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Simulation Design of Three Phase Grid Integrated EV Charging Station with Renewables

Abstract: - The potential for improving sustainability in the transportation sector is considerable when renewable energy sources are combined with electric vehicle (EV) charging stations. The design methodology for a three-phase grid-integrated EV charging station that integrates renewable energy sources is presented in this paper using simulation-based design. The suggested system seeks to reduce grid dependency, maximize the use of renewable energy sources, and optimize energy management. Utilizing cutting-edge software tools, the simulation model is created to evaluate the integrated system's viability and performance under various operating scenarios. The study offers insightful information for the planning and development of sustainable transportation solutions and emphasizes the possible advantages of incorporating renewable energy sources into EV charging infrastructure.In this paper, a power predictive model was presented to forecast EVs power demand and to enhance the CS performance, in order to avoid an extra burden on the grid during peak hours. PV array with storage battery supported by the grid increased the reliability and flexibility of the system.

Keywords: Electric Vehicle (EV), Charging Station, Renewable Energy, Grid Integration, Simulation, Energy Management, Grid, Battery, etc.

Introduction

The necessity for a better fuel economy and further reduction in greenhouse gas emissions is pushing automotive industry to go through a comprehensive restructuring to electrify the vehicles and introduce plug-in hybrid electric vehicles (PHEVs) and electric vehicles, cumulatively called plug-in electric vehicle (PEVs). The electrical powertrain of current and upcoming PEVs is composed of an energy storage system connected to propulsion machine through an inverter. In addition, an add-on battery charger is inevitable part of vehicle powertrain.

In majority of PEVs, a bidirectional dc/dc converter is deployed between the battery and propulsion machine inverter. This converter is responsible to boost the battery voltage and efficiently control the delivered or absorbed power during cruising and acceleration or regenerative braking, respectively. In this conventional structure, the bidirectional dc/dc converter is only operated during propulsion and an individual ac/dc converter is utilized to charge the battery. Regardless of the converter topologies, this architecture consists of two individual power electronic converters for two independent operation modes. An efficient solution to make the system more compact, lighter, and cost efficient would be integrating the add-on charger unit with the bidirectional dc/dc converter, which is used during cruising and acceleration. The prospective shortage of fossil fuels and the current environmental challenges of reducing the greenhouse gases motivate the extensive research on EV systems. However, the research on EVs is highly impacted by the consumer willingness for switching from using conventional internal combustion engine vehicles to EVs as an alternate means of transport. This willingness is the main factor in predicting the future demand for EVs. So many authors concluded that the charging time is one of the main challenges that the EV industry is facing. Thus, this dissertation focuses on providing novel solutions for reducing the EV charging time by providing fast charging rates.

The transportation industry faces several major challenges, some of which can be resolved by integrating renewable energy sources into EV charging infrastructure. These challenges include the following:

- **Grid Congestion and Peak Demand Management:** As EV adoption increases, current electrical grids may become overloaded, especially during times when EV charging is at its highest. Grid-integrated EV charging stations can improve overall grid stability by optimizing energy distribution and mitigating grid congestion through the integration of renewable energy sources and intelligent energy management systems.
- **Reducing Carbon Emissions:** The combustion of fossil fuels in conventional vehicles is the main way that the transportation sector contributes significantly to carbon emissions. Grid-integrated charging stations can greatly reduce transportation-related carbon emissions by using renewable energy sources for EV charging. This can support international efforts to mitigate climate change.
- **Energy Cost Savings:** By lowering reliance on grid electricity, especially during off-peak hours when renewable generation is plentiful, integrating renewable energy sources with EV charging infrastructure can result in significant cost savings. Furthermore, grid-integrated charging stations can offer ancillary grid services and take part in demand response programs, which increases their potential for revenue generation and cost effectiveness.

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- **Resilience and Reliability:** Compared to centralized fossil fuel-based power generation, renewable energy sources like solar and wind are naturally decentralized and less vulnerable to supply disruptions. Grid-integrated charging stations can improve energy resilience and reliability by integrating renewable energy generation into EV charging infrastructure. This is especially beneficial in areas that are vulnerable to natural disasters or grid outages.

Given these advantages, a crucial area of study with implications for sustainable energy and transportation systems is the design and optimization of grid-integrated EV charging stations using renewable energy sources. This study aims to provide important insights into the technical, financial, and environmental aspects of grid-integrated EV charging infrastructure through simulation-based modeling and analysis. This will help researchers, industry stakeholders, and policymakers understand how this novel approach could influence the direction of transportation in the future.

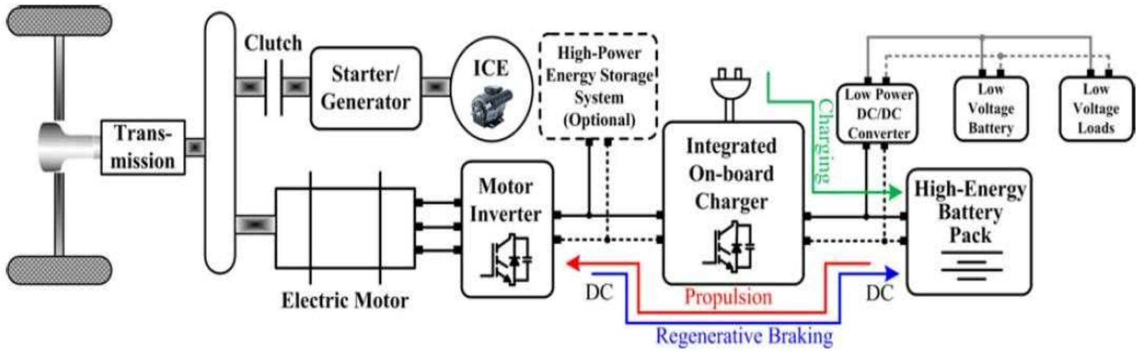

Fig. 1. System level structure of a parallel powertrain PHEV with on-board integrated battery charger

In order to minimize the need for repeated reverse conversions, more distributed renewable generation and different demands are anticipated to directly connect in distribution networks in the near future. The purpose of the hybrid AC/DC micro grid is to effectively integrate energy storage systems (ESS) and distributed energy resources (DER) into the current power systems. Nonetheless, the distinct characteristics of the micro grid present new difficulties for the Energy Management System (EMS). A hierarchical energy management strategy made up of multiple agents is suggested in order to manage these DGs and controllable loads, resulting in an efficient and adaptable hybrid grid and optimal power flow. It is thought that distributed generation (DG) using renewable resources, like wind and solar energy, can effectively lessen reliance on traditional power generation while improving the dependability and caliber of power systems [1]. The abundance of solar energy and clean energy that photovoltaic (PV) power systems offer have made them one of the most promising renewable generation technologies. PV technology is developing at a rapid pace, and falling installation costs are encouraging more PV to be installed in power systems. Nevertheless, because of the characteristics of solar energy and photovoltaic (PV) panels, a PV system's instantaneous power output is highly dependent on its operating environment, including solar irradiance and ambient temperature, leading to continuous variations in the output power [1]. As a result, battery storage systems are typically integrated with PV systems to address the variability issue and maintain a consistent output power. The key work objectives of this paper are listed as below:-

- EV-CS Development with Multiple RERS
- AC grid & DC grid both side energy management
- Energy storage device management(charging & discharging conditions)
- Main grid integration & energy management system(EMS) using hierarchal energy management algorithm
- Grid Parameters Control & Stability

EV Charging System

The PV array, diesel generator (DG), and brushless permanent magnet generator (PMBLDC) based WECS (Wind Energy Conversion System) are integrated by the CS to create a charging station that supplies backup power to nearby household loads and EV charging capabilities. The DC link and the point of common coupling (PCC) of the CS are interfaced by an insulated gate bi-polar junction transistor (IGBT) based converter. While the DG set and grid trade power with the PCC, the PV array and WECS supply power at the DC link via boost converters. Via a bidirectional DC-DC converter, the EV also receives power from the DC connection. The EV can transfer power from the grid to the home and vice versa thanks to the bi-directional converter. Through an active switch with two-way power transfer capabilities, the grid and the DG set are connected to the PCC.

