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IMPLEMENTATION OF BI- DIRECTIONAL BUCK BOOST CONVERTER FOR V2G SYSTEM WITH HYBRID ENERGY STORAGE SYSTEM

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Abstract: In modern power system operations, demand side integration is one of the key functions which enables active consumer participation. Electric vehicles (EVs) encourage active participation of consumers for power management. In vehicle to grid integration (V2G), energy storage system (ESS) is connected with the grid through bidirectional converters. The topology for V2G integration consists of ESS, switching bidirectional buck-boost converter, full bridge inverter, and grid. Now-a-days, hybrid energy storage system (HESS) is an attractive solution for EVs. In this work, a topology for V2G with HESS is proposed. This topology comprises of an active HESS in which Li-ion battery is connected to the super capacitor via a bidirectional dc-dc half bridge converter, and full bridge inverter. The fuzzy logic controller using triangular membership functions and hysteresis current controller are proposed for inverters and bi-directional dc-dc converter respectively. The simulation of proposed topology is developed in MATLAB 2021 and the performance is verified.

I. *Index Terms* - Vehicle to grid system(V2G), hybrid energy storage system, switching bi-direction buck-boost converter, Li-battery, Supercapacitor (SC).

II. INTRODUCTION

A. VEHICLE TO GRID SYSTEM

In the future, there will be a greater use of electric vehicles as a global solution to the problem of pollution (CO_2 emissions). It was agreed to switch to electric automobiles and stop using gasoline and diesel vehicles [1]. In addition, Electric Vehicles (EVs) are used for electric power demand management as a part of demand side integration [2]. This system consists of various power electronic circuits which enable bidirectional flow of power from grid to vehicle as well as vehicle to grid [1] – [2]. Energy storage system in EVs is highly essential for V2G system. Li-ion batteries are used as storage device. Appropriate controllers are required for controlling the power flow between vehicle and grid [3]. The V2G system can provide various grid support services, such as frequency regulation, voltage support, and peak shaving. This contributes to grid stability and reliability [4]. This V2G system with a switching bi-directional Buck-Boost Converter and a Hybrid Energy Storage System (HESS) illustrates a sophisticated and dynamic approach to EV integration into the power grid [5]. It not only facilitates efficient charging and discharging but also actively contributes to grid stability and user-driven economic benefits. EV owners can actively engage with the energy market [5] – [6]. They may choose to charge their vehicles during periods of low electricity demand when prices are lower and discharge energy back to the grid during peak demand, potentially benefiting from economic incentives.

B. HYBRID ENERGY STORAGE SYSTEM

HESS is an advanced energy storage solutions that integrate multiple energy storage technologies to optimize energy management, improve efficiency, and address diverse power and energy requirements [1] – [7]. A HESS typically combines different types of energy storage technologies, such as batteries, supercapacitors, flywheels, or other energy storage devices [2] – [8]. Each technology has distinct characteristics in terms of energy density, power density, response time, and cycle life. Fig 1 shows the block diagram of HESS [1]. The hybridization of energy storage technologies allows for optimized energy management [5] – [9]. The system can dynamically allocate tasks to specific storage components based on factors like energy demand, response time requirements, and overall efficiency, resulting in improved performance [4]. Different storage technologies have different aging characteristics [10]. By distributing the load among various components, a HESS can mitigate the impact of cycling on individual technologies, potentially extending the overall lifespan of the energy storage system and enhancing its reliability [11]. There are three topologies, passive topology, active topologies and semi-active topologies.

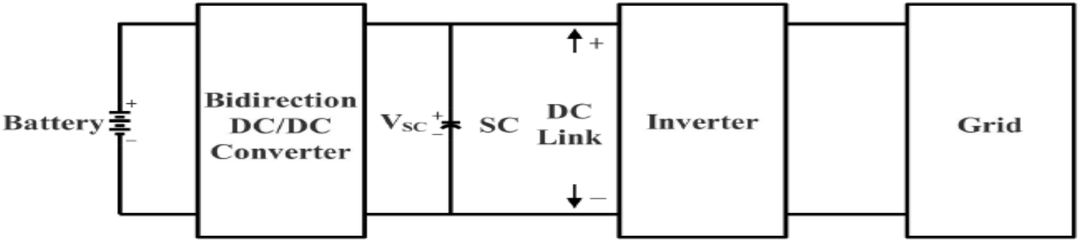

Fig.1 Block diagram of HESS

A HESS the Li-battery can be connected to the SC via a bi-directional dc-dc half-bridge or directly to the DC bus via a diode [12]. An active hybrid energy storage system (HESS) typically combines two or more energy storage technologies to optimize energy management and performance [12] – [13]. The topology can provide a bi-directional flow path for energy exchange between the Li-battery/super capacitor (SC) [13].

