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Bi-Directional Power Flow Rapid Charging System Using a Carrier Wave Modulated Self-Commutated Voltage Source Converter for Electric Vehicle

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***Abstract:** This paper examines a high-performance battery charger for electric vehicles (EVs). Active power line filtering capabilities in the battery charger can be used to develop a fast-charging infrastructure that is advantageous for EV users as well as power distributors. This article discusses battery charger modeling and design difficulties in depth using a carrier wave modulated self-commutated voltage source converter architecture. A full study of the controller's features is also provided using model-based controller synthesis. The battery charger's active filtering performance is emphasized. In active filter applications, the model-based control system's intrinsic phase deviation and sensitivity to system factors decrease the active filter's performance, which is disclosed in this study. Based on numerous integrators in diverse reference frames, we provide an improved control structure for active filters to offset the model-based controller's degradation. The suggested controller demonstrates minimal sensitivity to system factors and fully compensates for the intrinsic phase deviation, as shown both theoretically and empirically. The suggested active filter controller has outstanding steady-state conditioning performance.*

***Keywords:** Bidirectional Battery Charger, Grid-To-Vehicle (G2V), Vehicle-To-Home (V2H), Vehicle-To-Grid (V2G).*

1. INTRODUCTION

Recently, EVs have developed as an alternative to internal combustion engine (ICE) cars to minimize petroleum reliance and comply with stricter rules on emissions resulting from a big environmental concern about global warming [1–2]. Electric cars' market share hasn't yet reached the levels of traditional internal combustion engines, but recent breakthroughs in energy storage and electrical engineering have given them a boost. The first EV was conceived in 1834, and it was manufactured and commercialized throughout the 19th century. Although EVs were once considered a viable alternative to internal combustion engines for passenger transportation, their rapid development and the high upfront costs of their batteries prevented them from being taken seriously.

In order to address the shortcomings of both traditional internal combustion engines (ICE) and pure electric vehicles at the same time, certain automakers are actively promoting hybrid electric vehicles (HEV). This is due to the difficulties of a rapid transition to pure electric vehicles. HEV designs can be simple, complicated, parallel, series-parallel, or series [4]. Their control algorithms are crucial because the main goal of HEVs is to maximise driving efficiency by operating either an ICE or an electric motor drive, depending on the situation. Although these vehicles have very low emissions, they cannot be regarded as being emissions-free entirely. Additionally, the price of the system as a whole goes up due to the requirement for more motors, electric storage devices, and power converters. The hybrid electric vehicles (HEVs) that can be charged by plugging into the grid are referred to as PHEVs (plug-in hybrid electric vehicles) under the terminology that has been used.

On the other hand, due to recent advancements in power electronics and energy storage technologies, various companies are placing bets on fully electric vehicles. For instance, although EVs have many benefits, like high energy efficiency, independence from fossil fuels, and zero emissions, they also have several disadvantages, including a high initial cost, a relatively small driving range, a short battery life, and delayed charging. Both PHEVs and pure EVs will be referred to as EVs moving forward to keep the notation simple.

Theoretical Overview of Electrical Vehicle

There are a variety of battery chargers out there, each with its own set of advantages and disadvantages [28]. Batteries may be charged either inside or outside the car, depending on where the charger is positioned. On-board battery chargers are those that are positioned within the vehicle, whilst off-board chargers are those, which are located outside the vehicle. Because of their weight and space constraints, onboard battery chargers can only be utilised [27]. A vehicle's electric drive system may use onboard battery chargers rather than the separate inductors and switches required to charge the battery [29-31]. Off-board battery chargers, which are not constrained by weight and size, are generally suitable for battery charging modes 3 and 4 because of their lack of restrictions. Inductive and conductive battery chargers are also sub classified. Conductive battery chargers are those that employ a straight physical connection between the charger and the charge input [32]. Inductive chargers, on the other hand, use magnetism to transfer electricity. Inductive chargers are mostly used for fixed slow charging applications, even if some studies focus on mobile chargers [33]. Galvanic isolation is another attribute that may be used to identify battery chargers. However, despite the fact that isolation is strongly advised for security reasons, doing so frequently necessitate the employment of more complex controllers and heavier, larger buildings. Another thing to keep in mind is that, as opposed to unidirectional battery chargers, which can only charge the battery in one direction, bidirectional battery chargers may draw power from the grid and recirculate it. As may be inferred, bidirectional battery chargers typically require additional circuitry in order to operate in both directions of the power flow, making them more expensive, larger, and heavier than unidirectional chargers.