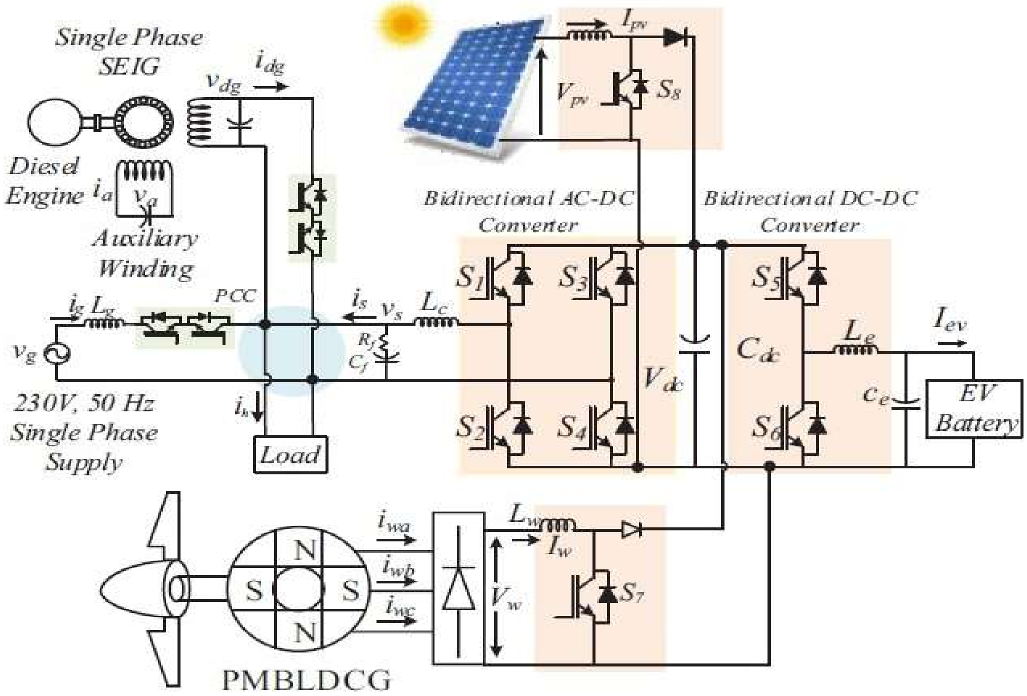

Figure-2. Structure of an Circuit Diagram of EV Charging Station [1]

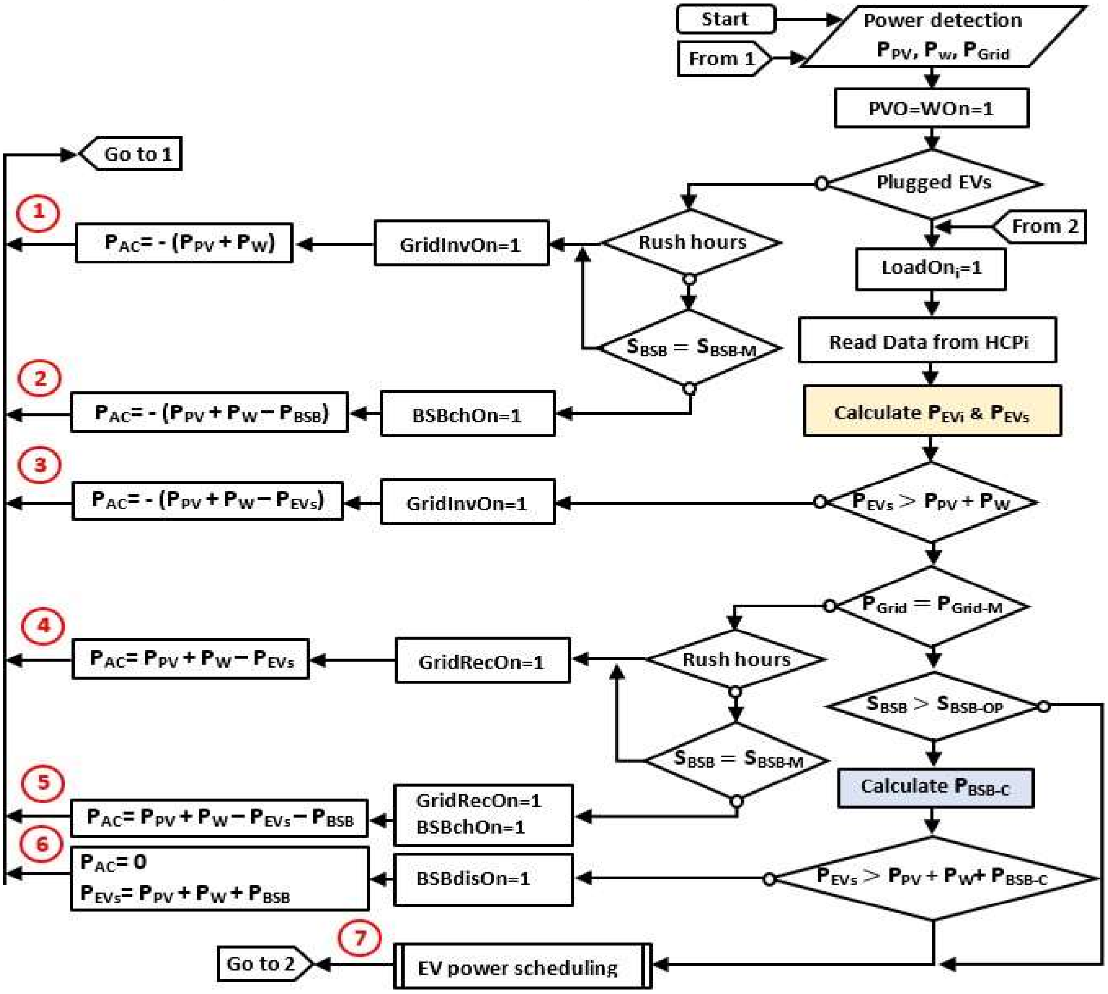

Figure-3. Flowchart of the predictive power management algorithm for EV Charging Station [1]

Integrating all energy sources into a hybrid electrical system is the goal of the optimization strategy. The energy management algorithm needs call control programs, such as MPPT for the boost converter, VSC for the inverter, and PI constant current control for the bidirectional dc/dc converter and SEPIC, in order to obtain simulation results that are comparable to the suggested goals and to apply the approach effectively. To optimize energy sources, i.e., to maximize solar energy and wind speed in the first place, benefiting the battery storage bank (BSB) and the grid, the power demand calculation from connected electric vehicles (Pevs) is updated continuously by the PPMS.

Calculate how long it will take to charge.