III. LITERATURE SURVEY

Plug-in Electric Vehicles (PEVs) are gaining popularity as a sustainable and efficient mode of transportation. To maximize the performance and efficiency of (PEVs), it is essential to optimize the energy storage system (ESS) and power distribution strategies. **Hassan H. Eldeeb, (2018) et al** elaborated the critical issues of ESS sizing and power splitting for hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs).

It proposed the state-space averaging method is used to analyze the stability of the topology in boost and buck modes. The control strategy is given according to the state of charge (SOC) of the energy storage system to ensure that the output voltage and current are stable **Shuo Liu and Xu Xi (2019).** By using this voltage and current controllers are designed in the frequency domain based on bode plots. Finally, the electrical feasibility of the topology, the suitability of the design controller and control strategy are verified by simulation.

A combination of battery and ultracapacitor as a hybrid energy storage system (HESS) for an electric vehicle (EV) can result in better acceleration performance, reduced battery charge-discharge cycle and longer driving range. **Ramasamy, (2015) et al** designed a converter combining triple-half-bridge (THB) and boost half-bridge (BHB) converter for battery-ultracapacitor HESS. The operation of this converter is detailed using a simplified delta type primary-referred equivalent circuit.

IV. TOPOLOGY AND MODULATION OF THE PROPOSED SWITCHING BI-DIRECTION BUCK-BOOST CONVERTER

A. PROPOSED TOPOLOGY

The proposed V2G system consists of five parts: Li-battery, switching bi-directional buck-boost circuit, SC, full bridge inverter and gird. The switching bi-directional buck-boost circuit has an inductor, a SC and the additional three switches (S_{D1}, S_{D2}, S_{D3}) Since the gate signals of switches S_{D2} and S_{D3} are the same and complementary to the gate signal of switch S_{D1}, one gate signal can control these three additional switches. This unique SBBBC network allows the system work on the buck and boost modes, and it can provide bi-directional power flow.

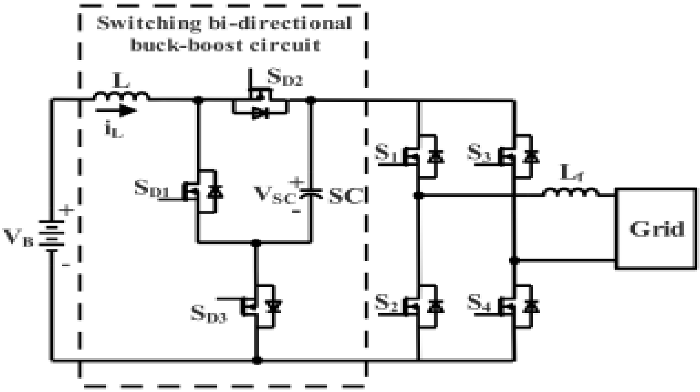

Fig 2 The proposed SBBBC

B. MODULATION METHOD

The converter, there are three switching-states include active state, zero state and shoot-through state respectively, as shown in Table 1 [1]. All switches of full bridge inverter. The switching bi-directional buck-boost circuit uses the shoot-through duty to achieve buck-boost voltage.

TABLE NO 1. Switching Combination and Inverter Output Voltage

N	U_{AC}	S_{D1}	S_{D2}	S_{D3}	S_1	S_3	S_2	S_4	State
1	0	0	1	1	0	0	1	1	Zero state
2	0	0	1	1	1	1	0	0	Zero state
3	$-U_{SC}$	0	1	1	0	1	1	0	Active state
4	U_{SC}	0	1	1	1	0	0	1	Active state
5	0	1	0	0	1	1	X	X	Shoot-through state
6	0	1	0	0	X	X	1	1	Shoot-through state

where *m* is the modulation index of the inverter; θ is the vector angle of the output voltage; *d*, *ds*, d_0 are the duty cycles of the output voltage active state, shoot-through state and zero voltage state, respectively.

