multifunctional charging system is presented with EV2G and G2EV modes along with the nonlinear load with adaptive technique. The highlights of this study are as follows:

- EV batteries are charged through the grid in G2EV mode.
- EV batteries are used to feed the grid, i.e., EV2G mode (during the peak load) and household loads.
- The control of the bidirectional converter is used for DC link voltage control according to the demand.
- The feasibility of the presented method: the presented charging system is utilized to accomplish feeding continuous power to the emergency loads and power quality unit, such as

a distribution static compensator (DSTATCOM), to mitigate the harmonics and compensate for the reactive power, which is very feasible to commercial utilities.

- The effectiveness of the presented multifunctional charging system and SCP-NLMF control are validated through simulated results.

II. POWER QUALITY

Our technological field had became totally depend upon the continual obtain ability of electrical power. In most areas economical power is made accessible via nationwide grids, number of generating stations connecting to each other to the loads. The grid should deliver basic countrywide requirements of lighting, air conditioning, heating, residential, refrigeration and shipping in addition to the considerable deliver to commercial, governmental, medicinal, fiscal, engineering, and communities of communications. Economical power authentically permits today's modern world to operate at its busy grid.

A perfect power supply would be one that is always available always within voltage and frequency tolerances and has a pure noise-free sinusoidal wave shape. Power Quality means the ability of utilities to provide electric power without interruption.

Mainly the seven types of Power Quality problems are there. They are

A. Transients.
B. Interruptions.
C. Voltage Sag.
D. Voltage Swell.
E. Waveform distortion.
F. Voltage fluctuations.
G. Frequency variations.

A. TRANSIENTS

Potentially the most disturbing type of power disruptions transients fall into two subclasses:

1. Impulsive.
2. Oscillatory.

1. IMPULSIVE

Impulsive transients are abrupt high peak contingency that increases the current and/or voltage levels in any direction of a positive or negative direction. These kinds of contingencies can be categorized further by the quick at which they happens (slow, medium and fast).

2. OSCILLATORY

An oscillatory transient is a quick alteration in the condition of a steady-state of a signal's voltage, current or both at the negative and positive signal boundaries swinging at the expected frequency of system.

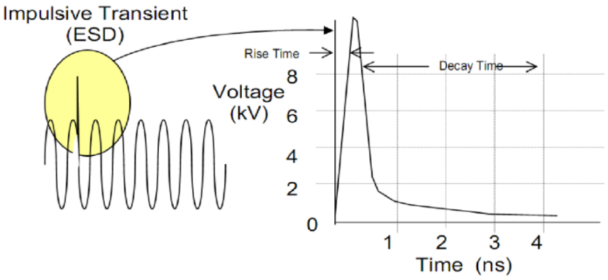


Fig.1 Positive Impulsive Transient

For instance leading distortion of a revolving motor it operates momentarily as a generator as it powers along, thus generating electricity and delivering it in the course of the allocation of electrical.

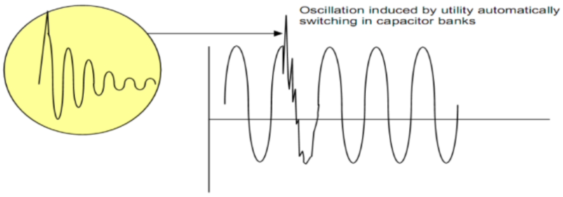


Fig.2 Oscillatory Transient

B. INTERRUPTIONS

Interruptions are explained as the total loss of load current or supply voltage. Be determining on it’s during something continues, an interruption is can be classified as transitory, immediate, sustained or temporary.

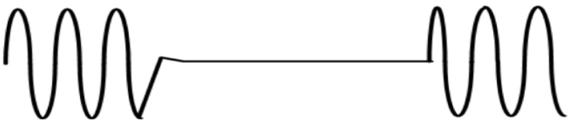


Fig.3 Momentary Interruption

C. VOLTAGE SAG

A Voltage Sag is a curtailment of AC voltage next to a specified frequency for the span of 0.5 cycles to 1 minute’s time. Sags be generally effected through system faults and be as well frequently the consequence of switching on loads through heavy startup currents.

Fig.4 Voltage Sag

D. VOLTAGE SWELL

A swell is a reverse form of sag, containing a increase in AC voltages for a duration of 0.5 cycles to 1 minute's interval. For swells, rapid (especially large) load declines high-impedance neutral associations and a fault of single-phase on a system with three-phase is general supply.

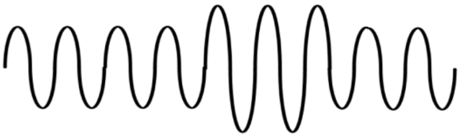


Fig.5 Voltage Swell

E. WAVEFORM DISTORTION

Presently there are five major types of distortion in waveform are, DC offset, Harmonics, Inter harmonics, Noise, Notching.

F. VOLTAGE FLUCTUATIONS

While voltage fluctuations are essentially dissimilar from the rest of the waveform abnormalities, these are located in their own group.

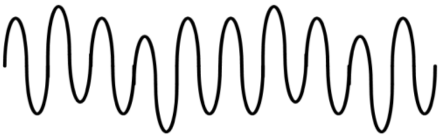


Fig.6 Voltage Fluctuations

G. FREQUENCY VARIATIONS

Frequency variation is enormously odd in stable utility power systems, particularly systems be linked via a power grid.

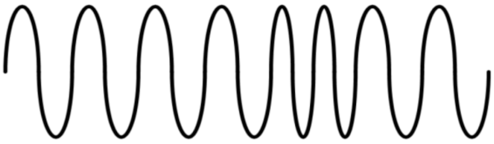


Fig.7 Variations of Frequency

III. SYSTEM MODELING

The topology of the charging system is shown in Fig. 8. The configuration shows the integration of the grid with EV battery and nonlinear loads. The grid is supplying power to the nonlinear load which is constructed by using a diode bridge rectifier, followed by R and L. The grid is connected to the bidirectional converter through a common DC link capacitor via a voltage source converter (VSC). The VSC transforms the AC power of the grid side to DC power, which is further fed to the bidirectional converter to feed the EV battery. The bidirectional converter is connected to the EV battery with a smoothing inductor. The ripple circuits having intermediate resistance and very low capacitance are employed for the reduction of the high frequency noise from the grid voltages.