The amount of time it takes to charge a battery is determined by the capacity of the battery and the charging capacity of the charger. Simply said, the charging time is determined by the charging level, and the charging rate is determined by the battery power source and the car's chargers.

SAE International, a company established in the United States, explains

- Level 1 Slowest setting (domestic 120V AC)
- Level 2 In the meanwhile, (upgraded 240 VAC home)
- Level 3 As quickly as possible, Level 3 (high charge, 480V DC or greater).

Although there has been a lot of industry dispute regarding whose standard should be generally adopted, the 3rd level charging time can be as quick as 30 minutes at an 80 percent rate.

The formula for calculating charging time is:

Battery Power [kWh] / Charging Power [kW] = Charging Time [h]

A first-generation electric car, such as the Nissan Leaf, has a battery capacity of roughly 20 kWh, which gives you a range of about 100 miles (160 km). Tesla was the first firm to produce long-range electric vehicles, beginning with the Model S, which came with 40 kWh, 60 kWh, and 85 kWh batteries, with a range of 480 kilometres on average (300 mi). Vehicles linked to the plug-in hybrid have a capacity of 3 to 5 kWh and a range of 20 to 40 kilometres on electricity alone, but the petrol engine ensures the full range of a standard automobile.

Operational Mode of EV charging station

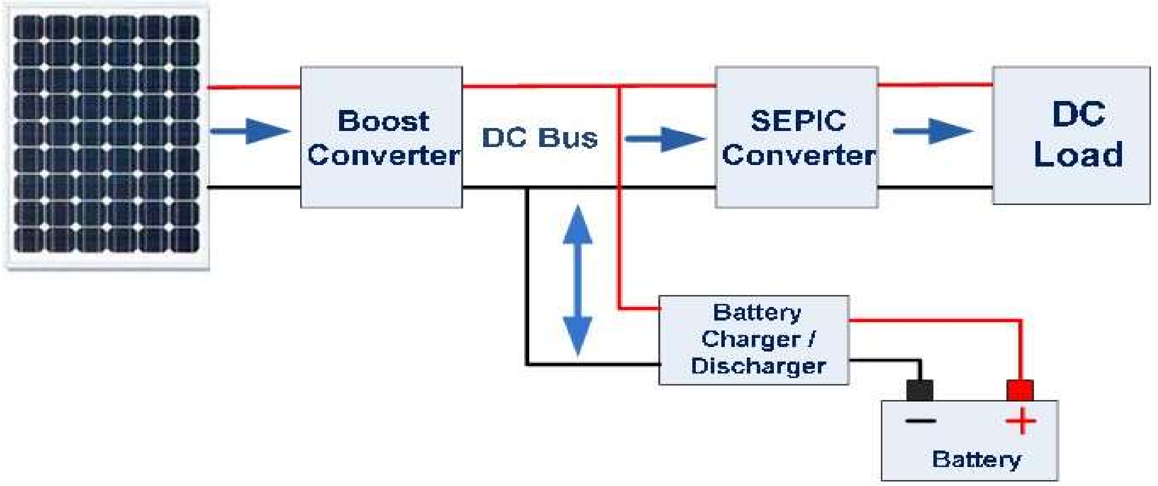

Figure-4 Operating Mode-I (Solar PV & Battery Storage using SEPIC Converter)

The proposed voltage regulation for the solar PV and battery system, which consists of two DC to DC converters, is depicted in Fig. 4's block diagram. The MPPT control and lower voltage boost of the PV cell are provided by the boost converter that is connected between the PV array and the DC bus. Because the SEPIC converter can step-up and step-down the input voltage, it is used to regulate voltage between the DC bus and the load. Voltage regulation is the primary use of the SEPIC converter. The converter under discussion is comparable to a buck-boost converter, which can step-up or step-down input voltage without causing a change in voltage polarity. In the continuous conduction mode, it has a right half-plane zero. In the output voltage regulation mode, it has peak-current mode control.

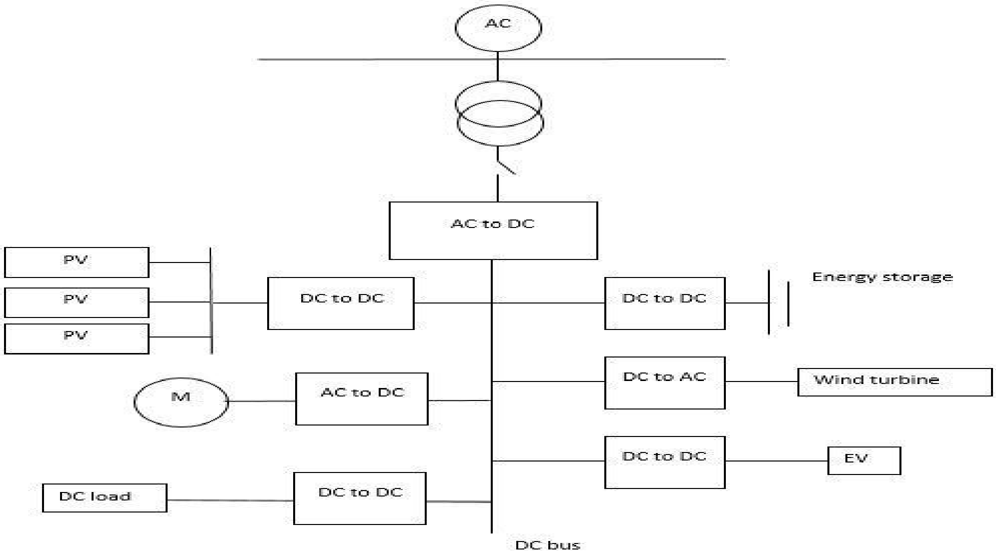

Figure-5 Operating Mode-II (DC Microgrid)

Figure 5 depicts the typical architecture of a direct-driven PMSG WT system. A fully rated back-to-back converter connects the synchronous generator's stator winding to the grid. The generator-side converter is usually in charge of managing the PMSG's active and reactive power output. On the other hand, the GSC transfers the active power that is taken out of the wind turbine and feeds it into the grid at a power factor that can be adjusted while also maintaining the DC-link voltage and managing the reactive power exchange between the generator and the grid. To keep the DC-link voltage steady during power grid outages, the DC chopper circuit is made up of series-connected power electronics and unloading resistors.
The AC bus is provided with the controlled output voltage.

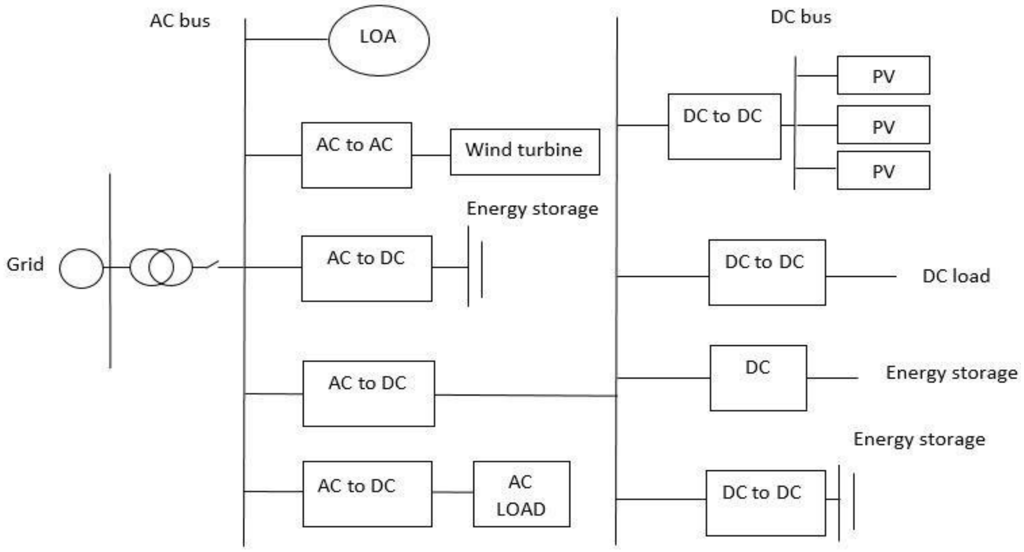

Figure-6 Operating Mode-III (Hybrid AC-DC grid Operation)