A. Overview of Electric Vehicle

EVs are a novel idea in the global transportation industry [34]. Because of this, over the previous several years, there was a considerable increase in interest in technology for EVs. G2V battery charging must be managed to maintain the quality of power in power networks. But if electric vehicles become more prevalent, they will have a large amount of energy stored in their batteries, which will allow for an energy flow in a reverse way (V2G). EVs will show a significant role in future smart grid, allowing the power system to operate autonomously. Currently, some smart grid-related projects are being developed globally. While the G2V and V2G modes of EVs can provide residential loads, they can also act as voltage sources capable of supplying EV charging stations. Nissan showcased the "LEAF-to-Home" system as an example of this novel strategy. Through the "EV Power Station" equipment, this technique leverages power from Nissan Leaf batteries to serve residential loads [35]. In actuality, the development of the smart grid will begin with smart households equipped with energy efficiency and management technologies. However, LEAF to-Home and similar solutions just allow for the return of stored energy to where the equipment is located. When the EV is parked, the V2G operation mode is supported by a bidirectional battery in this study. As a result of this battery charger, you can draw energy from the grid (G2V) as well as re-input some of that energy back into the grid (V2G). EVs have the power to improve auxiliary services and make up for the intermittent nature of renewable energy sources, according to the electric grid (providing backup, load-shift, and storage). According to a recent study, most private vehicles are left parked for up to 93% of their lifetimes and most are at home between the hours of 8pm and 7am [36]. Figure 1 depicts a bidirectional charger using V2G and G2V technology. The batteries (G2V and V2G) can receive and send energy when EV is linked to the grid [37]. As long as the power grid isn't down, an EV can be used as a supply voltage to power the necessary loads. The system has a supplementary energy storage structure, although it is not meant to provide real-time energy backup. As a result, it is feasible to seamlessly switch between modes.

Operational Mode of Electrical Vehicle in Bidirectional Converter

The 3 potential operation modes (V2H, G2V, and V2G) each have a unique control algorithm for the 2 converters, which is the following: A. V2G (Vehicle-to-Grid) mode of operation The inverter supplies sinusoidal current and has a power factor of one, but a boost converter (a DC-DC converter that can be transformed back into an inverter) has the opposite property [38]. Just like in G2V mode, the full-bridge AC-DC bidirectional converter should be synced with the grid's fundamental voltage in V2G mode. The synchronization is performed using single-phase α-β PLL in α-β coordinates, as previously described. To facilitate the cooperative incorporation of EV into a smart grid environment, active power that is going to be distributed to the power grid is determined as an external input parameter that is received from the serial communication port. as a result, the control technique utilised in V2G operating mode is similar to the control approach utilised in the G2V operation mode. A boost converter (a DC-DC converter that can be converted back into an inverter) has the opposite property from an inverter in that it produces a sinusoidal current and has a unitary power factor [39]. It is necessary for V2G mode to synchronise the full-bridge AC-DC bidirectional converter, much like in the G2V mode. Single□phase α-β PLL in α-β coordinates is used to accomplish synchronizations. A serial communication port receives an external input parameter, which is used to determine the amount of active power that will be fed into the power grid from the electric vehicle. Consequently, the control algorithm used in V2G mode is comparable to the control approach utilised in G2V mode. Consequently, to achieve this, a predictive current control was employed to generate an appropriate reference current for the experiment [40]. For the full-bridge AC-DC bidirectional converter to return stored traction battery energy to the grid, the DC link voltage must be greater than the peak grid voltage. When the traction battery voltage falls below compulsory DC link voltage, a reversible DC-DC converter must be employed as a boost converter. If traction batteries, which have a very stable voltage, are drained of current, they can be used to limit the amount of active power that returns to utility systems [41].

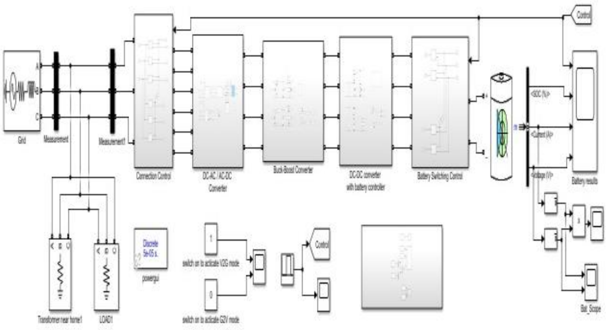

Figure 1: Bidirectional charger Technology.

