Enhancing Electric Vehicle Grid Integration Efficiency through Vienna Rectifier Converter Technology

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***Abstract*- Protection of the environment has become one of the main tasks of social agents, policymakers and the scientific community due to factors such as greenhouse gas (GHG) emissions, shortage of fossil fuels and volatility of their prices. The emission of greenhouse gases and shortage of fossil fuels have diverted the focus of the scientific community, industry and society on the electric vehicle (EV). In order to decrease CO2 emissions, cutting-edge policies and regulations are being imposed worldwide, where the use of EVs is being encouraged. In the best of scenarios reaching 245 million EVs by 2030 is expected. Proper use of EVs requires the installation of a wide grid of charging stations and it is very important to set up the best charging power topology in terms of efficiency and impact in the grid. After nearly a century with the internal combustion engine dominating the transportation sector, it now appears that the electric vehicle is on the verge of experiencing rapid growth in both developed and developing vehicle markets. The internal combustion engine has an advantage over the electrical engine is that the internal combustion engine is more reliable than the electric engine and one more advantage of the internal combustion engine vehicle is it requires less time to fuel up than electric vehicle. In this paper, we are going to discuss about fast charging technique of electric vehicles using a Vienna T-type converter and Partial power processing technique. We are also going to discuss about grid impact of electric vehicles' fast charging stations. In which voltage and current fluctuation in harmonics are going to be discussed. Vienna T-type converter is a grid-facing AC/DC converter. These power converters provide an interface between the grid and a regulated DC bus. The important attributes required for these converters are having high power quality on the AC and DC sides. These converters must have negligible input current harmonics and must have nearly unity power factor and the simulation result has been analyzed by MATLAB Simulink.**

***Index Terms*: electric vehicle, solar, wind, battery grid, inverter.**

I. INTRODUCTION

An Electric vehicle are gaining popularity because they emit less pollution and are less reliant on fossil fuels. By integrating smart grid charging stations with distributed renewable energy sources, energy efficiency and carbon reduction can be achieved. It is possible to have a micro grid that is both linked to the grid and separated from it, where various sorts of loads make local use of energy sources. However, widespread adoption of high-capacity EV charging stations increases demand for charging infrastructure, which in turn increases demand on the power grid [Antennas, J 2016]. Power converter topologies and local renewable energy sources are used to help people who have trouble using a lot of energy. Tesla and Nissan are two of the companies that make electric cars. They build the infrastructure for charging stations. As a result, electric-vehicle charging stations that use renewable energy cut charging costs and emissions while improving the synchronization of the utility grid [Hernandez, 2016]. Combining the use of renewable energy sources with smart grid technology to electrify charging stations increases power conversion efficiency and decreases emissions. Locally used by various loads, microgrids may function in either grid-connected or islanding modes, and they consist of a network of distributed energy sources. Various energy sources and storage technologies comprise the microgrid. An example of a standard microgrid component is a charging station for electric vehicles. However, the burden that is placed on the power system increases in tandem with the number of electric vehicle charging stations. Because of this, an increasing number of individuals are driving electric automobiles. Here, the right power converter topologies used in combination with nearby renewable energy sources solve power consumption problems.

Electric vehicles (EVs) are considered as future transportation means because of the cost, availability and environmental constraints associated with conventional fossil fuel-driven vehicles. An essential constituent of all EVs is the battery charger system, which can either be an on-board AC charger fixed inside a vehicle or an off-board DC charging system fixed at specified locations (like garage etc.) providing EVs regulated DC power. The AC charging outlet demands an

AC-to-DC on-board battery charger with corrected power factor (pf). These chargers are categorized according to the level of power, they are designed to provide to the storage systems of EVs, namely, level-1 chargers, level-2 chargers and level-3 chargers (ul Hassan et al., 2021) Level-1 chargers are prescribed up to 120 V and 16 A rating (1.92 kW), level-2 are rated up to 240 V and 60 A (14.4 kW), and level-3 chargers are fast chargers with power rating > 14.4 kW (Habib et al., 2020).