C. MODELLING AND ANALYSIS OF SBBBC

The converter can provide bi-directional power flow among SC, Li-battery and grid, as shown in Figure 1 [1] And the converter can work in boost mode and buck mode. Boost Mode during the converter boosts the low Li-battery voltage to high dc-link voltage. There are three work states: Zero state, Active state and Shoot-through state.

BOOST MODE

During boost mode, the proposed converter boosts the low Li-battery voltage to high dc-link voltage. There are three work states: zero state, active state and shoot-through state.

1) BOOST MODE- SHOOT-THROUGH STATE

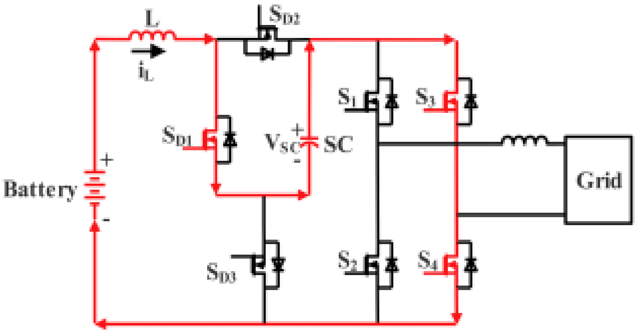

Fig 3. Flow path in shoot-through state of boost mode

In shoot-through state, the switches S_{D1} and S_3 & S_4 (S_1 & S_2) are turned ON while switches S_{D2} and S_{D3} are simultaneously turned OFF, as shown in Figure 3 [1]. In this state, the power is transferred from the Li-battery and SC to the inductor *L*.

The state equation is given by:

$$\begin{cases} L\dfrac{di_L}{dt} = -(R_L + R_C)i_L + V_{SC} + V_B \\ C\dfrac{dv_{SC}}{dt} = -i_L \end{cases} \quad (1)$$

where V_B is the Li-battery voltage; V_{SC} is the SC voltage; i_L is the current through the inductor *L*; R_L and R_C are parasitic resistances of the inductor *L* and SC, respectively.

2) BOOST MODE-ACTIVE STATE

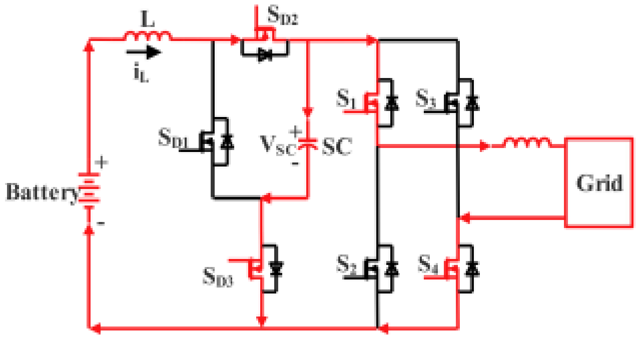

Fig 4. Flow path in active state of boost mode

In active state, both switches S_{D2} and S_{D3} are turned ON while switches S_{D1} is simultaneously turned OFF, as shown in Figure 4[1]. In this state, the Li-battery V_B and inductor *L* charge SC and power is transferred from the Li-battery V_B and inductor *L* to the grid. The state equation can be calculated as follows:

$$\begin{cases} L\dfrac{di_L}{dt} = -(R_L + R_C)i_L - V_{SC} + V_B + R_C i_o \\ C\dfrac{dv_{sc}}{dt} = i_L - i_o \end{cases} \qquad (2)$$

where *io* is the output current.