To keep the discharging active power constant, a higher reference current is needed. To get the traction battery's reference current, divide the traction battery voltage (vTB) by (P*). Reference current (iTB*) that is different from the real current (iTB) utilised to alter duty cycle PI controller of 20 kHz PWM modulator duty cycle PI controller. B. Grid-to-Vehicle (G2V) Mode of Operation An active rectifier is used in this mode to supply sinusoidal current and unit power factor from AC-DC bidirectional converter. Buck converter is what the DC-DC converter is. To maximize the amplitude of individual harmonics, AC/DC bidirectional controller should be in sync with the fundamental voltage of the power grid [42]. A Phase-locked Loop (PLL) with a single phase is therefore the first algorithm that the digital controller executes. Single-phase PLL in α-β coordinates is utilised to meet this need. A 90-degree shift in amplitude produces pll and pll sine waves with identical amplitudes. Signal PLL is generated when the PLL is synchronized with the grid's fundamental voltage. Control algorithm implementations use this signal as input. The reference current for a full-bridge AC-DC bidirectional converter is determined by the second control algorithm. The reference active power, which is influenced by the pll signal, is divided by the power grid voltage to provide the reference current's amplitude. To get the reference active power, the DC link voltage must be kept constant with a PI controller. the system block diagram shows the current reference (iS*). Circuit model characteristics and prior samplings are used to determine this voltage when k volts of voltage are needed in each switching period. The actual current (iTB) and the reference current (iTB*) are compared during the constant current stage. Due to the 20 kHz triangular carrier frequency used in a PWM modulator, the output duty cycle can be modified. A constant voltage control algorithm is proposed by battery manufacturers when the maximum voltage is reached. The reversible DC-DC converter's output voltage (vTB) is controlled by the second PI controller to keep it in step with the voltage reference (vTB*). Buck-Boost Converter [43] an output voltage of either larger or lesser magnitude may be generated by an on/off the switch-mode buck-boost converter. Figure 3 shows this configuration for the buck-boost converter, Voltage is provided between the inductor and inductor L when transistor Q1 is turned on, increasing linearly current flowing through the inductor; the capacitor C and is partially depleted at this moment. Seconds after the transistor is turned off, inductor voltage across the diode flips in polarity. Energy from the inductor powers the increased load & recharges the capacitor during this time.

B. Sinusoidal Pulse Width Modulation (SPWM)

Conventionally, DC-AC inverters use PWM to manage their output voltage. Using a PWM to limit the thickness of the gate pulses is a very helpful technique. No matter the output load, PWM inverters keep the output voltage stable at an increased level. Due to the simplicity of the circuit and the robustness of the management system, pulse size inflection inverters have been the leading choice in power electronics over the last decade. Sinusoidal Pulse Width Modulation (SPWM) and the modulating signal as depicted will be employed depending on the switching performance and excellent characteristics. As stated in, the benefits of usage of SPWM encompass low power absorption, excessive power proficiency to 90%, excessive power controlling ability, no temperature alternative, and era basis traveling or degradation in linearity and SPWM is simply applied and mange. SPWM strategies are classified by using regular amplitude pulses with an extraordinary obligation cycle for all duration depicted in figure 2 and figure 3.

C. Voltage Source Converter (VSC)

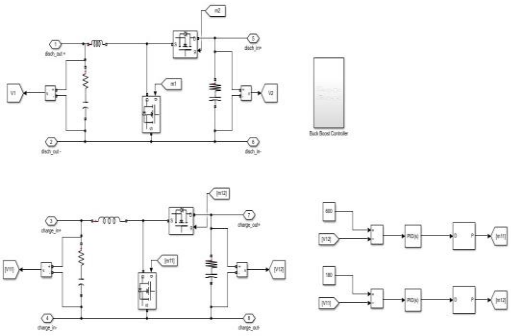

Figure 2: Conversion Buck Booster

As was discussed before in this section of the book, the primary purpose of the inverter is to serve as an interface between the various components. At the same time, the inverter is employed to ensure the voltage on the output port of the boost converter, which is known as the DC link of the inverter. Because of the acquisition, the VSC is used. To facilitate the introduction of a practical three-phase AC that is addicted to the network, the VSC is constrained inside the rotating d-q frame. It implies that the design proposed makes it possible to charge and discharge with a single unit. It uses constant current while adjusting unit power factors to charge batteries at a constant voltage. By altering the control signal from the controller, the operating parameters can be changed. With this arrangement, charging and discharging are possible at various power levels. This signal helps to reduce the amount of error that exists between the actual inject current as well as the reference current that is determined by the DC link controller. The larger picture of vector-based control's general architecture.

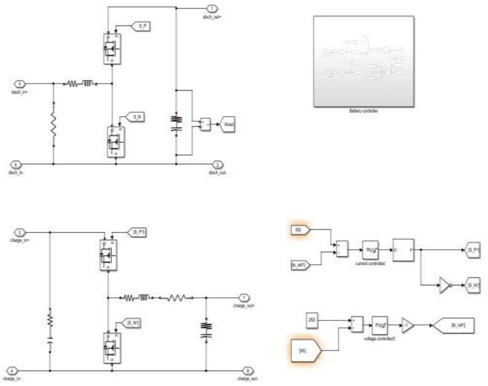

Figure 3: DC-DC converter with battery controller.

Simulation Model

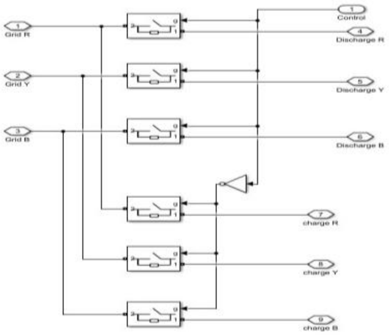

Figure 4: Simulation Model of Connection Control.