The hybrid grid's streamlined structure is depicted in Figure 6. It is split into two categories: AC grid and DC grid. The DC bus, being a platform with universal access for distributed generation, energy storage devices, and loads, can effortlessly establish integrated control of DC micro-grids that utilize solar photovoltaic and battery storage. Through a wind power plant, the AC microgrid is directly connected to the distribution network, or main grid. A grid-connected switch connects the distribution network to the AC bus. Bidirectional AC-DC converters allow bidirectional controllable power flow between two grids, enabling two systems to support one another.

Hierarchical Energy Management Strategy

This section discusses a three-level hierarchical energy management strategy along with an energy storage strategy based on the multi-agent model, based on the operation and control characteristics of distributed generation in hybrid grids. Managing the relationships between different agents is one of the most significant responsibilities of a multi-intelligent agent system. In general, a coordination model must be developed to handle a variety of relationships, including agent synchronization, task distribution, and communication. Maximizing the effectiveness of renewable energy resources and achieving power balance on both sides of the hybrid grid are the primary control objectives in this EES. In order to meet this goal, WT and PV must supply the loads with as much power as possible, and a main convertor is needed to coordinate all of the ESS and DGs in order to guarantee the stable and dependable operation of the hybrid grid [4]. Grid-connected and islanding modes of operation are both possible for simultaneous AC-DC grids. The microgrid cannot affect the distribution network's ability to operate steadily because it is an active load on it. To guarantee operation stability and specific adjustable margins, distributed generation within the microgrid must establish coordination.

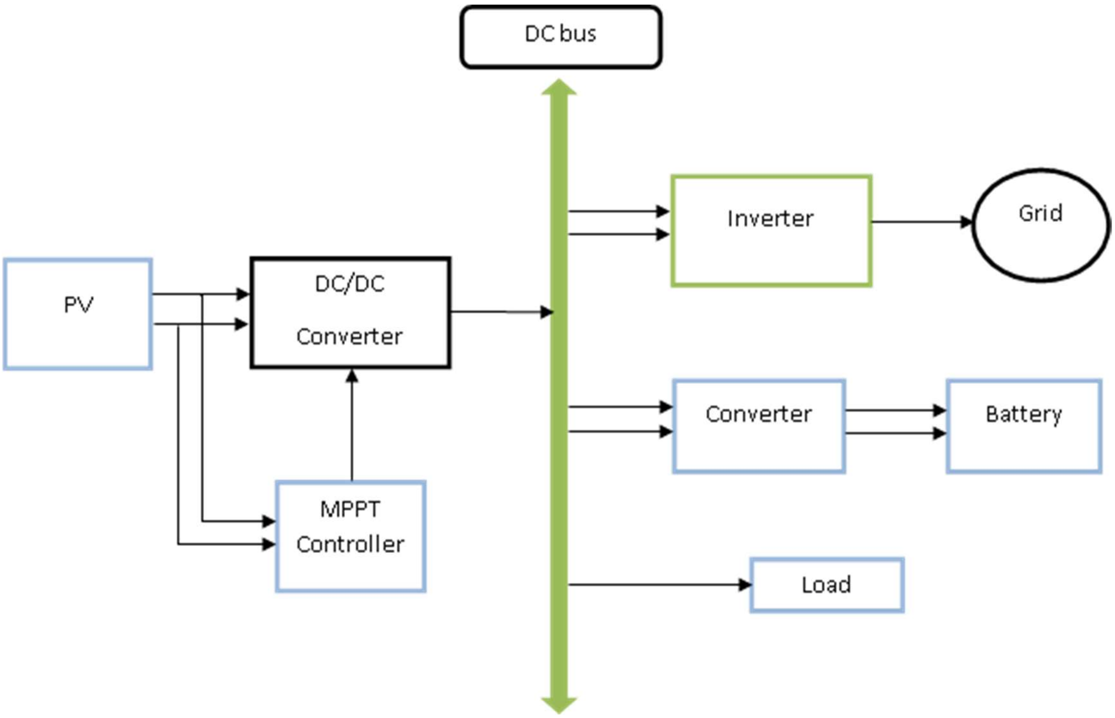

Figure-7 Basic block diagram of Proposed system

Operation Mode	Energy Flow	Mode	#	S_1	S_2	S_3	S_4	D_5	D_6	D_7	D_8
Propulsion	$V_{bat}\rightarrow V_{dc}$	BOOST	1	PWM	OFF	ON	OFF	-	-	-	PWM'
	$V_{bat}\rightarrow V_{dc}$	BUCK	2	OFF	OFF	PWM	OFF	-	PWM'	-	ON
Regenerative Braking	$V_{dc}\rightarrow V_{bat}$	BOOST	3	OFF	PWM	OFF	ON	-	-	PWM'	-
	$V_{dc}\rightarrow V_{bat}$	BUCK	4	OFF	OFF	OFF	PWM	PWM'	-	ON	-
Charging	$V_{grid}\rightarrow V_{bat}$	BOOST	5	OFF	PWM	OFF	OFF	-	-	PWM'	-

Table-1 Operating Modes of Proposed System

- The PV system with P&O technique is part of this proposed scheme.
- Boost converter, DC to AC inverter and controller, PWM inverter and control scheme.
- This converter improves the overall system's concert and dynamic response while lowering component losses.
- The MPPT technique provides the maximum power. The above figure depicts a basic schematic of the entire system.
- The system was designed and implemented using MATLAB, and the DC supply is connected to the loads after being converted to AC via an inverter.
- P&O algorithm provides maximum power.

Simulation & Results

The full grid-connected RES/BSB scheme of the chosen strategy is displayed in the simulation below. The MPPT algorithm, which is based on a dc/dc converter, connects the PV system to the DC link in order to maximize the power extracted from solar irradiation. An additional method of connecting the BSB to the group is through a bidirectional DC/DC converter, which transforms the medium battery voltage into a DC link reference voltage. To transfer electricity at a large rating under all charging conditions, a sophisticated control system that satisfies customer requirements is required. In order to meet the selected power demand from plugged-in EVs, DC-DC buck converters are used to settle the DC voltage and current that will be required for charging.