A key component of the on-board AC charging system is an AC-to-DC converter, which is used as a front-end power stage to achieve pf correction and voltage regulation (VR). The front-end AC-to-DC power stage is followed by a back-end isolated DC-to-DC power stage converter to constitute the charger system. A simplified block diagram of an on-board battery charger system for EVs is shown in Fig. 1. The front-end AC-to-DC power stage of the battery charger system alters the input AC voltage into a regulated output DC voltage available at the intermediate DC-link capacitors. Along with pf correction function, the frontend stage converter transfers power from input to output with high efficiency. The following isolated DC-to-DC power stage then changes the regulated DC-link capacitors voltage into output DC voltage required for charging the storage batteries (usually lead– acid batteries) of the charger system.

As an essential part of battery charger system, the front-end AC-to-DC power stage must acquire peak efficiency and high power density with harmonic content injection level and pf correction within allowable limits. In addition, it must have to comply with internationally adopted regulatory rules of the AC supply to ensure power quality and control deficiencies such as line voltage distortion, harmonic content of load current and overheating etc. IEC 61000, IEC 1000-3-2, IEEE 519-1992, IEC 555-2, ECE R100 are some of the international protocols developed in this context (Ali et al., 2019).

The widely adopted state of the art methods exist in the literature, that perform front-end power conversion of the EV battery chargers (Praneeth and Williamson, 2018; Musavi et al., 2012b). The important aspects of the front-end power stage of a battery charger are: efficiency, power density, power factor, cost, total harmonic injection (THD), and control circuit complexity. These front-end stage converters of the battery charger mainly include boost-type and its variant topologies (Figueiredo et al., 2010; Musavi et al., 2011) such as conventional and interleaved PFC boost converters, bridgeless and phase-shifted (PS) semi bridgeless (SB) PFC boost converters, bridgeless interleaved boost converter (IBC) along with its resonant variant, full-bridge (FB) bidirectional rectifier, modular multilevel topologies, traditional rectifiers including diode bridge and multipulse converters, three level rectifier topologies with recent trend of vienna rectifier, and hybrid rectifiers such as hybrid vienna based rectifier and hybrid FB boost converter (Izadinia and Karshenas, 2017; Soeiro and Kolar, 2013) etc.

A conventional boost PFC (Xu et al., 2002) inherits high output capacitor current ripple and degraded efficiency due to losses associated with Diode Bridge and hence, heat dissipation problems. Inductance design and limited power rating for current sense resistors at high power levels are other challenges related to this topology. IBCs (Jang and Jovanovic, 2007; Loughlin, 2007) are employed to improve performance and reduce size of the front end PFC, because interleaving effectively doubles the switching frequency and also partially cancels the input and output ripples. The sizes of the energy-storage inductors and differential-mode electromagnetic interference (EMI) filter (Chen et al., 2020) in interleaved implementations reduce. However, similar to the conventional boost PFC, this topology has the heat management problem for the input diode bridge rectifiers (DBRs); therefore, it is also limited to low power levels (up to approximately 3.5 kW). The bridgeless dual-boost (DB) converter (Jang and Jovanovic, 2009) keeps off need of the input DBRs, realizing the minimum semiconductors count and resolving the heat management problem, which is inherited to conventional boost PFC due to presence of DBRs, however, it induces the sever electromagnetic interference (EMI) (Baur et al., 2006) due to the floating input voltage with respect to ground and high start-up inrush current. To handle the EMI issue, larger input chokes are required, which increases the cost and reduces power density (Kong et al., 2008).