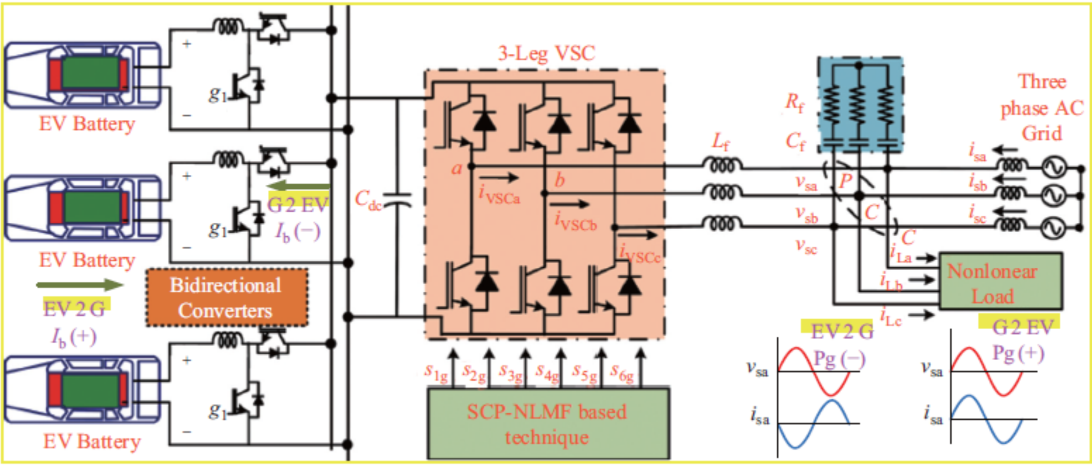


Fig. 8. Circuit topology of the charging system.

The parameters of the EV battery storage are rated at 240 V and 20 Ah. For the control of Vdc and Iba, the bidirectional converter is used. The switching frequency which is used here for the operation is considered as 20 kHz. The DC voltage across the capacitor of the VSC should be greater than twice the peak grid voltage. The VSC is switched at high frequency and at this frequency, harmonics are generated, which are mitigated by a series connected resistance and capacitor. The primary focus is to maintain the power flow between the grid, EV battery, and household utilities. In this charging system, the EV battery is charged and discharged depending upon the requirements, and accordingly the direction of the battery current is changed by the presented control. Therefore, the control is developed in such a way so that its multi functionalities are achieved. It has prime controls, the DCAC converter and the EV battery storage controls. The SCPNLMF control helps to connect the VSC to the grid and the bidirectional converter control sustains actual DC bus voltage along with providing the basis for determining the phase and peak values of grid voltages and fundamental weight signals of load currents. This section describes the various control mechanisms that are used in the charging system.

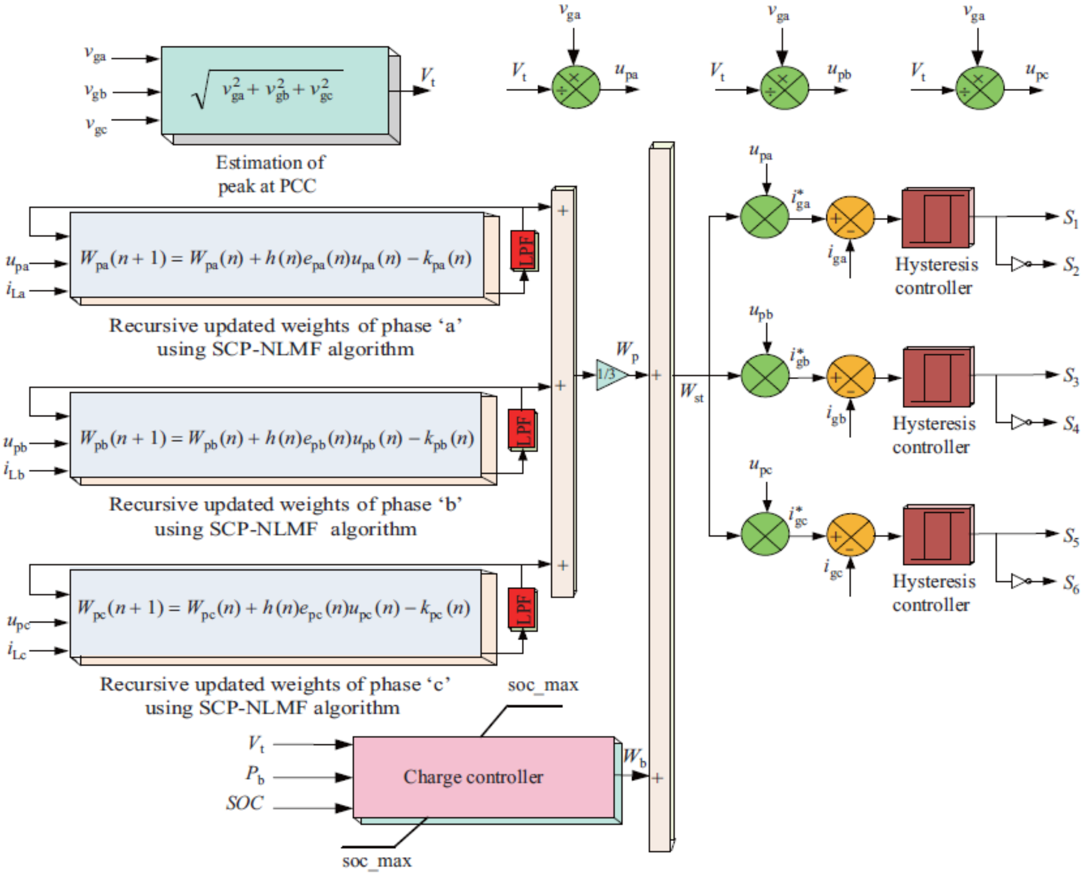


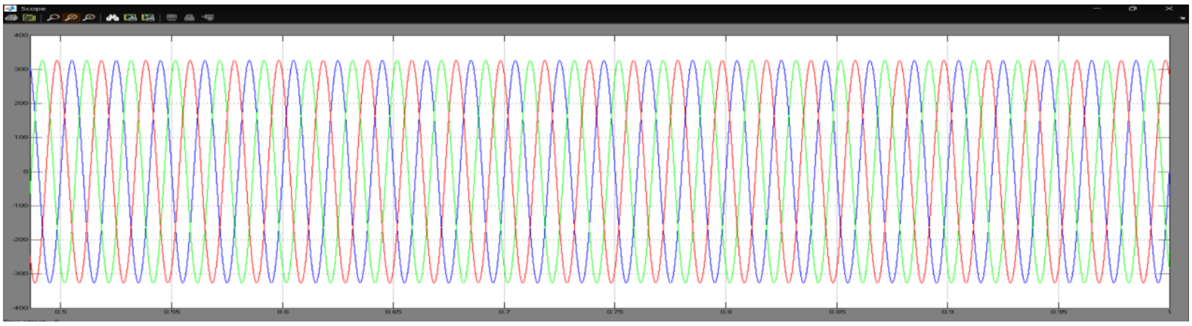
Fig. 9. Sparse constrained proportionate normalized least mean fourth (SCP-NLMF) control technique.