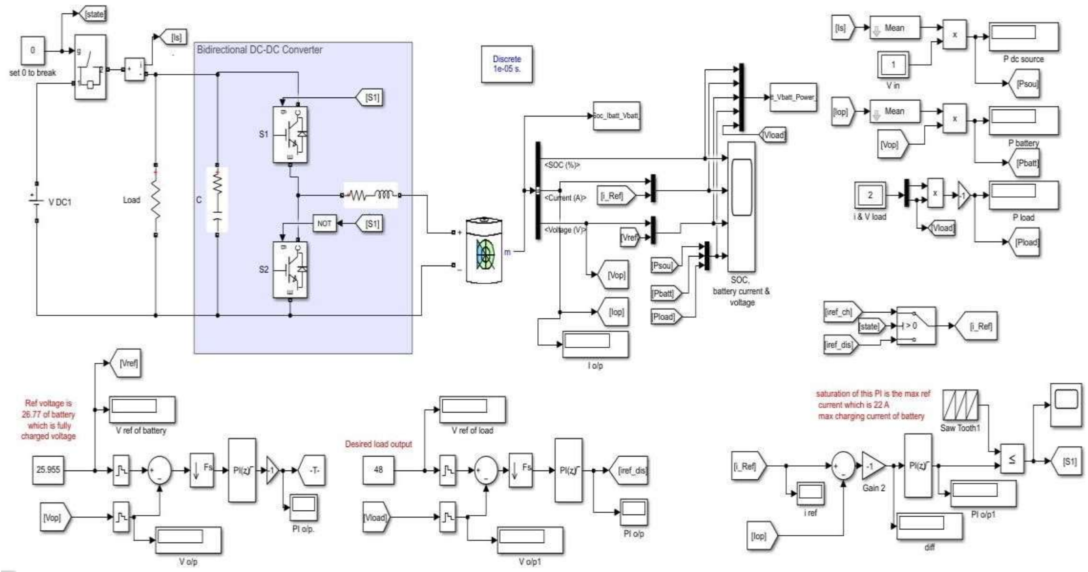

Figure-9 Simulation of BES charging & Discharging Control

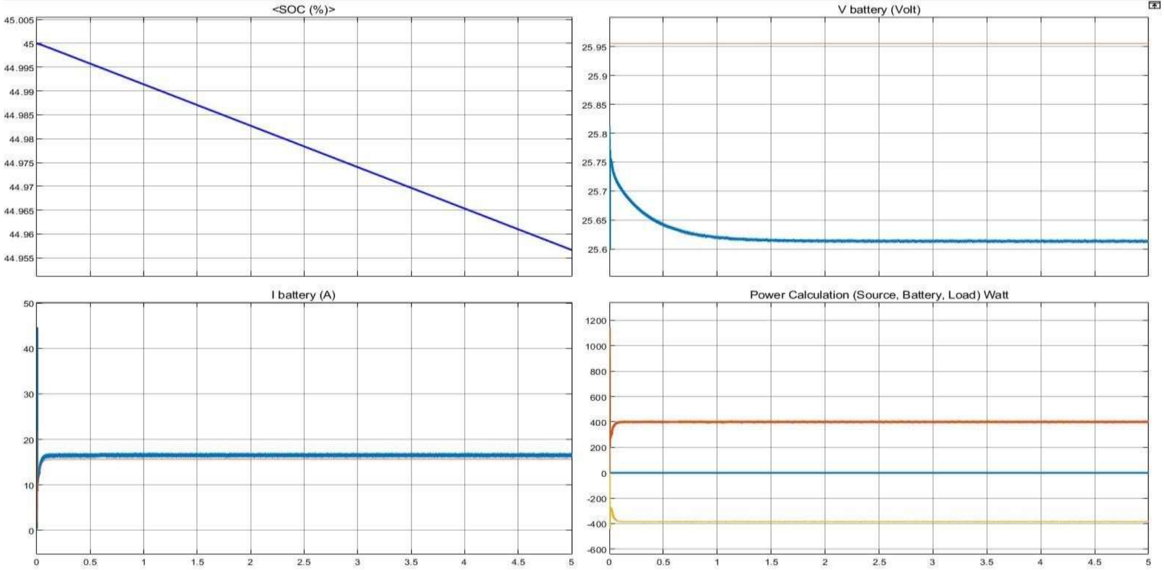

Figure-10 Simulation results of Battery Parameters

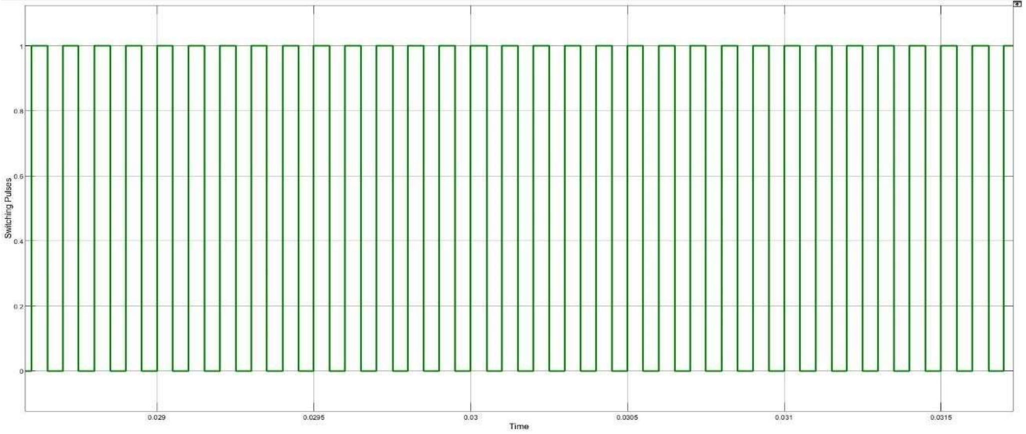

Figure-11 Simulation results of PWM switching pulses control

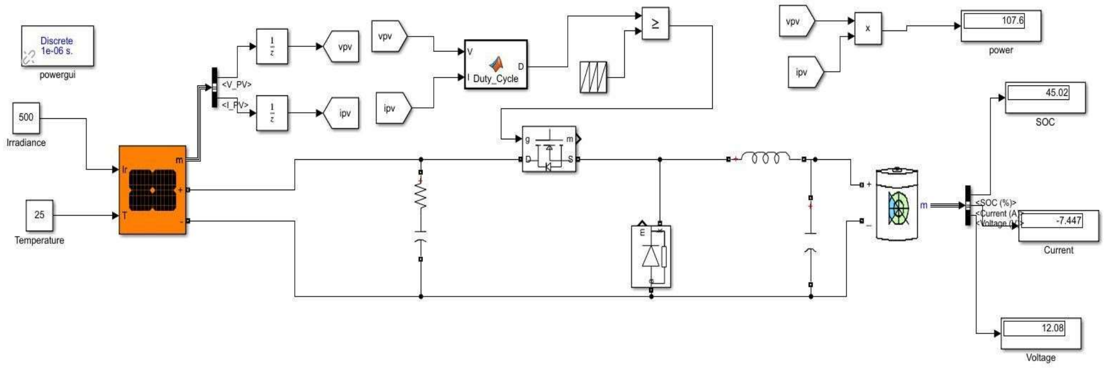

Figure-12 Simulation model of PV connected with BES through buck converter

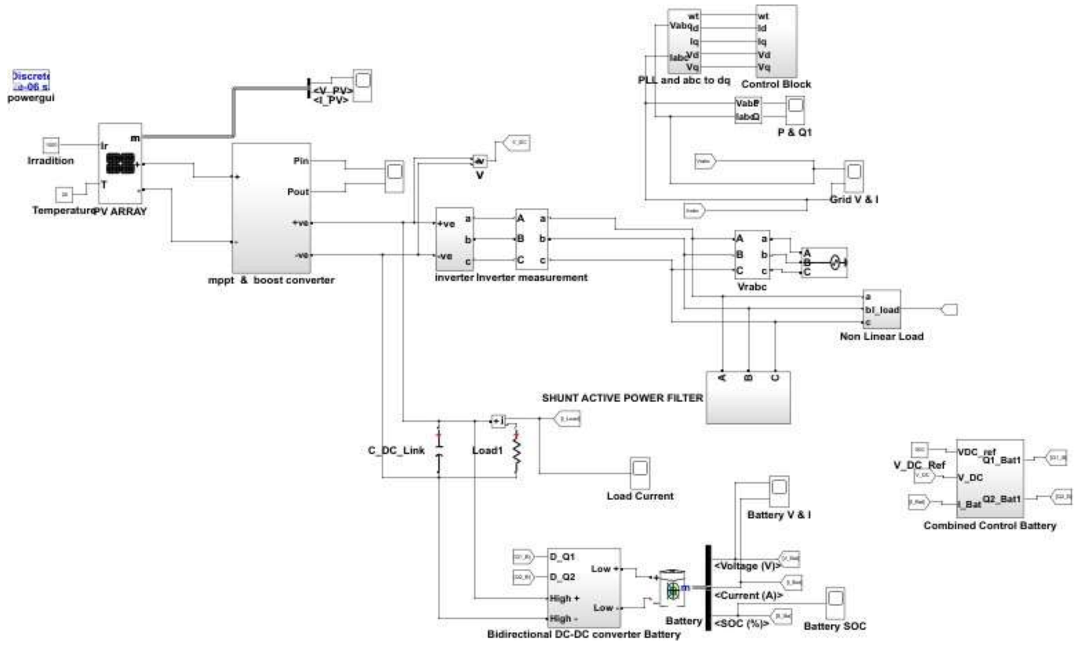

Figure-13 Simulation of EVs Charging with Solar PV System

Sir. No	Parameter	Value
1	Parallel string	**12**
2	Series- connected string	**9**
3	V max	**30.2V**
4	I max	**8.06A**
5	V total	**271.8V**
6	**I total**	**96.72A**

Table-2 Parameters of PV array

Sir. no	Parameter	Value
1	Inductor L	**$1.343*10^{-4}$H**
2	Capacitor C	**1.4410^{-6}F**
3	Input voltage Vs	**304V**
4	Output voltage Vo	**623V**
5	Duty ratio	**0.52**
6	Output Current	**35A**
7	**Power**	**21.77KW**