3) BOOST MODE- ZERO STATE

In zero state, both switches S_{D2} and S_{D3} and S_1 & S_3 (S_2 & S_4) are turned ON while switches S_{D1} is simultaneously turned OFF, as shown in Figure 5[1]. The state equation can be calculated as follows:

$$\frac{V_{out}}{V_{in}} = \frac{(1-D_t)Z_H}{(1-D_t)^2 Z_H + R_L} \qquad (3)$$

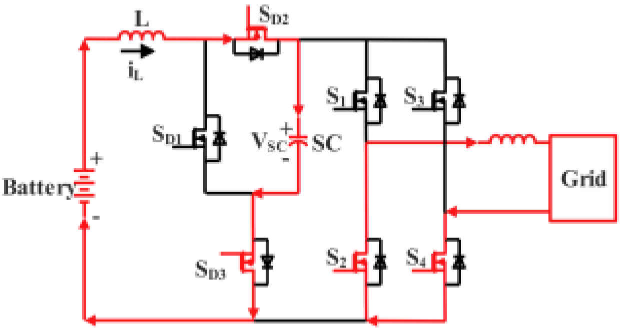

Fig 5. Flow path in zero state of boost mode

From equation (1) to (3), due to the average value of the inductor voltage and the capacitor current should be zero in one switching period of *Ts*.

$$\frac{V_{out}}{V_{in}} + \frac{(1-D)Z_H}{(1-D)^2 Z_H + R_L} \qquad (4)$$

The voltage gains in boost mode comparison between the conventional dc-dc half-bridge converter and the proposed converter. the voltage gain of the proposed converter is higher than that of the dc-dc half-bridge under the same R_L/Z_H ratio. Therefore, compared with the conventional dc-dc half-bridge converter, the topology proposed in this paper has a smaller duty cycle variation range and higher voltage gain.

BUCK MODE

In buck mode, energy is transferred from the AC side to the DC side, and the single-phase full bridge converter operates in the rectification mode. Therefore, the dc link voltage is higher than the input AC voltage.

1) BOOST MODE- SHOOT-THROUGH STATE

In active state and zero state, the switches S_{D2} and S_{D3} are turned ON while switch S_{D1} is simultaneously turned OFF, as shown in Fig 6[1]. In this state, the voltage of the DC bus is equal to the SC voltage, and power is transferred from the dc link to the Li-battery and inductor *L*. The state equation can be calculated as follows:

$$\begin{cases} L\dfrac{di_L}{dt} = -(R_L + R_{C1})i_L - V_{c1} + V_{SC} + R_{C1} i_O \\ C\dfrac{dv_{c1}}{dt} = i_L - i_o \end{cases} \qquad (5)$$

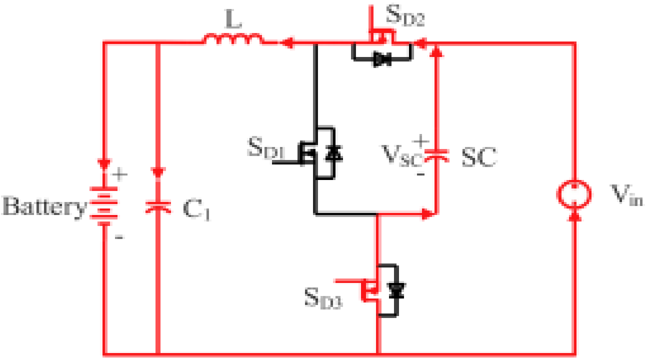

Fig 6. Flow path in active state and zero state of buck mode

2) BUCK MODE- SHOOT-THROUGH STATE

In shoot-through state, the switches S_{D1} and S_3 & S_4 (S_1 & S_2) are turned ON while switches S_{D2} and S_{D3} are simultaneously turned OFF, as shown in Figure 7[1]. In this state, the inductor L charges SC and Li-battery V_B The power is transferred from inductor L to the Li-battery V_B and SC.

$$\begin{cases} L\,\dfrac{di_L}{dt} = -(R_L + R_{C1})i_L - V_{C1} - V_{SC} + R_{C1}i_O \\ C\,\dfrac{dV_{C1}}{dt} = i_L - i_O \end{cases} \tag{6}$$