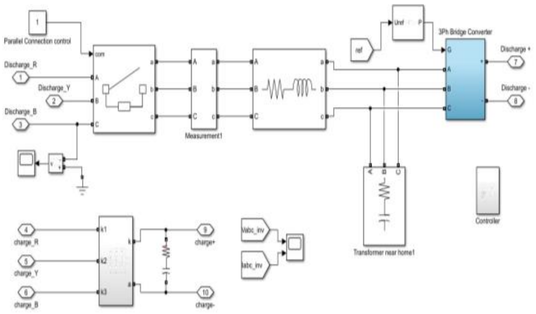

Figure 5: Simulation Model of DC – AC/ AC – DC Converter

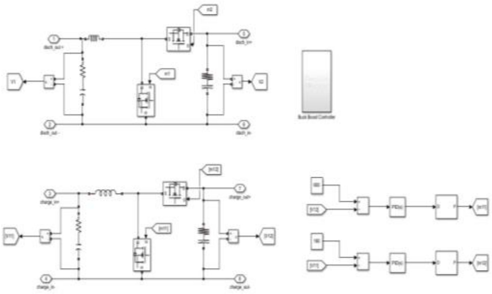

Figure 6: Simulation Model of Buck Boost Converter.

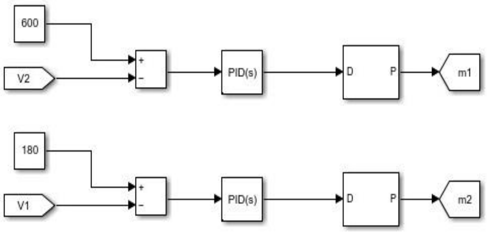

Figure 7: Simulation Model of Buck Boost Controller.

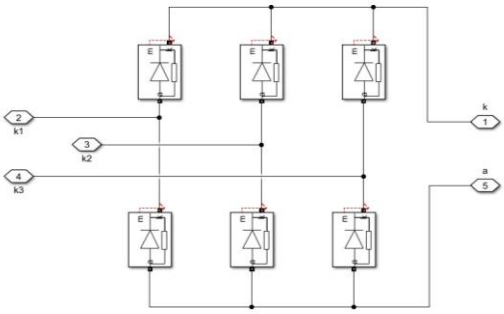

Figure 8: Subsystem Simulation Model of AC – DC / DC – AC Converter.

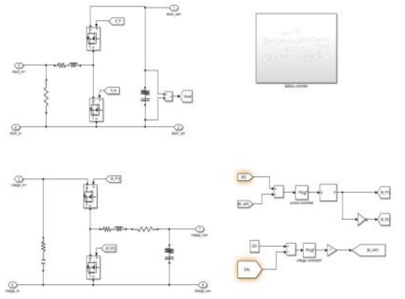

Figure 9: Simulation Model of DC – DC Converter with Battery Controller.

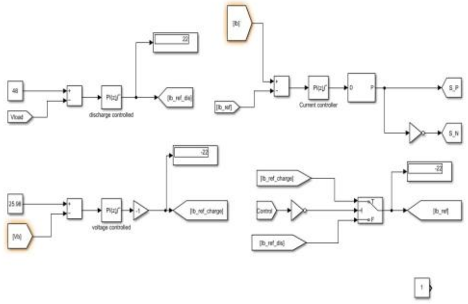

Figure 10: Simulation Model of Battery Controller.

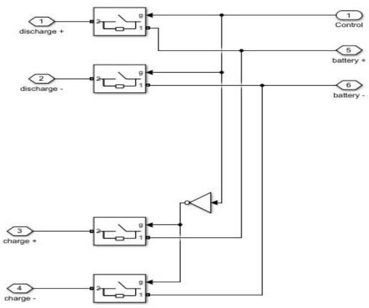

Figure 11: Simulation Model of Battery Switching Control.

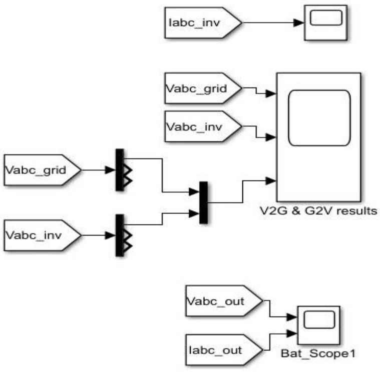

Figure 12: Subsystem Simulation Model of Grid and Inverter Three Phase Voltage.

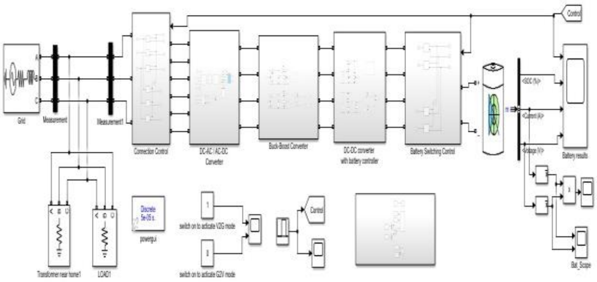

Figure 13: Simulation Model of Bidirectional Charger Technology.