Table-3 Parameters of Boost Converter

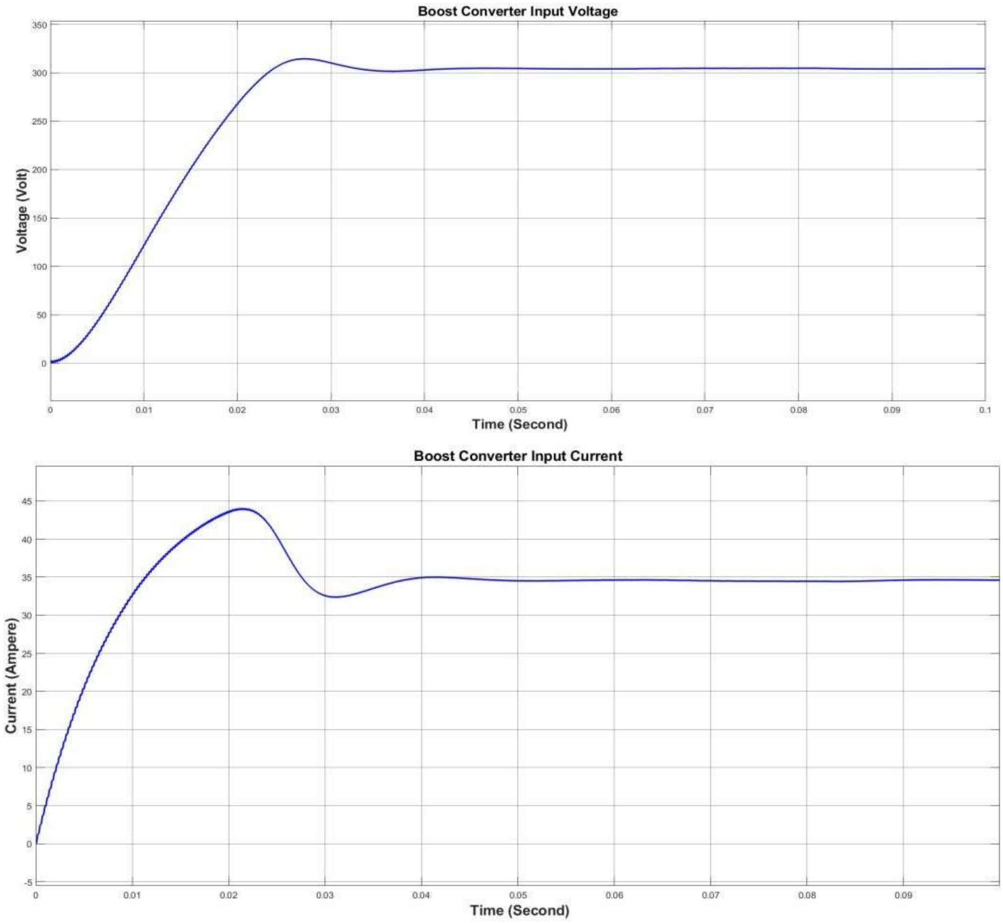

Figure -14 Boost Converter Input Voltage & Current waveform

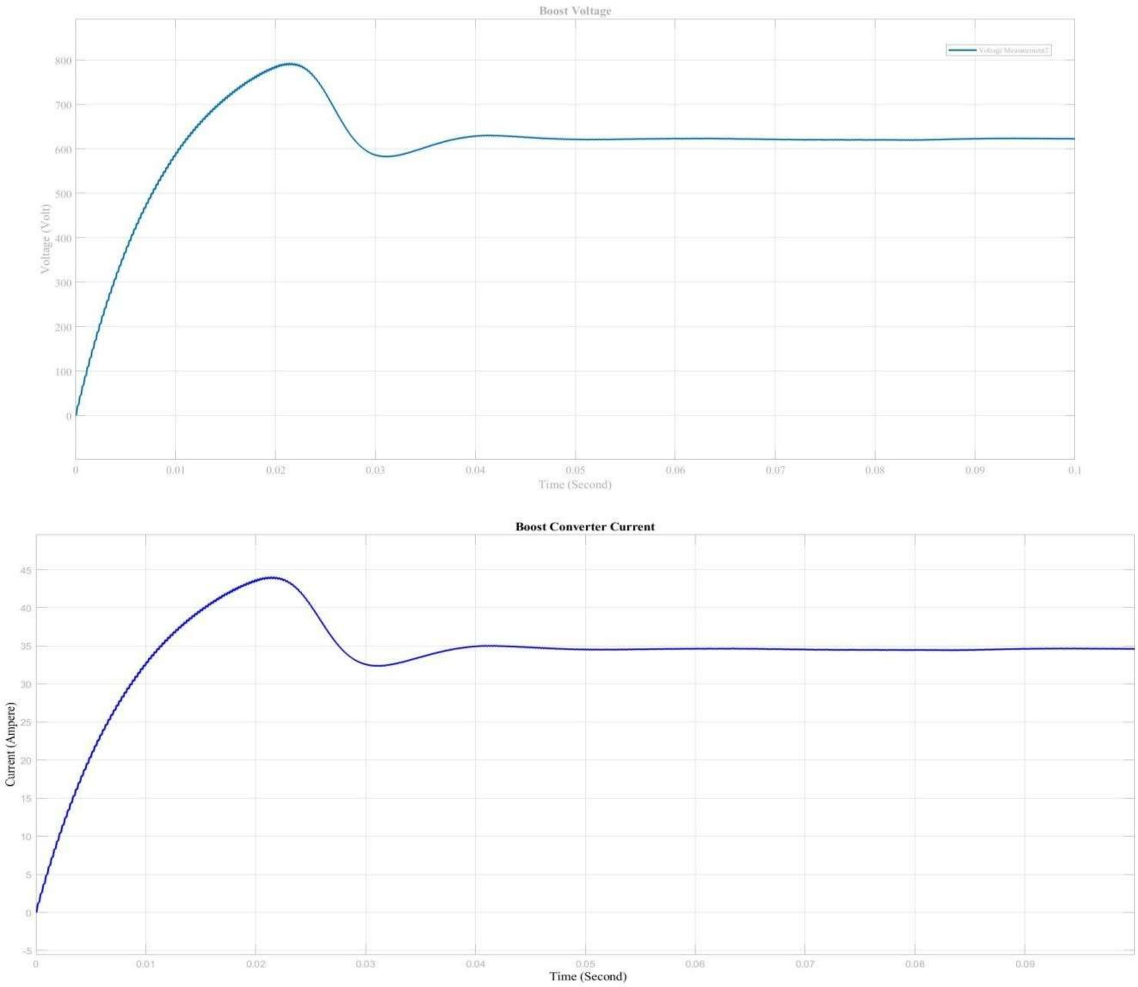

Figure -15 Boost Converter Output Voltage & Current waveform