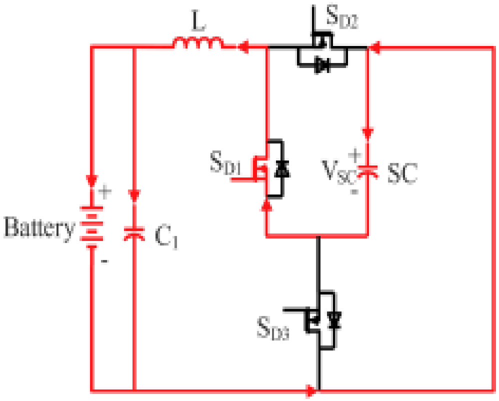

Fig 7. Flow path in shoot-through state of buck mode

The voltage gains of the proposed converter in buck mode using the method mentioned in reference, the voltage gain of the e conventional dc-dc half-bridge in the buck mode can be obtained the voltage gain in buck mode comparison between the conventional dc-dc half-bridge and the proposed converter.

TABLE NO.2 DESIGN PARAMETERS

Parameters	Value	Units
Li-battery voltage Va	180	V
SC voltage V_{sc}	500	V
Grid voltage	230	V
Inductor L	0.052	mH
Filter inductor L_f	1	mH
Supercapacitor SC	99.5	F
Parallel capacitance of the Li-battery	227	Mf
Gird voltage frequency	50	Hz
Parasitic resistors R_L	R-0.25 L-1	mΩ
Parasitic resistors R_C	R-1 C-100	mΩ
Switching frequency	5	kHz

IV SIMULATION OF SBBBC

A bi-directional Buck-Boost Converter for a V2G system with a HESS has been simulated using MATLAB Simulink as shown in Fig 8 Blocks represent the bi-directional converter, HESS components, control system, and any other relevant subsystems.

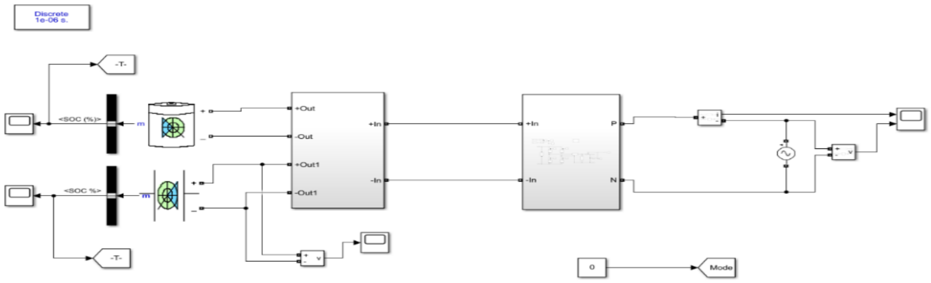

Fig 8. Overview for bi-directional buck boost converter for V2G system with HESS.

V2G SYSTEM OPERATIONS

Mode of Operation 0

In this scenario, a Lithium-Ion (Li-ion) battery is discharging while a supercapacitor is charging with SBBBC. The discharging characteristics of Li-ion battery is shown in Figure 9. The charging characteristics of supercapacitor is presented in Figure 10. equations that represent the battery's discharging characteristics, voltage, and state of charge (SoC). The switches S_{D1} and S_3 & S_4 (S_1 & S_2) are turned ON while switches S_{D2} and S_{D3} are turned OFF. By following the Equation 3.1. the switches work according to it.

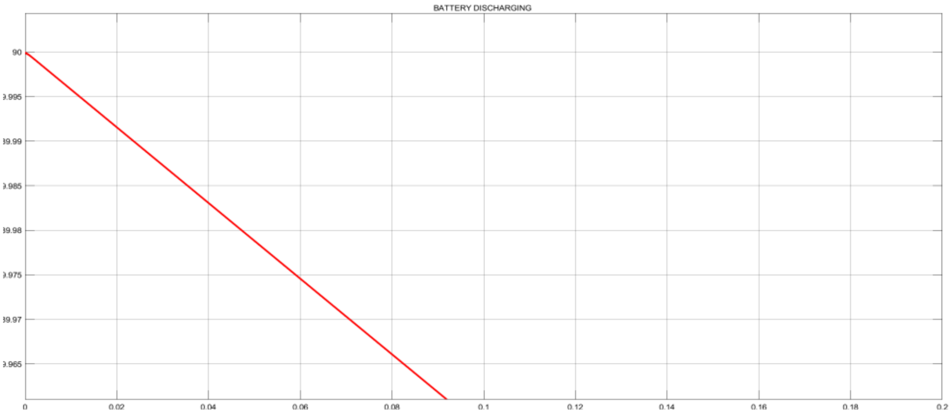

Fig 9. Battery Discharging Mode Waveform.