2. RESULTS AND DISCUSSIONS

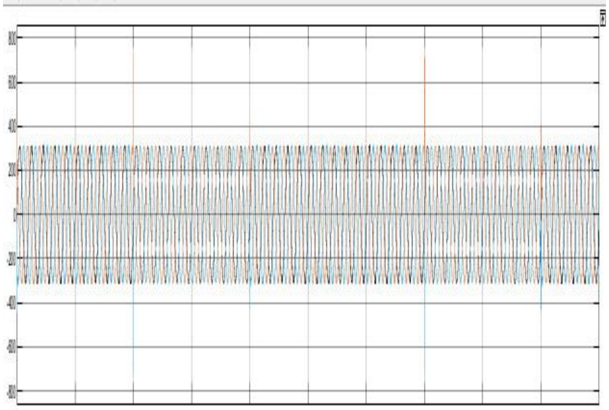

Figure 14: Simulation Result of V2G.

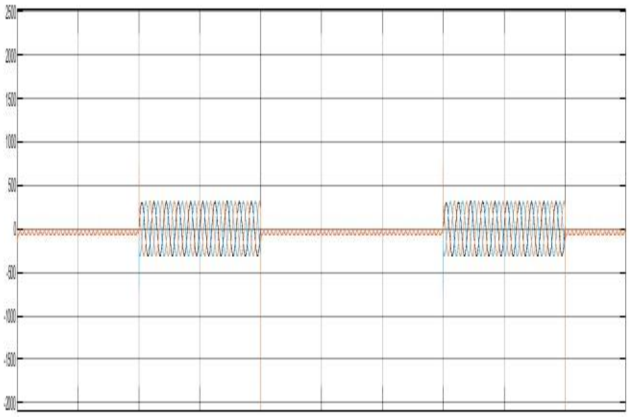

Figure 15: Simulation Result of G2V.

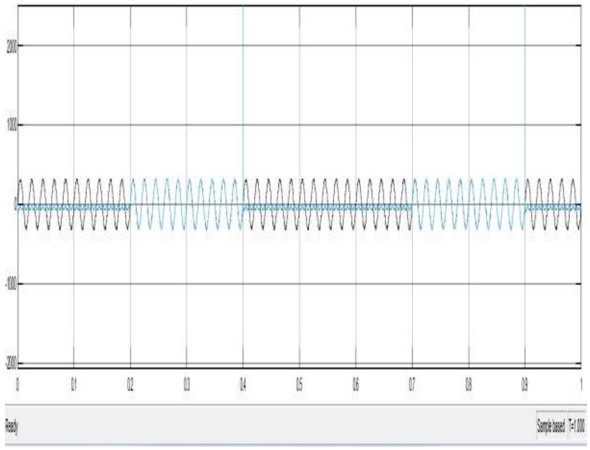

Figure 16: Simulation Result of V2G and G2V.

Simulation in MATLAB is used to test and validate charger design. In both operating modes, the charger's performance meets the requirements of the global grid. The simulation results are displayed in Figures 15 to 32. A high-frequency transformer is shown in G2V and V2G modes in Figure 15 and 18, respectively, to show voltage and current waveforms. When the transformer is in G2V mode, the secondary side voltage (v2) is phase-shifted concerning the primary voltage (v1). Each cycle's regulated value of ipri current is determined by Iφ(n) and I(π+φ) whereas the sampled value is determined by I0(n) and Iπ(n). Above Figure shows the ipri current waveform achieving the controlled value provided by the current controller during each cycle of switching. Figure 17 and 18 shows the V2G mode transformer waveforms similarly. The battery is initially charged using ibat's constant current before switching from G2V to V2G operation at time t =1s. The battery is depleted by a steady current in V2G mode. Figure 15 and 16 assess the suggested charger's performance at the grid side.

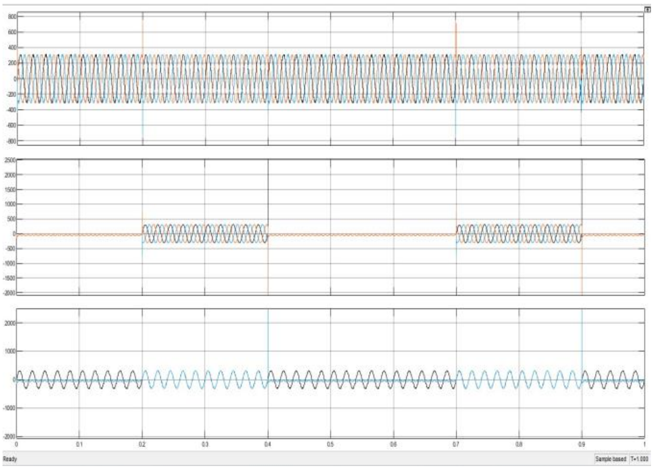

Figure 17: Comparative Result of V2G and G2V in MATLAB/Simulink.