Figure 9 shows the SCP-NLMF based approach to manage the power flow in the charging system. The merit of this control technique is that it extracts the fundamental weight component with less harmonic contents and has the capability of mitigation of noise and disturbances which makes this technique superior as compared to other controls. The sparse channel estimation behavior of the presented filter is good and therefore it increased the convergence speed to estimate the fundamental load current. The incorporation of unit templates are necessary in this control. Moreover, the unit templates are generated for each phase and then these unit templates are integrated with the presented adaptive technique to develop the battery charging/discharging. For VSC, the sparse constrained proportionate normalized least mean fourth algorithm is used to control for VSC. However, for distribution grid voltages, a bandpass filter is utilized in sensed grid line voltages. To determine the unit templates and PCC amplitude voltage, the phase voltages are obtained by sensed line voltages. The unit templates are incorporated to generate the pulses for the VSC. It helps in the generation of sinusoidal grid reference current. The large value of step size corresponds to the fast response. However, there is a significant amount of steady state error in the extracted active weight component of the load current. Moreover, the small value of the step size is subjected to slow convergence and poor dynamic response. The sparse constraint NLMF efficiently performs under sparsity estimation phenomenon. This term reduces the effect of second term and the next recursive updated weight is similar to the previous weight. Moreover, as the proposed technique incorporates variable step term h(n), which mitigates the weight other than the estimated fundamental weight of the load current. The capability of fundamental load current extraction of the current controller is good when compared to other conventional controllers. Therefore, it also improves the current injected to the grid. Therefore, the power quality of the charging system is also improved. Similarly, the active weight signal of phase b and c are estimated for the three phase system.

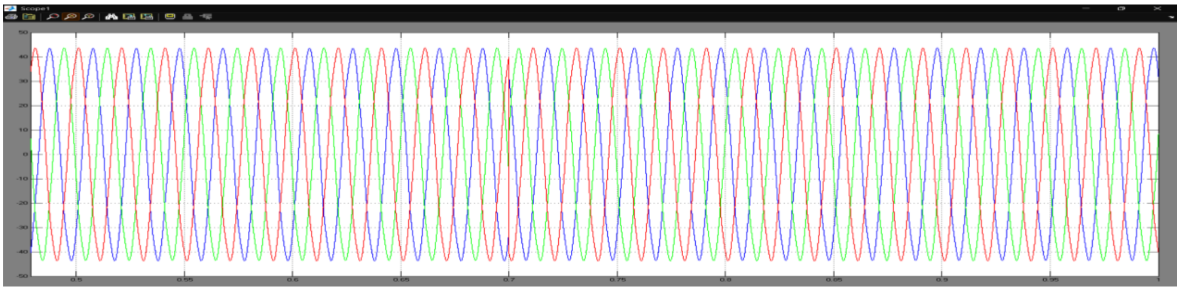
IV. SIMULATION RESULTS

A configuration of the charging system, with grid, EV battery and non-linear loads is established from the MATLAB/Simulink software. For investigating the behavior of the developed model, the response of VSC and bidirectional converter based charging system is analyzed for various dynamic conditions. The behavior of the developed model is analyzed for the grid voltage as Vg, grid current as Ig, load current as iL, DC link voltage as Vdc, battery voltage Vb, battery current Ib and SOC. The simulated results are observed and recorded to validate the various operations.

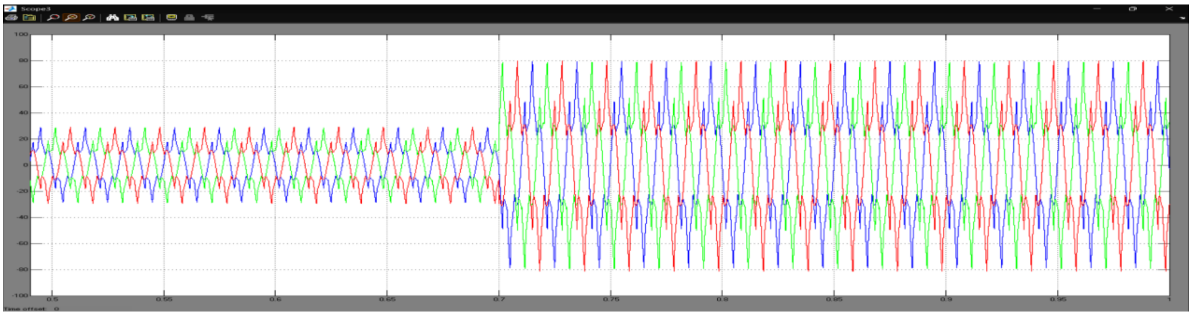
CASE A- Dynamic Performance of the Charging System at Mode Transfer from G2EV to EV2G and Vice-Versa:



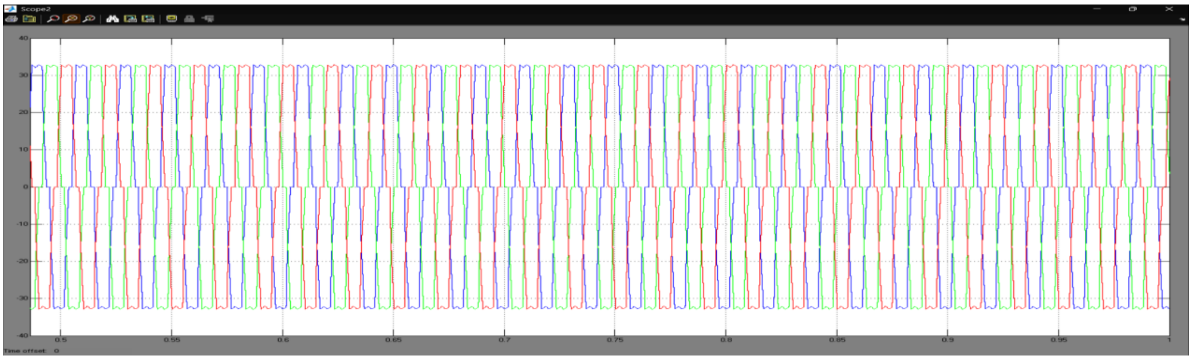
(a) Grid Voltage



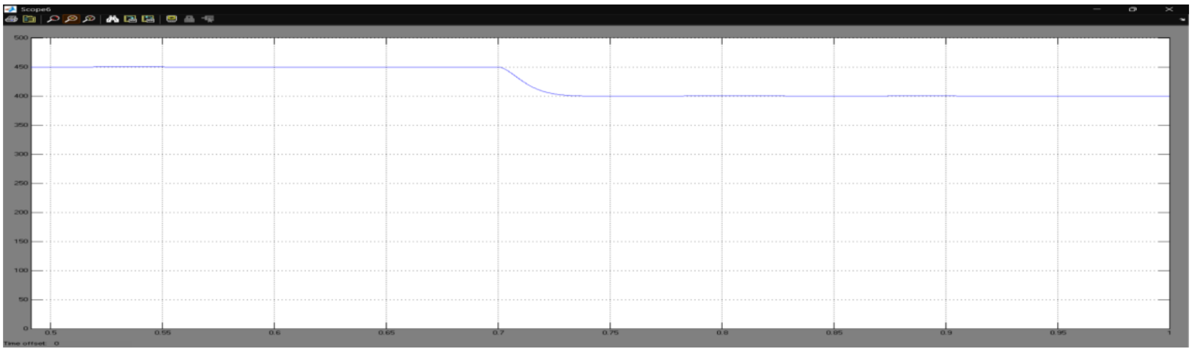
(b) Grid Current



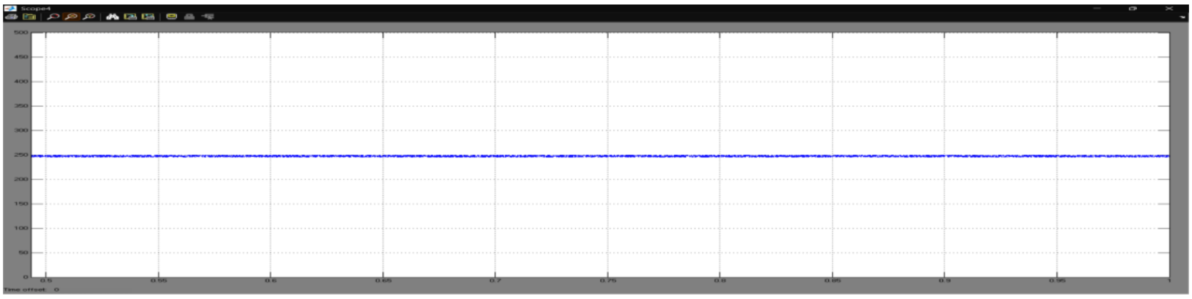
(c) VSC Current



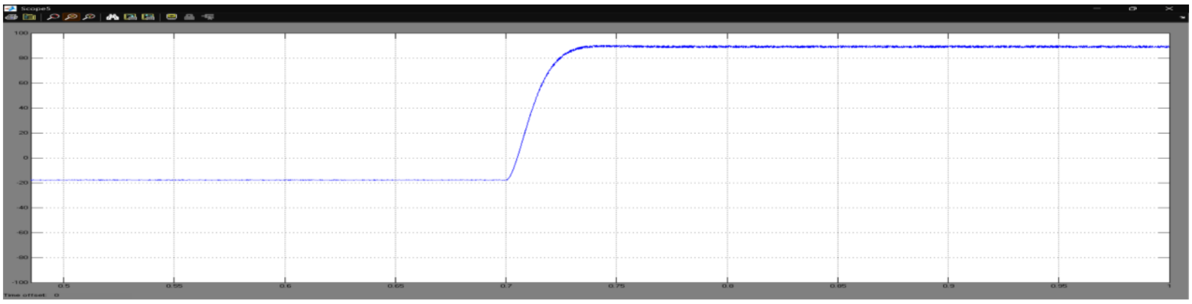
(d) Load Current



(e) DC voltage

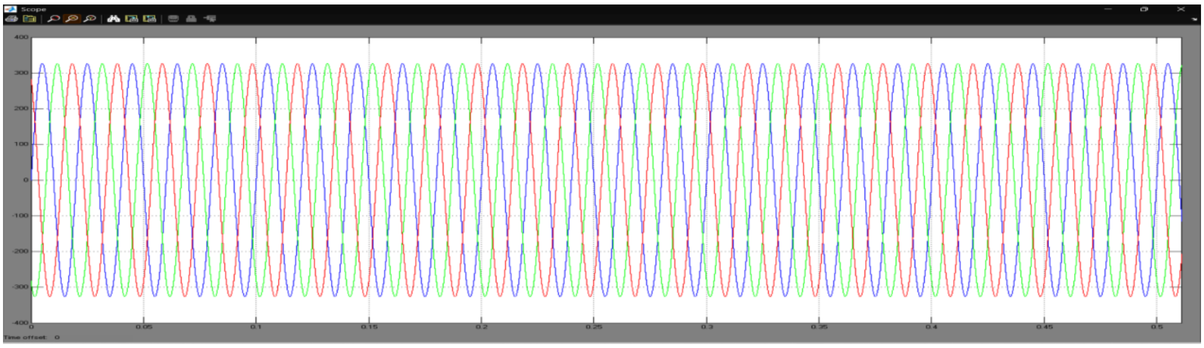


(f) Battery Voltage

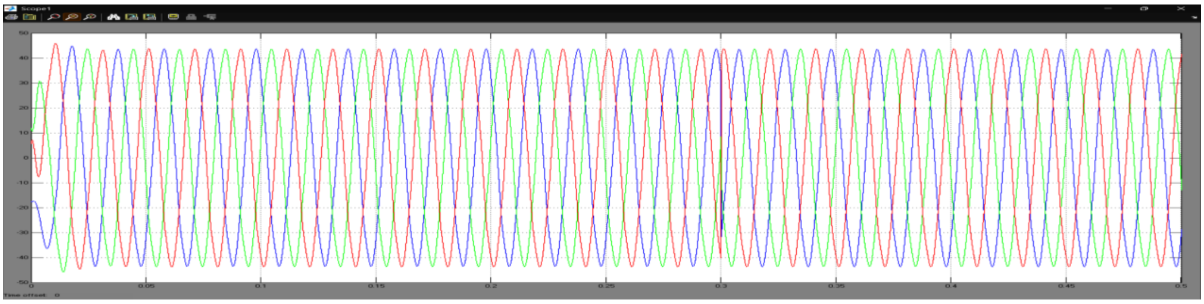


(g) Battery Current

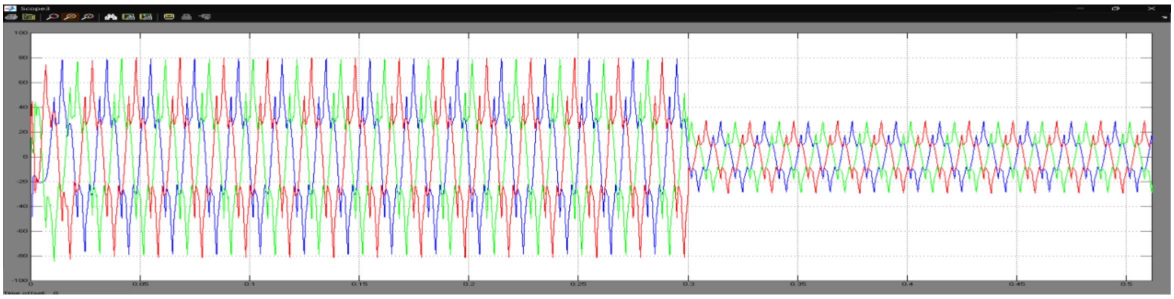
Fig. 10. Dynamic performance of the charging system under mode transfer from G2EV to EV2G.