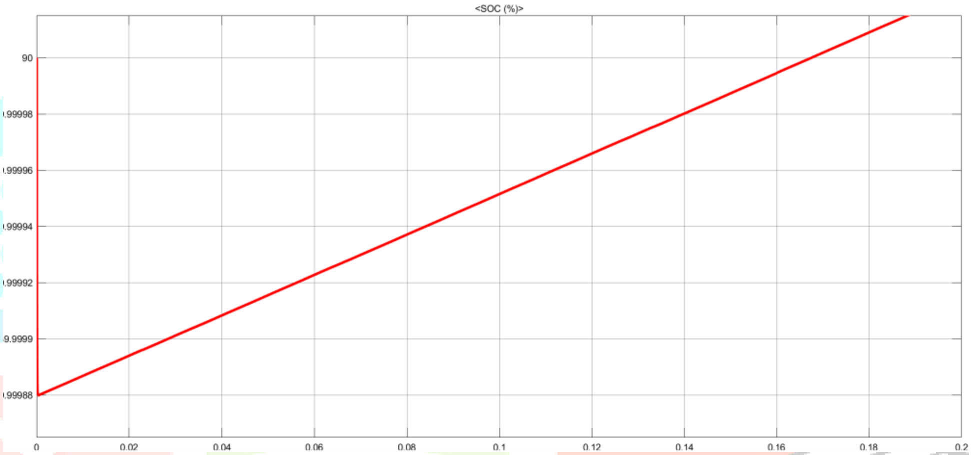

Fig 10. Capacitor Charging Mode Waveform.

Mode of Operation 1

In this mode of operation, a Lithium-Ion (Li-ion) battery is charging while a supercapacitor is discharging with a SBBBC**.** A model for the Li-ion battery charging process as shown in Figure 11. This includes equations that represent the battery's charging characteristics, voltage, and state of charge (SoC). A model for the supercapacitor discharging process as shown in Figure 12. the supercapacitor's discharge characteristics, voltage, and state of charge. Supercapacitors discharge rapidly. The switches S_{D1} and S_3 & S_4 (S_1 & S_2) are turned ON while switches S_{D2} and S_{D3} are turned OFF. By following the switches work according to it.

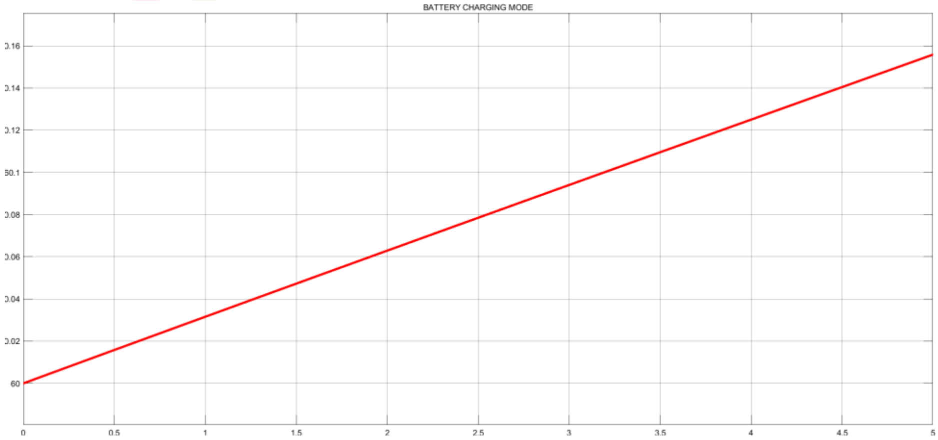

Fig 11. Battery Charging Mode Waveform.