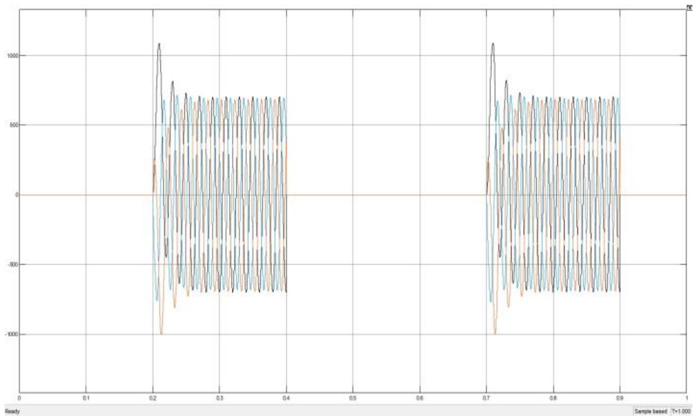

Figure 18: 3 Phase Inverter Current Result.

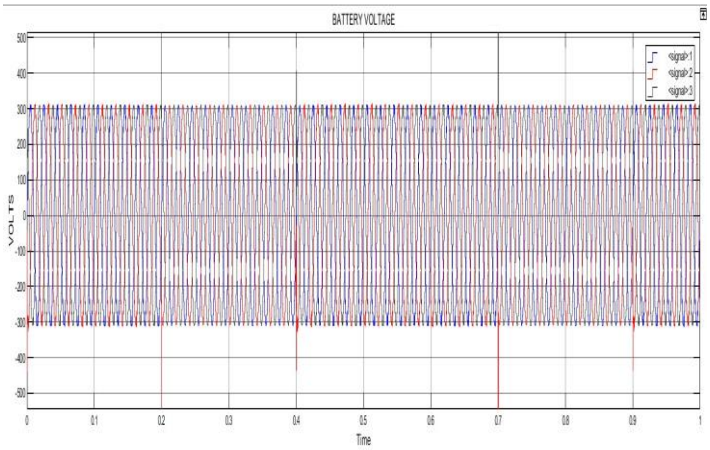

Figure 19: Simulation Result of 3 Phase Output Battery Voltage.

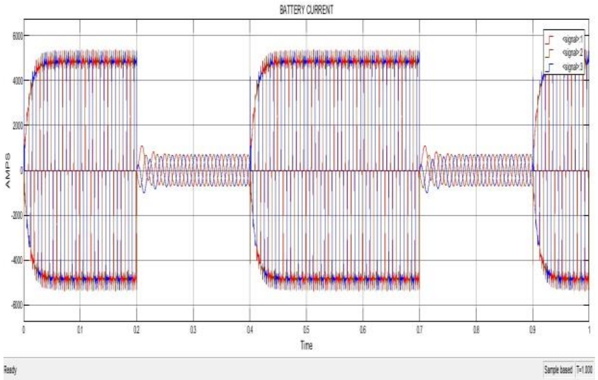

Figure 20: Simulation Result of 3 Phase Output Battery Current.

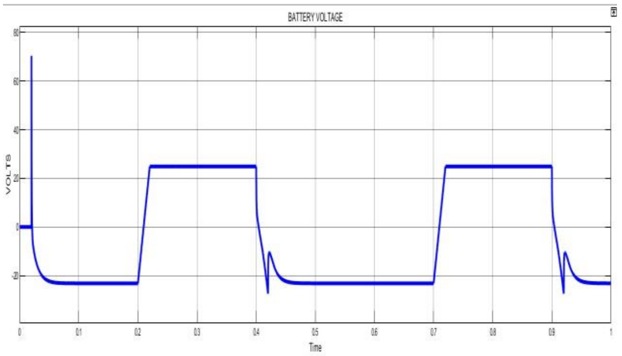

Figure 21: Battery Voltage Simulation Result.

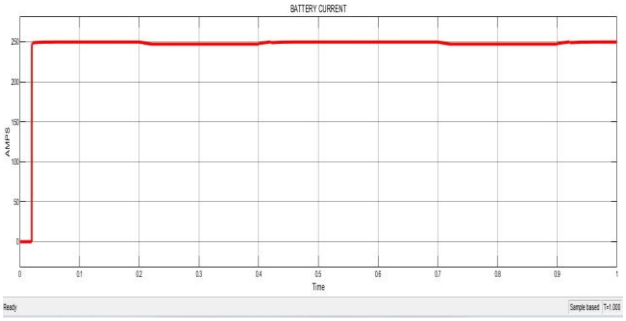

Figure 22: Battery Current Result.