II. RELETED WORK

EVs have been enhanced significantly to allow for a long driving range using novel battery technologies and fast-charging stations. The growth of the EV market has led to the significant issues of coming up with novel and innovative ideas to charge them [6–8]. Three significant barriers of EVs are high cost and cycle life of batteries, the complication of chargers, and the lack of charging infrastructures [9]. The chargers are an integral part of EV grid-to-vehicle (G2V) drive train efficiency. The G2V efficiency for EVs should be close to 45–50%. In order to improve the G2V energy efficiency, a high efficiency, high reliability, high power density, and cost-effective charger design are mandatory [5]. The battery chargers can introduce deleterious harmonic effects on electric utility distribution systems which is another drawback. The introduction of harmonics in the input line current causes low power factor of the fast-charging stations, thus drawing more current from utility, increasing line losses, and reducing the life of the distribution transformers [10]. Based on the power ratings, the chargers are classified as Level 1, Level 2, and Level 3. Level 1 and Level 2 chargers are typically designed for home charging with power less than 2 kW with a standard voltage of 120/230 V and public charging stations with power 20 kW with a standard voltage of 120/230 V, respectively [11]. The EV charging plug and the adapter for both Level 1 and Level 2 chargers typically comply with the SAE J1772 standard [12]. Level 3 chargers are typically designed for a fast charging using DC with the power rating around 100 kW with a charging time of less than 30 min. Level 3 chargers are used in commercial charging stations. They are normally connected directly to the medium-voltage three-phase systems. The DC fast-charging station's standards are presented in [13]. Further information for all the levels of charging is provided in Table 1. As a test case, the Nissan Leaf® 24 kWh Li-ion battery pack is considered [14]. The review of available Level 3/DC fast-charging techniques is the cornerstone of this paper. The advantages and limitations are also highlighted for better clarity. Generally, DC fast-charging stations for EVs are designed to supply about 50 kW of power [15]. The established trend is to place these chargers of-board as these stations are bulky. The general block diagram of a DC fast charging station is shown in Fig. 1, and the charger is connected to a common AC link. EV battery chargers can be integrated into an EV as an on-board charger or separated as an off-board charger. The power flows between the grids, and EV batteries can be unidirectional or bidirectional. The unidirectional power flow chargers are used as grid-to-vehicle charger applications, and bidirectional power flow chargers are used as grid-to-vehicle and vehicle-to-grid charger applications [16]. Unidirectional chargers can be controlled to charge the EV battery from the grid [17–19].

Abdar Ali et.al. 2021 The requirement of high power rated, efficient and high power density grid-connected converters has increased due to their extended use in multiple applications such as battery chargers. The proliferation of electric vehicles (EVs) in the transportation market is essentially associated with the performance and reliability of battery chargers. An efficient, compact and fast battery charger is indispensable in order to provide a way to charge an EV in a short time. In view of this fact, this article proposes a softswitching three-level T-type Vienna rectifier, which can be used as a front-end power stage converter in an on-board EV battery charger. The proposed topology achieves high efficiency and high power density by employing soft-switching strategy, which is achieved by incorporating a simple auxiliary network in the proposed circuit. The reduced component stresses and simple control strategy make it an appealing candidate for EV industries to develop this front-end PFC rectifier as a fast battery charger. The high switching operation with reduced power losses, regulated DC at the output, lowharmonic grid current and power factor correction operation are achieved with the proposed topology. The construction, operating principle and simulation analysis of the proposed converter are discussed in detail. In order to show the stand-point of the proposed scheme, a fair comparison of the proposed soft-switched converter with an existing soft-switched 3-level neutral-point diode-clamped converter is carried out in terms of the number of components and complexity in the PWM signals generation. Additionally, an efficiency comparison of the suggested converter is carried out with some existing well-known rectifier topologies at different power loads. The practical implementation of the proposed power converter scheme is checked by building a laboratory-prototype to perform an experimental analysis.

III PROPOSE SYSTEM

The proposed system in this dissertation focuses on addressing the challenges and optimizing the fast-charging technique of electric vehicles (EVs) using the Vienna T-type converter and Partial Power Processing (PPP) technique. The dissertation aims to explore the use of the Vienna T-type converter, a grid-facing AC/DC converter known for its high-power quality on both the AC and DC sides. This converter interface between the grid and a regulated DC bus, with attributes including negligible input current harmonics and nearly unity power factor. Despite its high efficiency, the Vienna T-type converter requires a large number of devices, which can pose challenges in terms of complexity and cost. The dissertation delves into the Partial Power Processing (PPP) unit, which is designed to reduce the power processed by the converter. By processing only a fraction of the total power flowing from the source to the load, the PPP unit aims to minimize power losses and reduce the size of the converter. This reduction in power processed leads to lower losses generated by the converter, thereby increasing overall system efficiency while maintaining the same converter efficiency. The proposed system integrates these two techniques to optimize the fast charging of electric vehicles. By leveraging the efficiency of the Vienna T-type converter and the power reduction capabilities of the PPP unit, the system aims to achieve faster charging times while minimizing grid impact and maximizing overall system efficiency. The dissertation will explore the design, implementation, and performance evaluation of this integrated system, with a focus on voltage and current fluctuations, harmonics, and efficiency. Through this research, the goal is to contribute to the advancement of electric vehicle charging infrastructure, ultimately promoting widespread adoption of electric vehicles and reducing greenhouse gas emissions in the transportation sector.