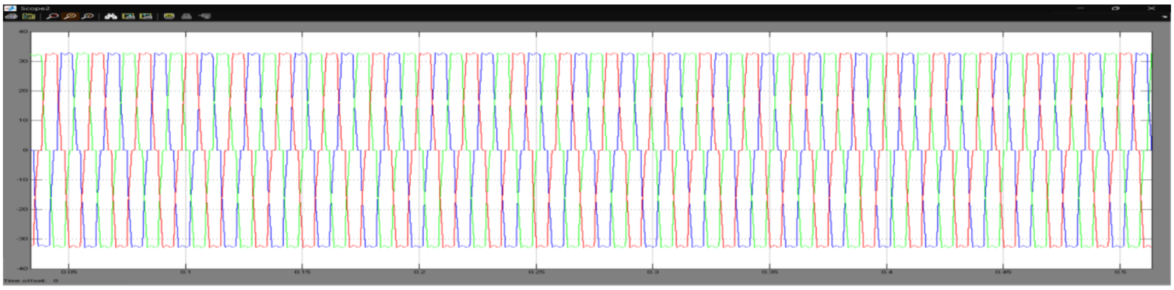
(a) Grid Voltage



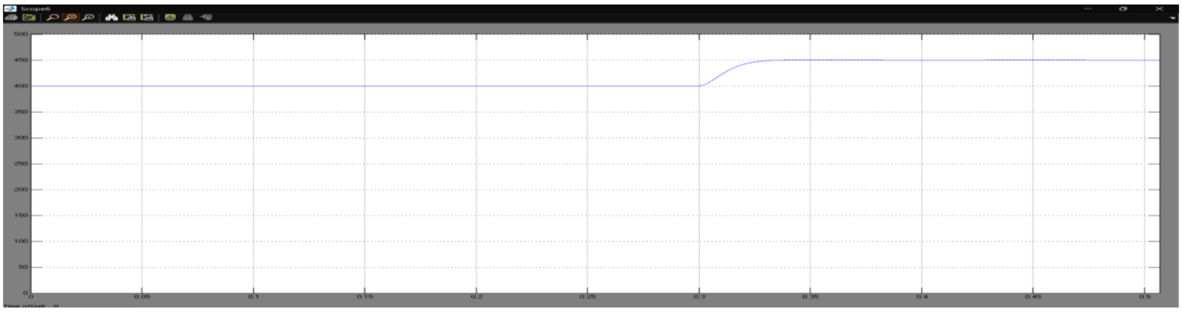
(b) Grid Current



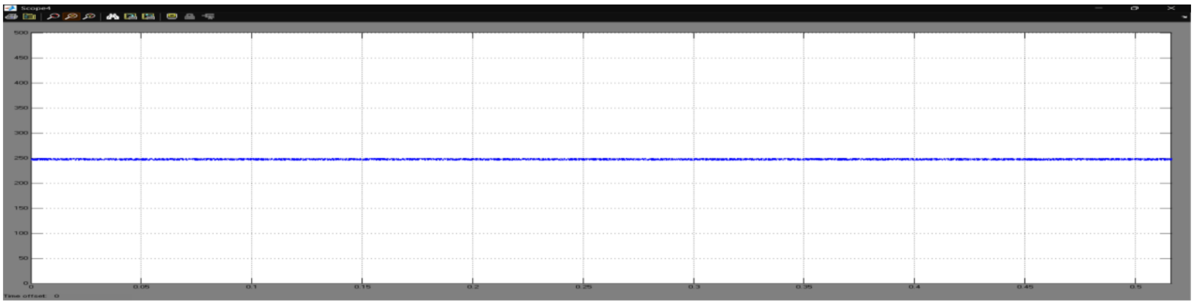
(c) VSC Current



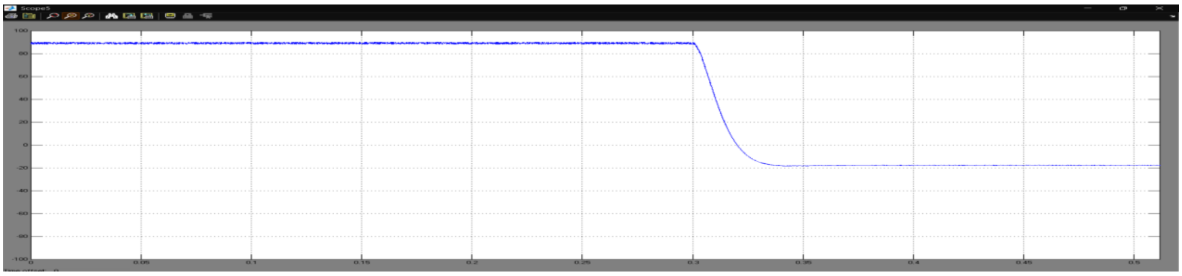
(d) Load Current



(e) DC voltage



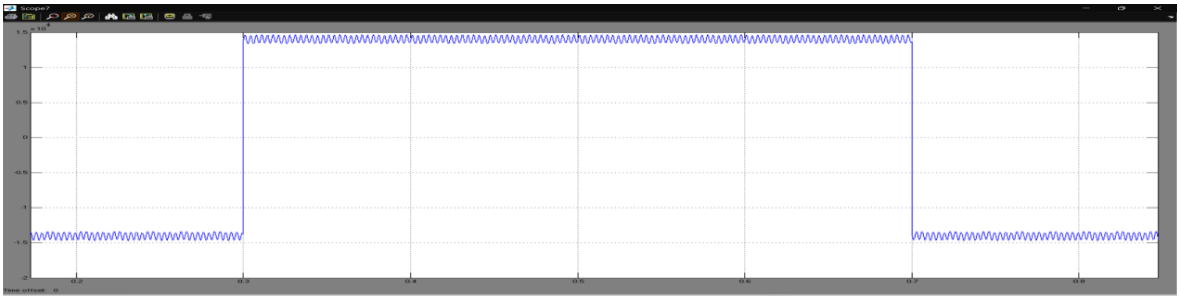
(f) Battery Voltage



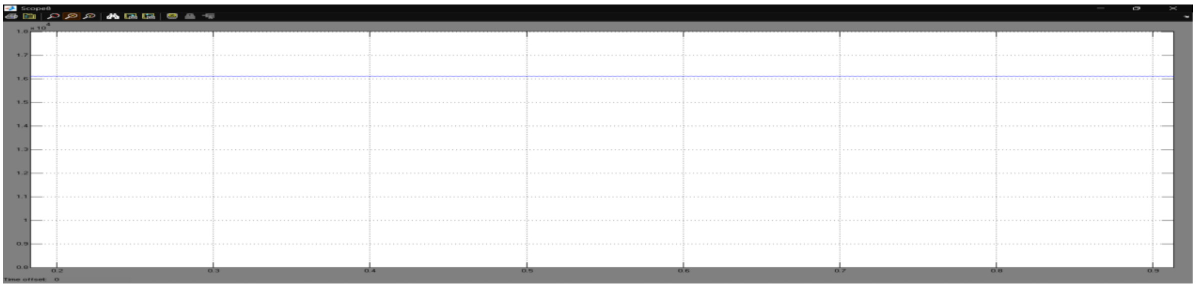
(g) Battery Current

Fig. 11. Dynamic performance of the charging system under mode transfer from EV2G to G2EV.