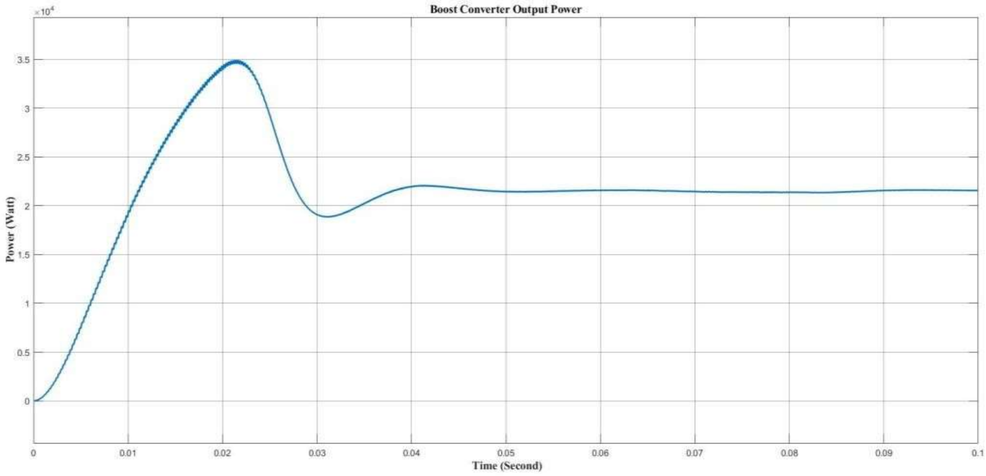

Figure -16 Boost Converter output Power [21.77 KW]

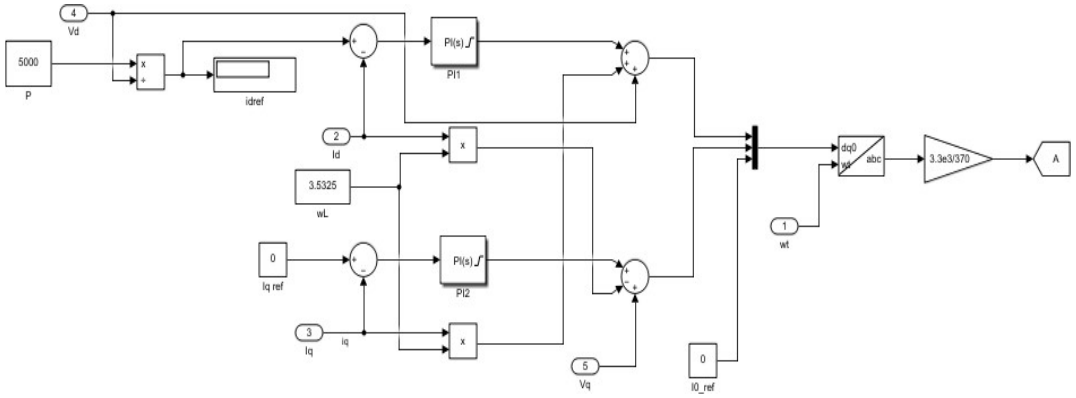

Figure-17 Inverter Control Block

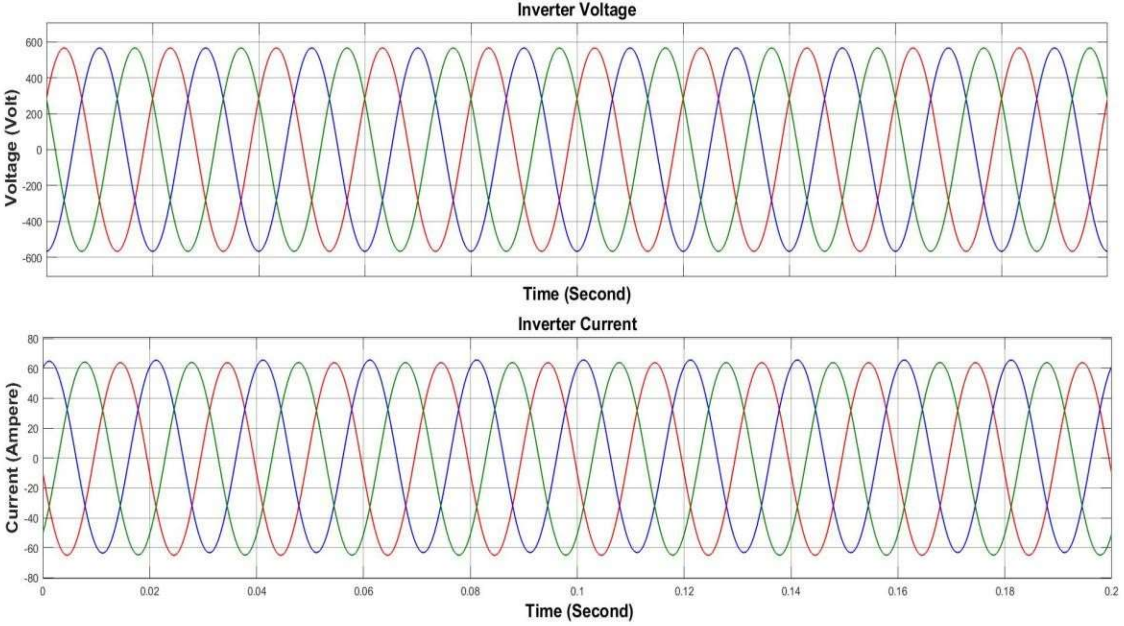

Figure-18 Inverter Voltage [400V] & Current [62A]