Modules description

***AC Grid*:** The AC grid refers to the alternating current electrical grid, which supplies power to homes, businesses, and infrastructure. In the context of electric vehicles, it is the source of electricity for charging EV batteries.

DC Link: The DC link is a component in power electronic systems that connect different stages of power conversion. It typically consists of capacitors and inductors and serves to smooth out voltage and current fluctuations.

Battery: The battery is the energy storage device used in electric vehicles to store electrical energy for propulsion. It is typically a lithium-ion battery, although other types may also be used.

***PWM* (Pulse Width Modulation):** PWM is a technique used in power electronics to control the amount of power delivered to a load by varying the width of pulses of current or voltage.

Boost Converter: A boost converter is a type of DC-DC converter that increases the voltage of a DC power source. It is commonly used in electric vehicle charging systems to step up the voltage from the battery to the level required for charging.

Bidirectional Converter: A bidirectional converter is capable of converting power in both directions, either from AC to DC or DC to AC. In electric vehicle charging systems, bidirectional converters are used for vehicle-to-grid (V2G) applications, allowing power to flow both to and from the vehicle's battery.

Vienna Converter: The Vienna converter is a type of three-level converter used in power electronics. It is commonly employed in grid-tied applications to convert AC power from the grid to DC power for use in applications such as electric vehicle charging.

Partial Power Processing: Partial power processing (PPP) is a technique used to reduce the power processed by a converter, thereby reducing losses and increasing efficiency. It involves processing only a fraction of the total power flowing from the source to the load.

Single Phase Inverter: A single-phase inverter is a device that converts DC power to single-phase AC power. It is commonly used in residential and small-scale applications, including electric vehicle charging stations that require single-phase AC power.