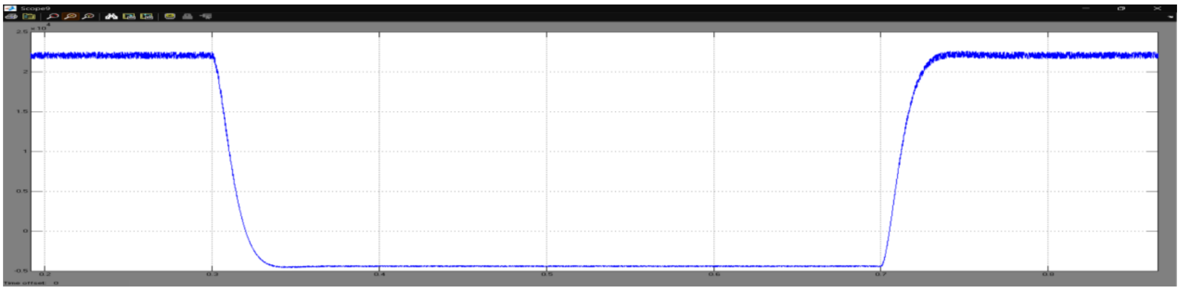
Figures 10–11 show the dynamic operating mode transition of the charging system from G2EV and EV2G and vice-versa. The behavior is analyzed based on the grid voltage (vg), grid current (ig), VSC current (iVSC), load current (iL), DC link voltage (Vdc) and battery parameters (Vb&Ib). Fig. 10 illustrates the transition of the charging system from G2EV to EV2G after 0.3 s. Moreover, after 0.3 s, the ig and vg both are in the opposite phase as the battery supporting the grid by supplying power to the grid. However, after 0.7 s, the transition of the system from EV2G to G2EV is presented in Fig. 11. Moreover, in the G2EV mode, the battery current is negative, which means the battery is charged and (battery and load) are drawing power from the grid as vg and ig both are in the same phase. In these transitions, DC link voltage, and load current are constant. The battery current is positive/negative while the battery is discharged/charged. In Fig. 11, the switching of EV2G to G2EV is presented. The vehicle battery is initially in the charging position and suddenly it is switched to the discharging mode to reduce the burden on the grid.



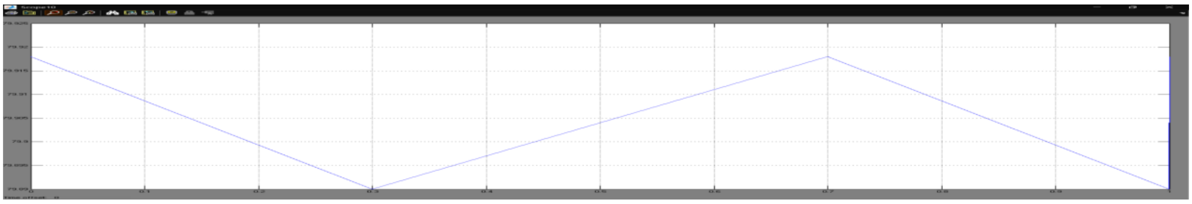
(a) Grid Power



(b) Load Power



(c) Battery Power

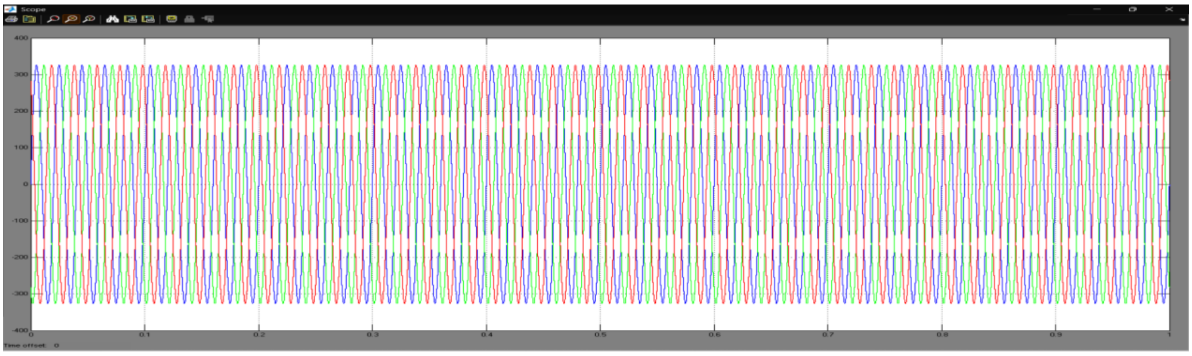


(d) SOC

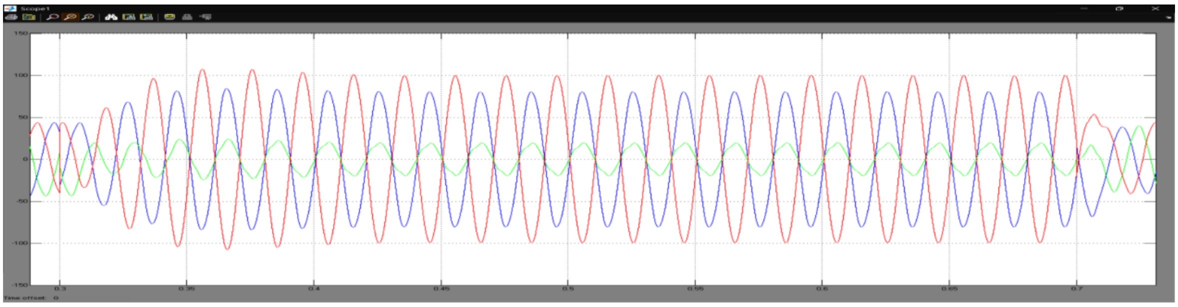
Fig. 12. Power analysis of the CS under G2EV and EV2G mode of operation.

Moreover, Fig. 12 presents the grid power, load power, battery power and SOC of the battery under EV2G to G2EV and G2EV to EV2G transition modes at 0.3 and 0.7 s. While the battery discharges (positive battery current), the grid power is negative, which ensures that the power is fed to the grid. The charging system is under the EV2G mode of operation. Moreover, when the battery is charging, the grid power is positive and the battery power is negative. It illustrates that the battery is charged via the grid, and depicts the G2V performance of the system. Moreover, accordingly, the battery SOC is also perturbed.

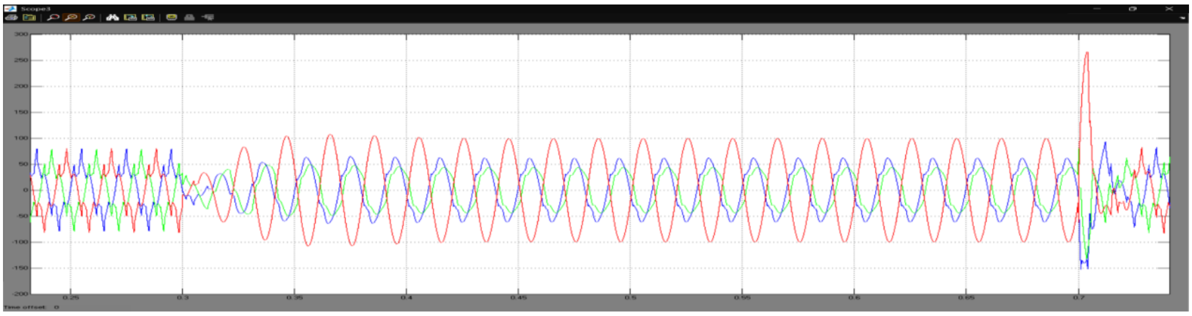
Case-B: Dynamic Response of the Charging Station Under Sudden Load Disconnection and Reconnection:



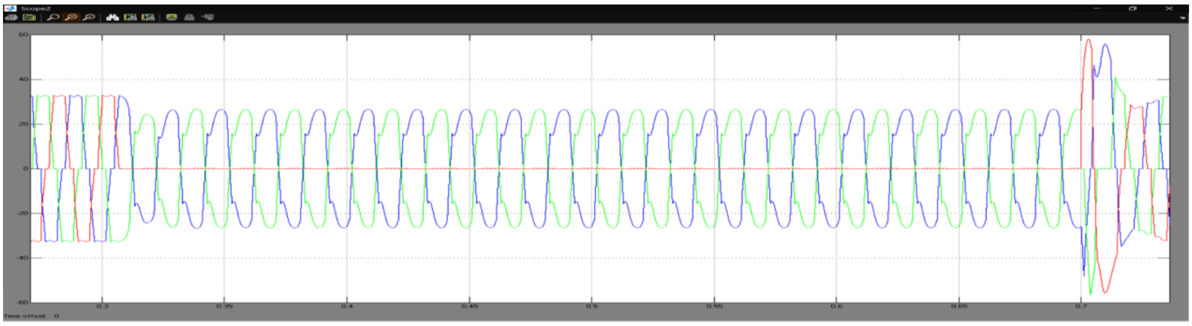
(a) Grid Voltage



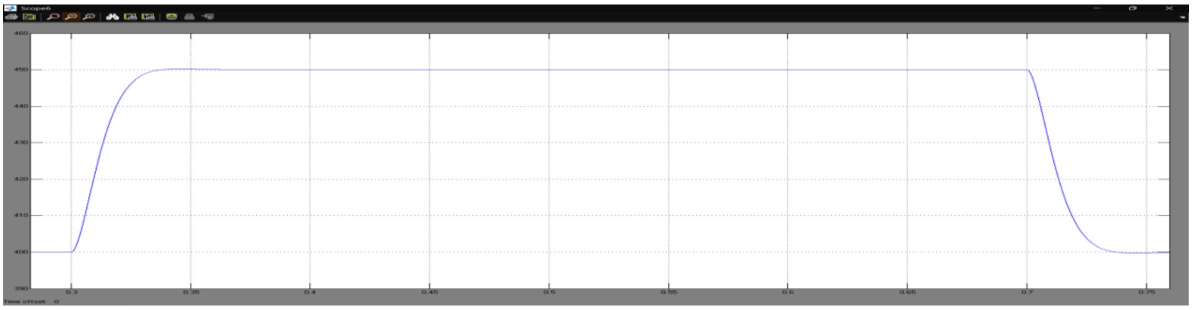
(b) Grid Current



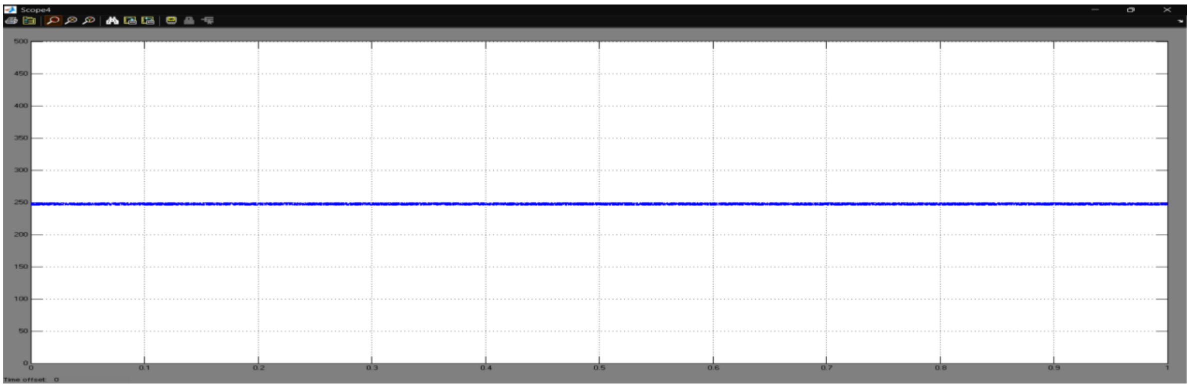
(c) VSC Current



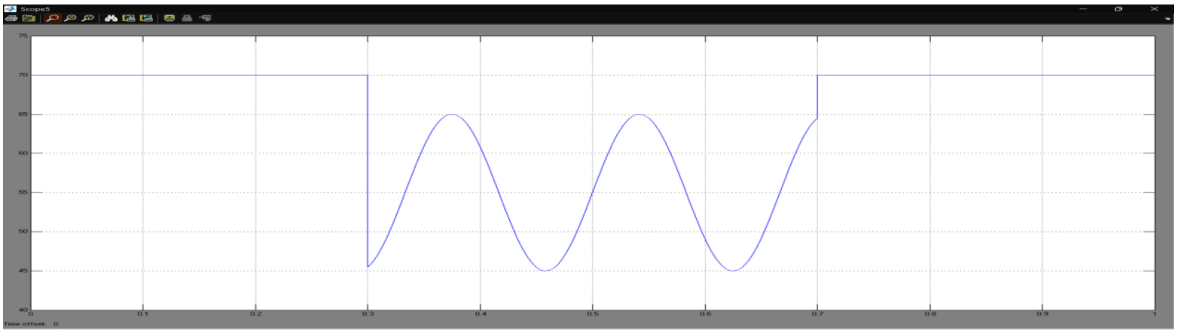
(d) Load Current



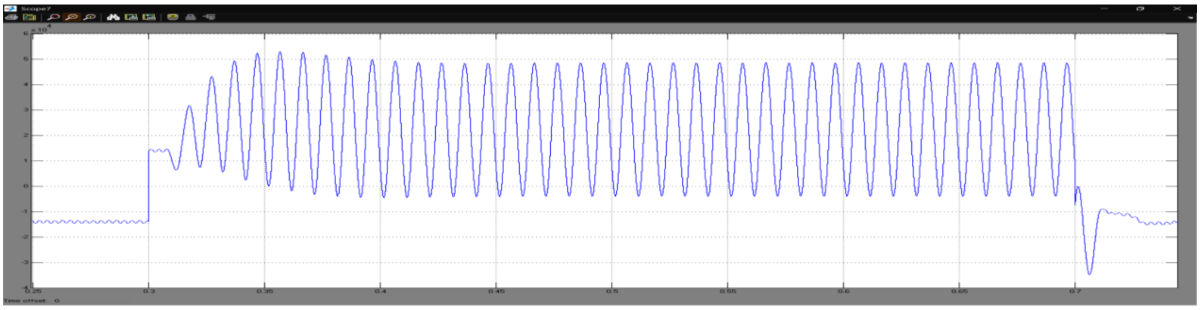
(e) DC Voltage



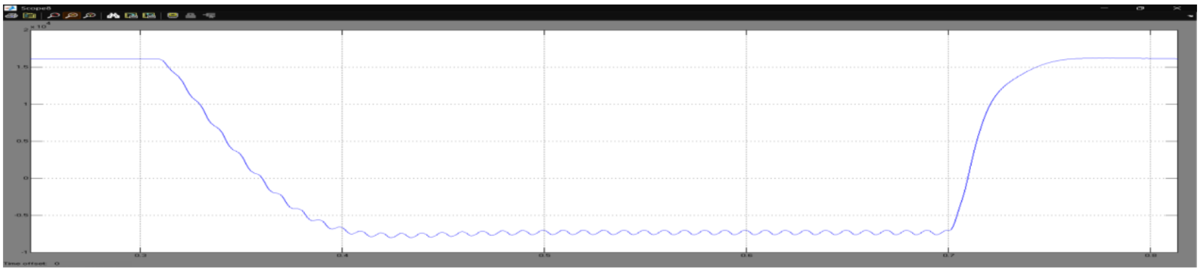
(f) Battery Voltage



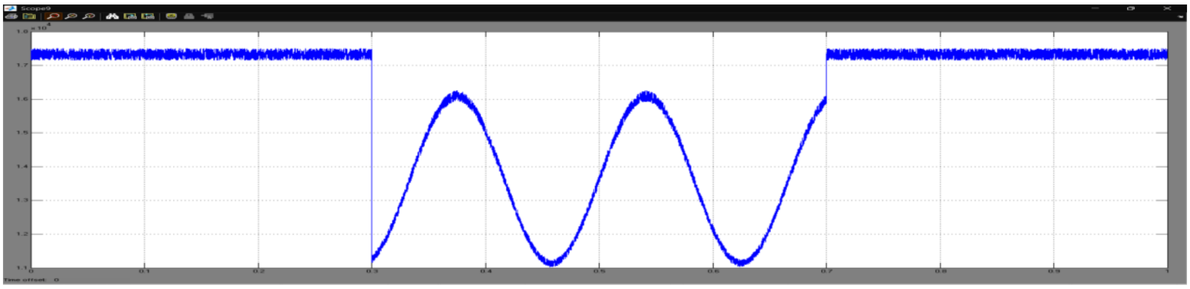
(g) Battery Current



(h) Gird Power



(i) Load Power



(j) Battery Power

Fig. 13. Performance of CS under load disconnection and reconnection.

Figure 13 illustrates the operation of the charging system under the sudden load disconnection and reconnection. It is observed that the grid voltage and grid current are out of phase and the battery current is positive, which ensures that the battery is giving energy to the grid. The sudden load disconnection is realized at 0.3 s and reconnection at 0.7 s. The VSC currents are non-sinusoidal and unbalanced to compensate for the load current. Therefore, the grid parameters are balanced and sinusoidal under the load transient. The behavior of the internal parameters of the adaptive SCPNLMF controller, such as mean square error, fundamental load component, are also shown. The mean square error and fundamental active weight signal are reached as the load of a particular phase is removed.