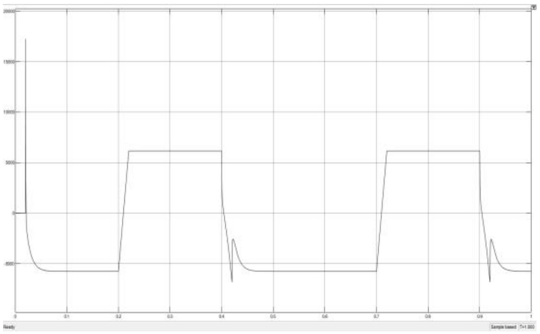

Figure 23: Mean Simulation Result of Battery Voltage and Current.

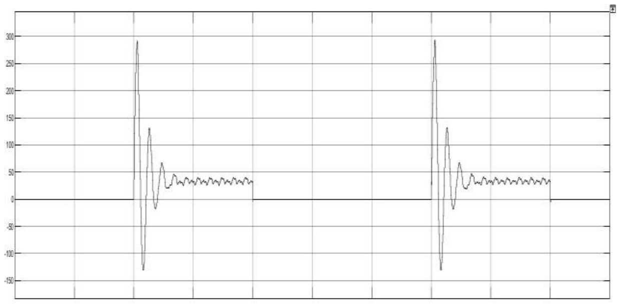

Figure 24: 3 Phase Voltage DC – AC Converter (Inverter) Controller Result.

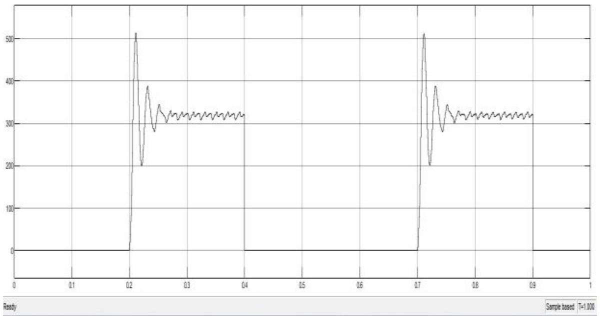

Figure 25: 3 Phases Current DC – AC Converter (Inverter) Controller Result.

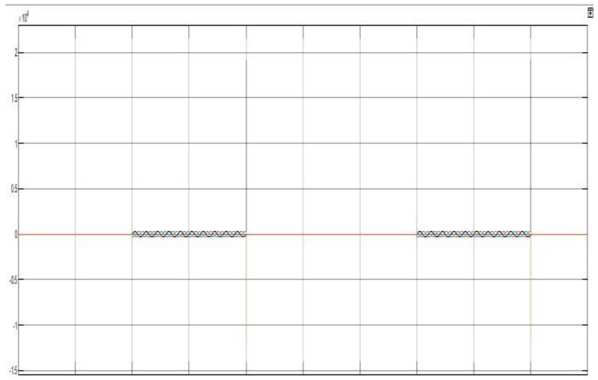

Figure 26: 3 Phase Voltage DC – AC Converter Controller Result.

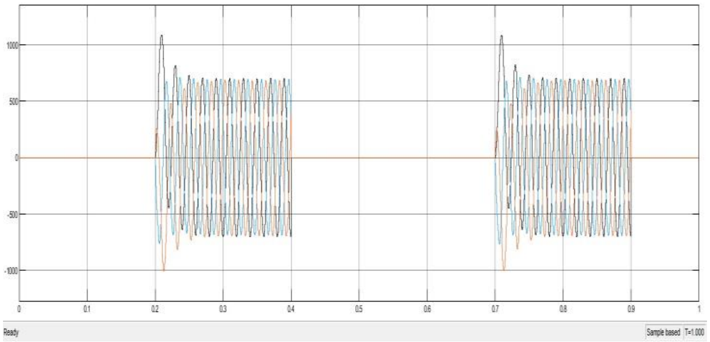

Figure 27: 3 Phases Current DC – AC Converter Controller Result.

Figure 18 depicts the G2V mode's steady state waveform. In this system, the least amount of grid current THD is used to power the battery (Total Harmonic Distortion). The DC link voltage is also maintained in phase with the grid current. Figure 32 illustrates how switching from one mode to another has an impact. With the DC link voltage maintained, the transition from G2V to V2G or vice versa happens quickly. The grid currently has the lowest THD in G2V mode, where it is out of phase with the grid voltage.

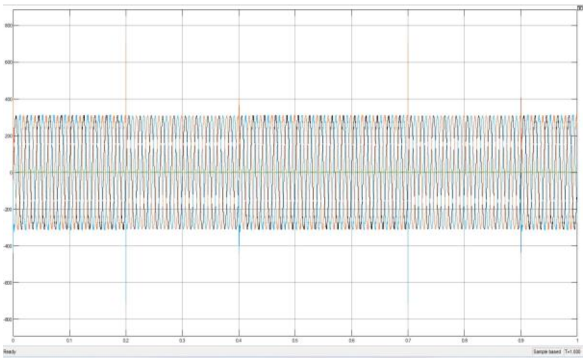

Figure 28: Simulation Result of 3 Phase Grid Voltage.