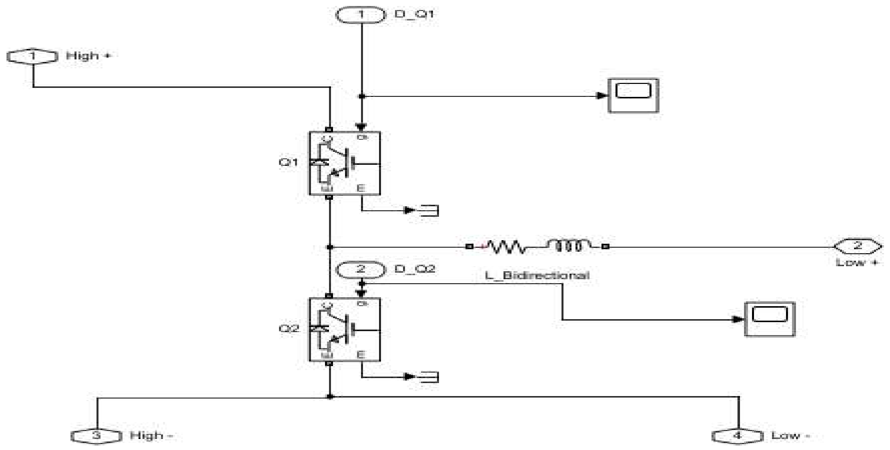

Figure-19 Bidirectional Converter model in simulink

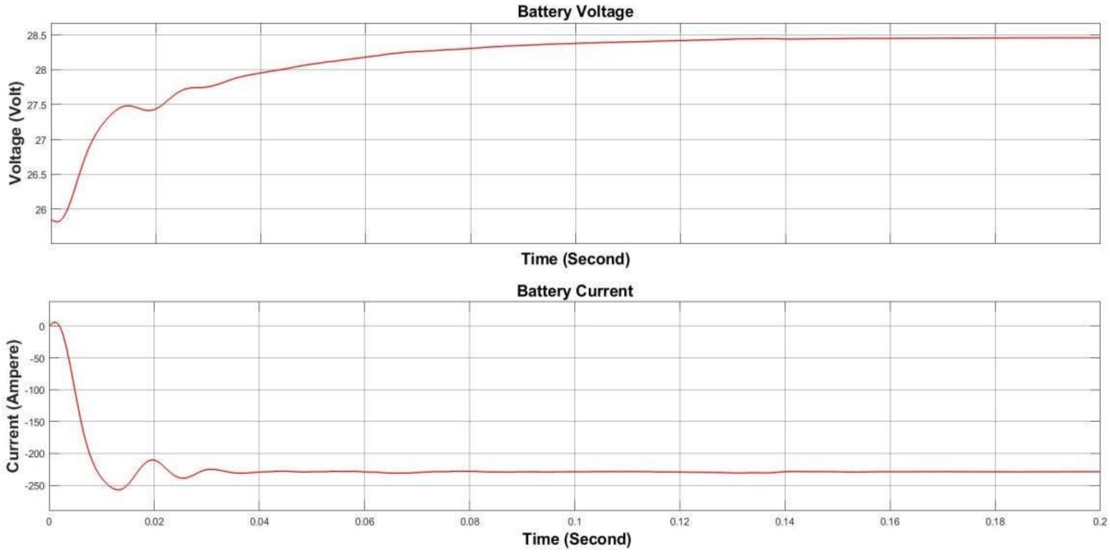

Figure-20 Voltage & Current Characteristic in Charging Mode

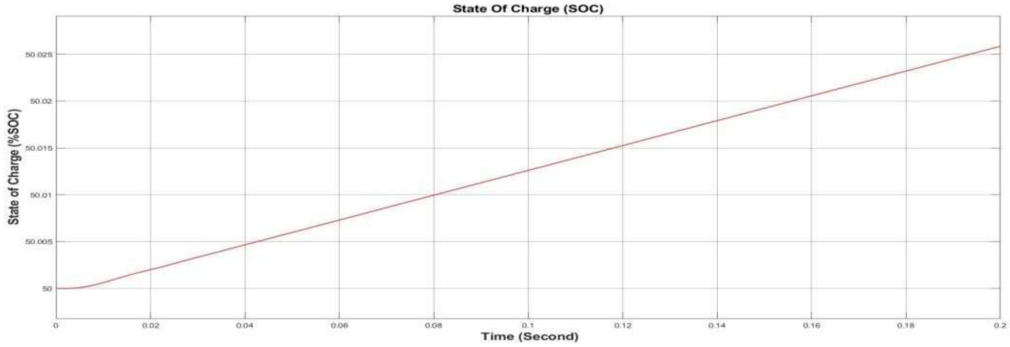

Figure-21 Battery SOC %

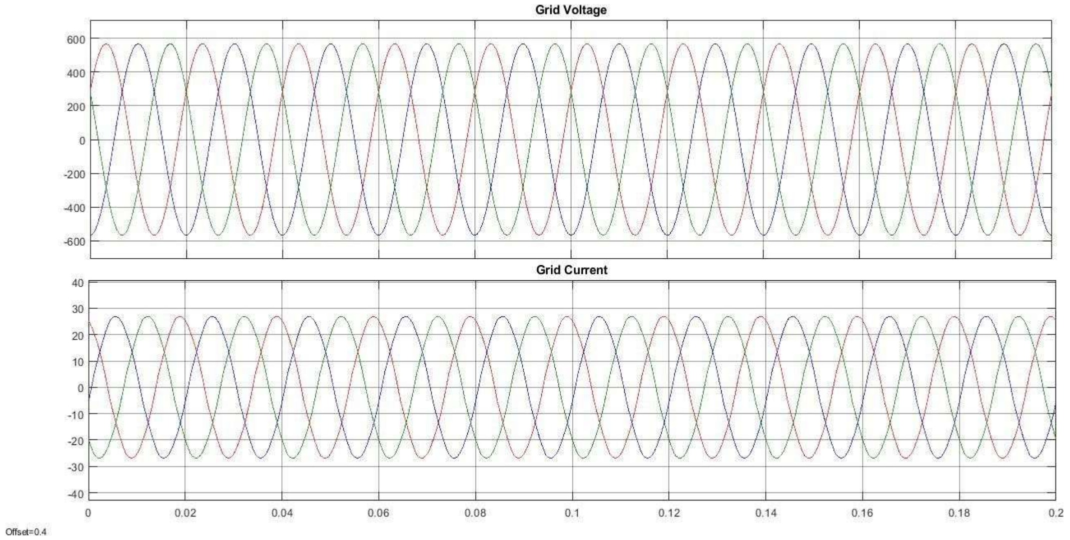

Figure-22 Grid Voltage [400V] &Current [20A]

Conclusion

Through this paper study, I learn how the various PV charging methods work and what their current status is also derived. The challenge of PV-grid integration with the charger will increase due to the anticipated high penetration rate of EVs into the grid system. It is anticipated that a more advanced energy management system will be needed to oversee the charging stations for a sizable fleet of electric vehicles. The solar PV simulation results with BES charging and discharging control are carried out using BDC. In this system, grid tie operation is also observed for the PV system with boost converter performance. The results may have several limitations, including a reduction in power availability at the charging station at night due to the grid operating in peak events mode and the BSB's limited stored energy. Matlab/Simulink simulation results have been used to validate the suggested optimization algorithm. The PPMS would determine the best charging scenario for the RES battery and grid based on intelligent power scheduling, thereby reducing the cost of charging from excessive reliance on the grid and facilitating a seamless integration of RES. The reliability and the flexibility of the hybrid power sources are achieved via seven operating phases by which a large scale of power for any EV charging mode is fulfilled.

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