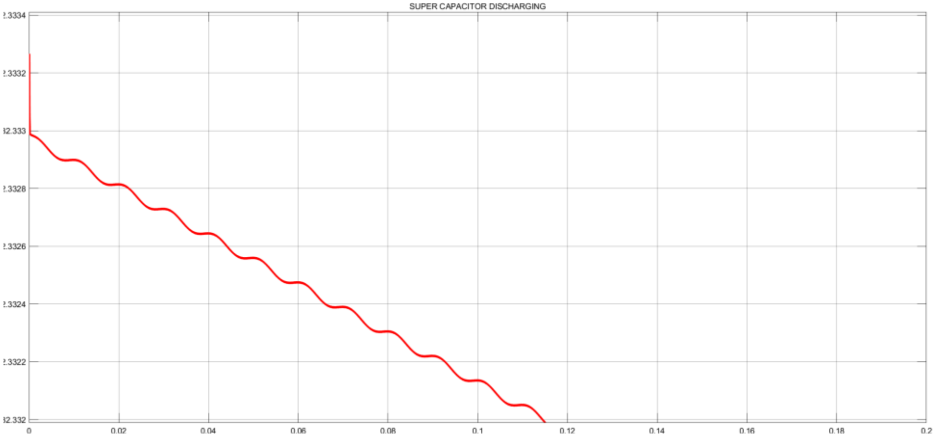

Fig 12. Capacitor Discharging Mode Waveform.

Grid Current &Grid Voltage Waveform

A current measurement block to monitor the grid current. observe the waveform during the simulation. A grid voltage source in the simulation to represent the grid as shown in Figure 13. This can be a simple sinusoidal voltage source or a more detailed model. The use Simulink's Scope or other visualization tools to observe the waveforms of the grid current and grid voltage.

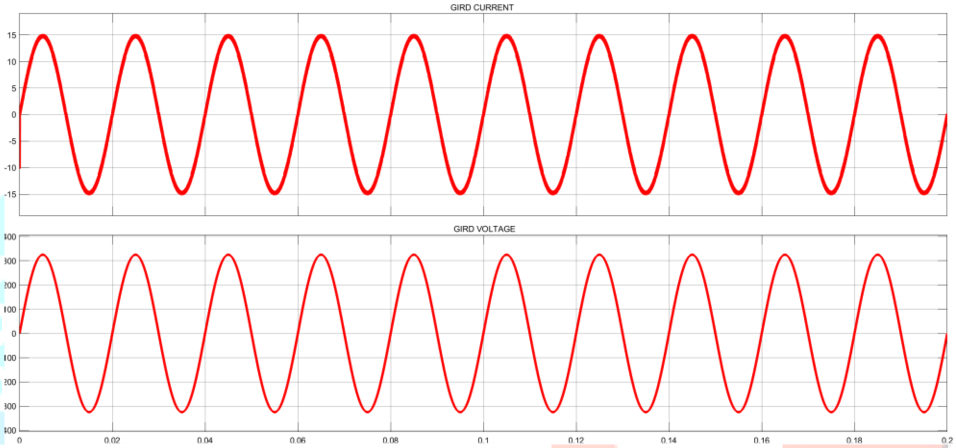

Fig 13. Grid Current and Grid Voltage Waveform.

V CONCLUSIONS

In conclusion, the proposed Vehicle-to-Grid system with a Switching Bi-directional Buck-Boost Converter and a Hybrid Energy Storage System presents a sophisticated approach to integrating electric vehicles into the power grid. The system utilizes a combination of Li-ion batteries and supercapacitors, allowing bidirectional power flow and contributing to grid stability. The Hybrid Energy Storage System optimizes energy management by combining different storage technologies, mitigating aging effects and enhancing overall reliability. The V2G system offers grid support services, such as frequency regulation and voltage stabilization, improving grid stability. The bi-directional Buck-Boost Converter plays a vital role, enabling efficient power transfer between the electric vehicle and the grid. The proposed Fuzzy Logic Controller (FLC) enhances energy efficiency and overall system performance by regulating bidirectional power flow based on various parameters like state of charge and grid conditions. Simulation results demonstrate the effectiveness of the system, showcasing scenarios such as battery charging/discharging and grid interaction. Additionally, the Hysteresis Current Controller ensures the converter operates within desired current limits. In summary, the V2G system outlined in this work not only addresses the transition to electric vehicles but actively contributes to grid stability, supports demand-side integration, and empowers electric vehicle owners to engage with the energy market for economic benefits.

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