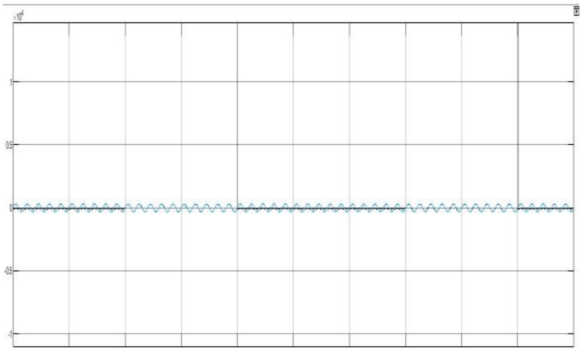

Figure 29: Simulation Result of 3 Phase Ref. Inverter Voltage.

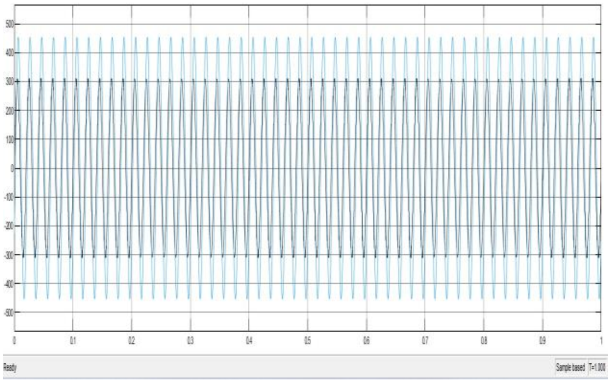

Figure 30: Simulation Result of 3 Phase Ref. Grid Voltage.

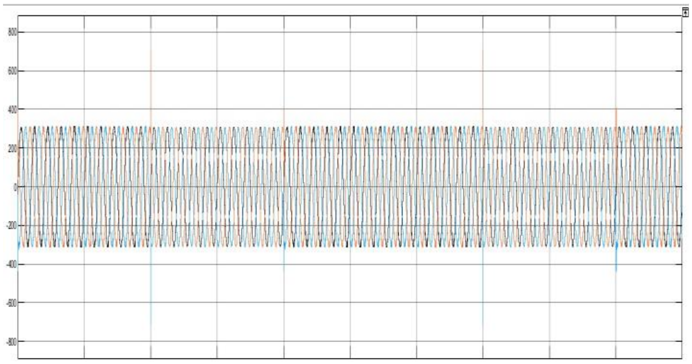

Figure 31: Comparative Result of 3 Phase Grid Voltage.

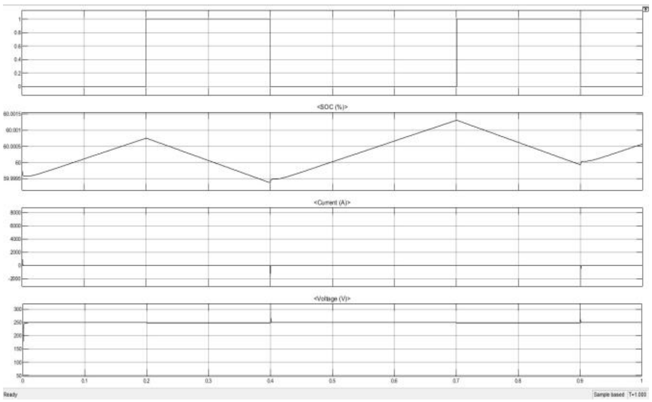

Figure 32: Behavior on Charging-Discharging of Battery.

3. CONCLUSIONS

In this project, the creation of an EV on-board bidirectional battery charger is covered. This charger will be capable of functioning in both the vehicle-to-grid (V2G) modes as well as the grid-to-vehicle (G2V) modes. EVs will be able to charge their batteries from the grid as well as vice versa. These two modes of operation each contain crucial technology for the ultimate introduction of smart grids. By using MATLAB software, computer simulations of the supplied battery charger's hardware and control algorithms have been verified. Bidirectional technology, which enables electricity to flow into & out of EVs, has just recently been widely applicable. the purpose of this work is merely to verify the control algorithms and the topology that are used by the technology. With time, as technology advances, so do its potential. You can only benefit as an EV owner by choosing a bidirectional charger. Going bidirectional has obvious benefits, from earning extra money by retailing electricity return to the grid to being energy independent. The V2G and G2V power flow will utilize the developed bidirectional charger. This indicates that the design being described makes it possible to charge and discharge with the same device. It runs on constant current, and unit power factor changes while battery charging techniques use constant voltage. By altering the controller's control signal, the operational parameters can be changed. This architecture enables charging and discharging at various power level.

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