Comparison results:

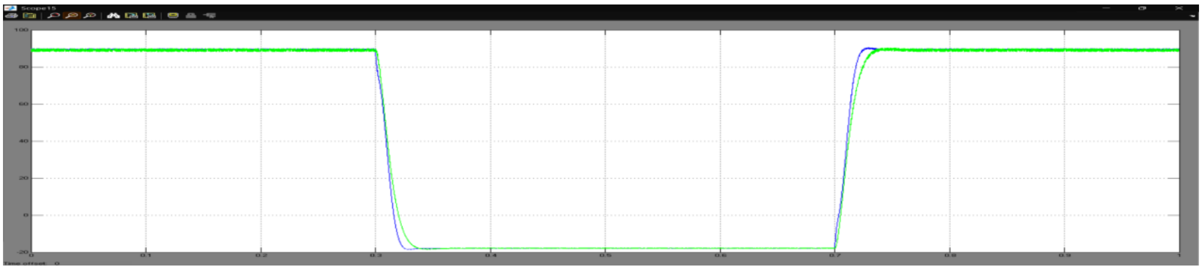


Fig: Battery current

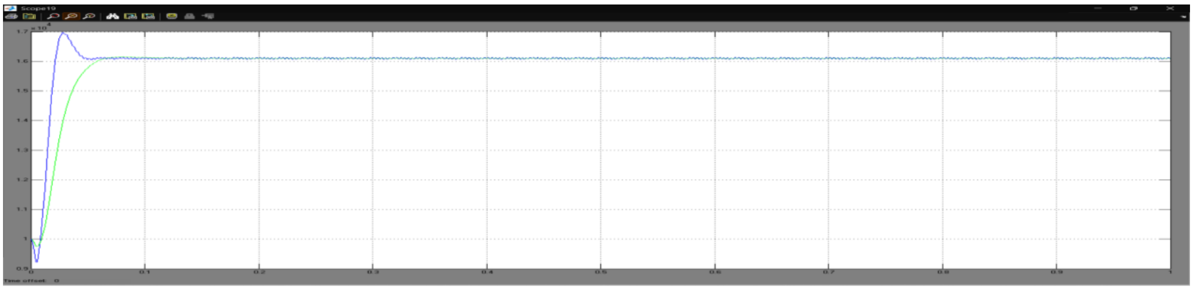


Fig: Load Power

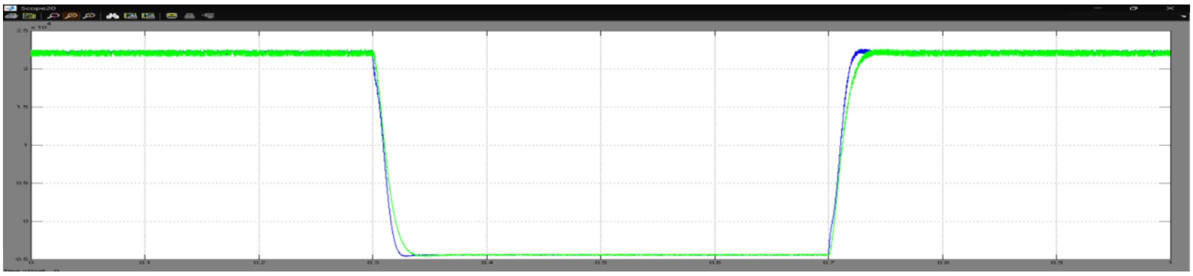


Fig: Battery Power

CONCLUSION

The proposed topology of the Multifunctional charging system for the EVs is designed, modeled and implemented. In this study, the SCP-NLMF control technique is used to control the VSC by generating fundamental weight signals and unit templates of each phase and then generating the VSC switching pulses. The simulation results show that the grid parameters are in range and battery characteristics are changing in accordance to the change in charging, discharging and load disconnections. The presented results through the proposed technique are effective and more compatible with the charging system as compared to other conventional techniques, such as LMS and NLMS. The error shown in this technique is very low and also the oscillations of the active weight signal is also less. Therefore, it has been observed that the presented charging system is efficient, relevant and has faster response time than the other conventional systems and control methods.

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