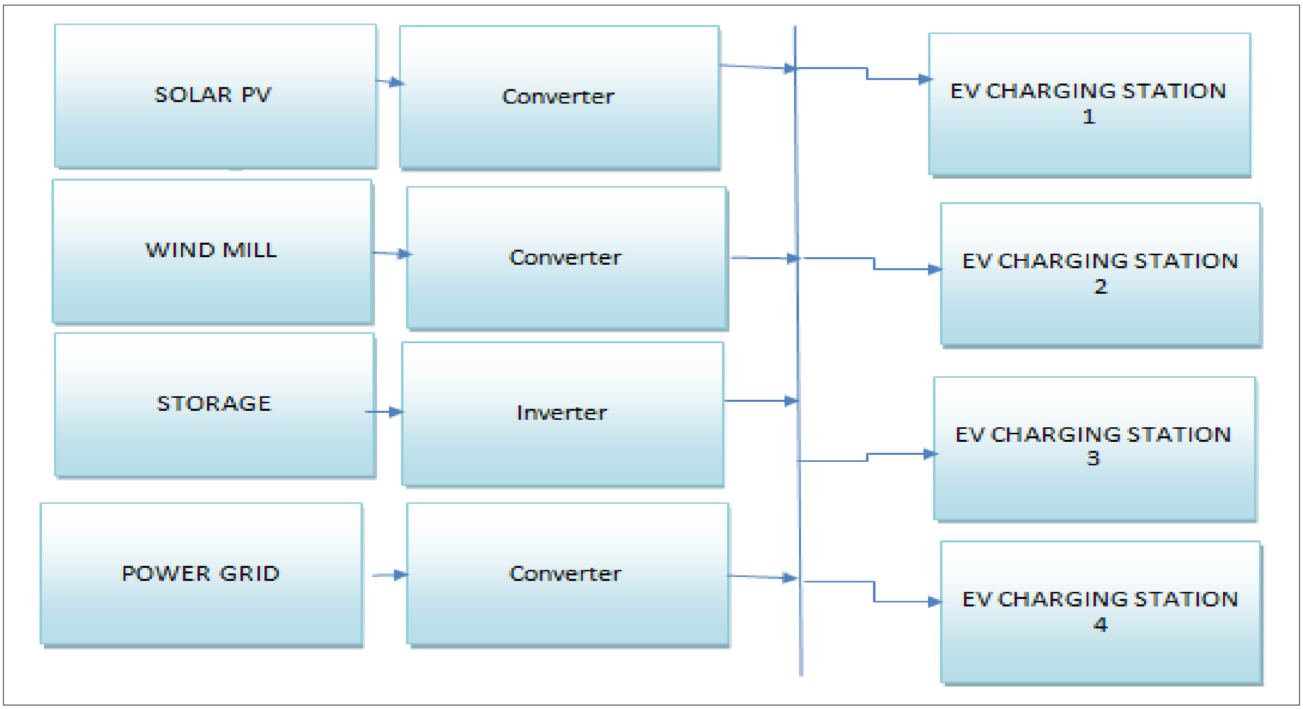

Fig.1 proposed flow diagram

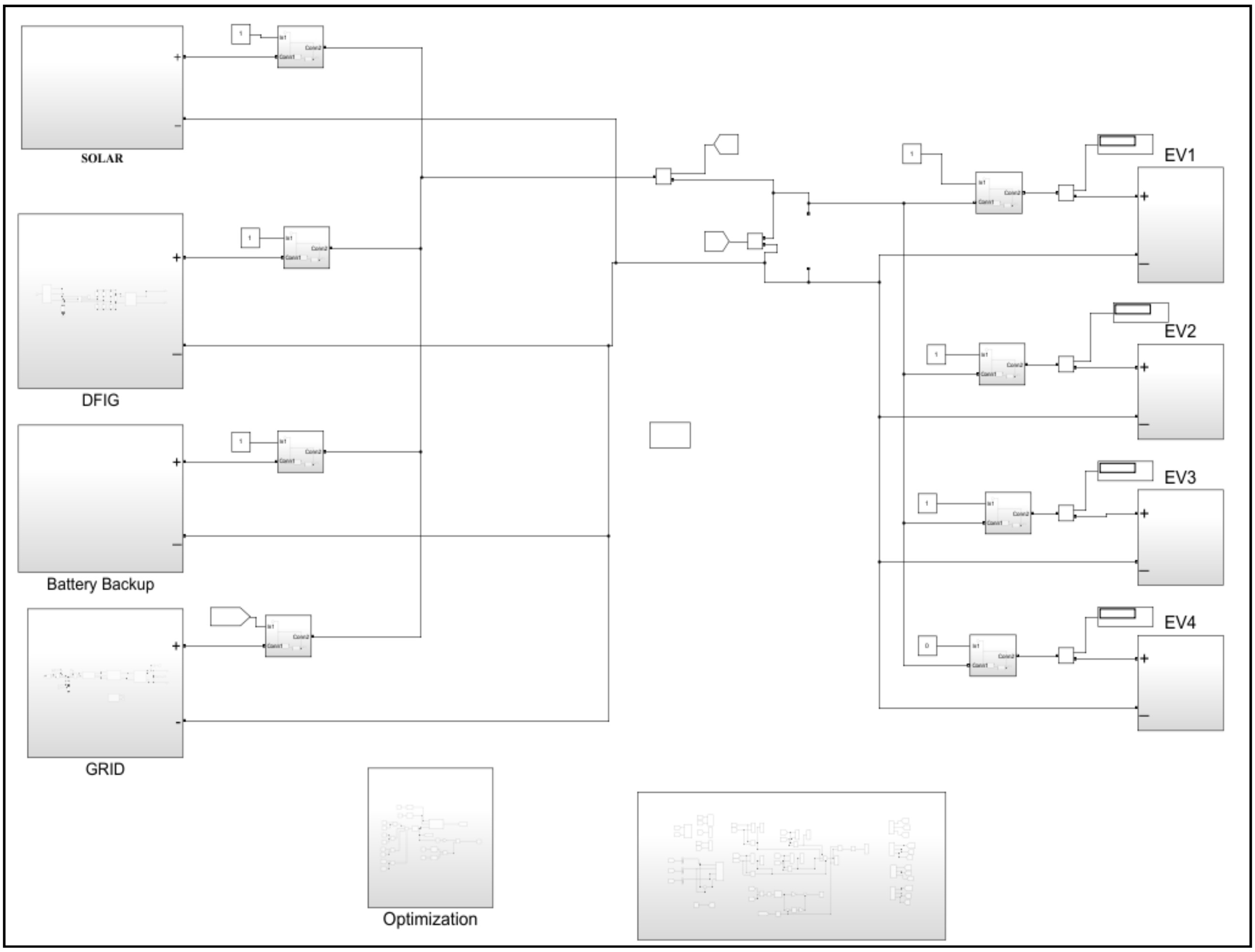

Fig. 2 MATLAB Simulink model

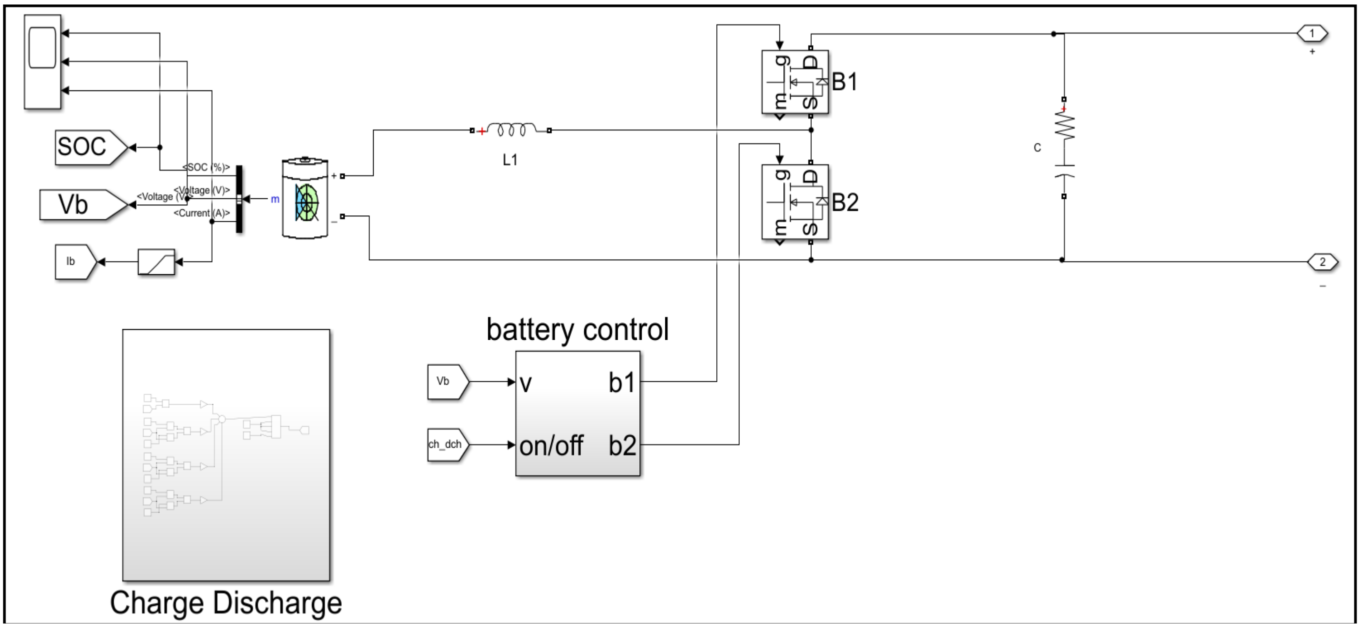

Fig.3 Battery subsystem

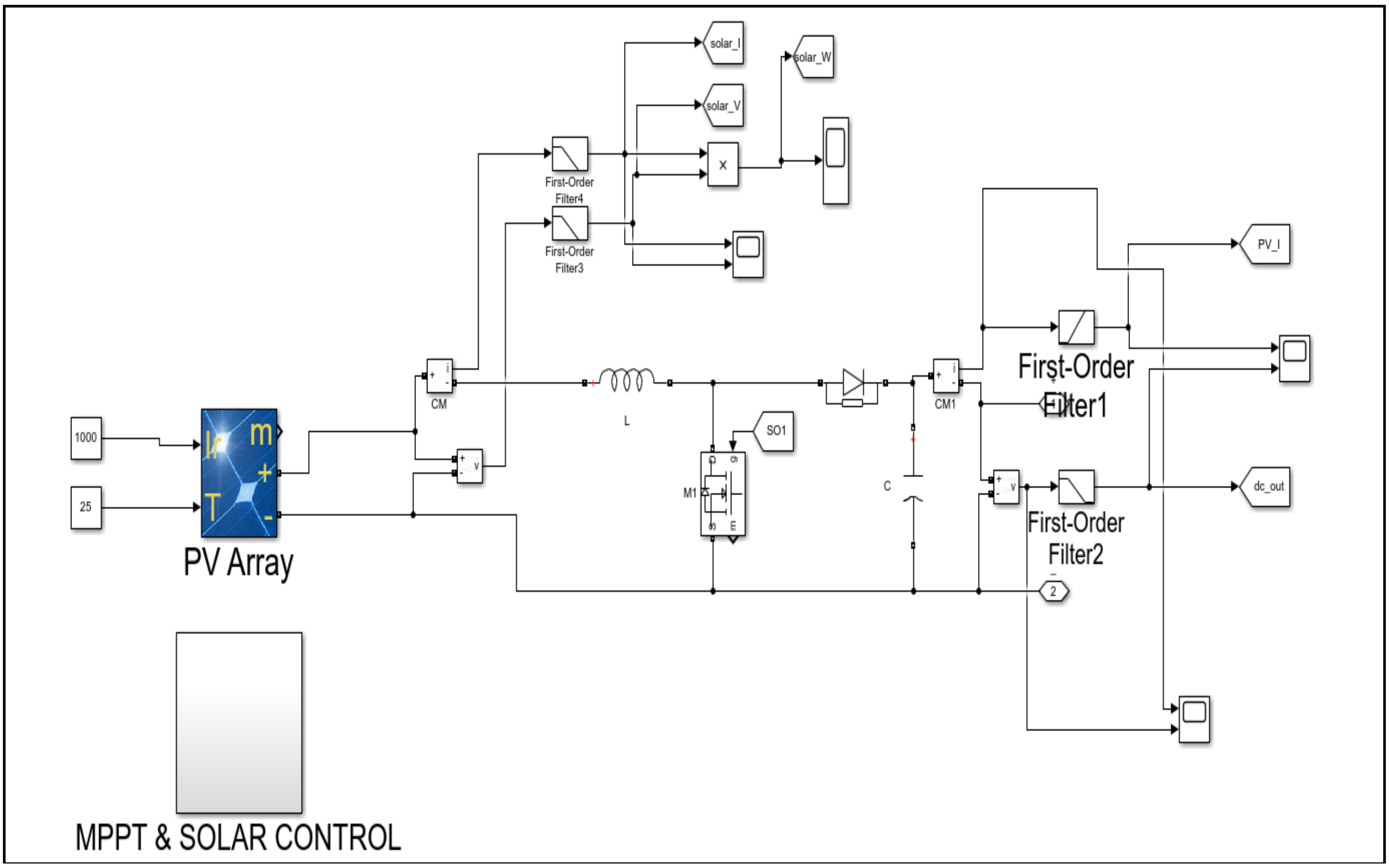

Fig.4 Solar Subsystem

Wind Turbine

A wind turbine is a device designed to convert the kinetic energy of wind into mechanical power, which can then be converted into electricity. In the wind turbine the blades are connected to a rotor, which spins when the wind blows. The rotor is connected to the main shaft. The main shaft of the wind turbine is connected to a generator. As the rotor spins, it drives the generator, which converts the mechanical energy into electrical energy. Wind turbines are equipped with power control systems that regulate the speed of the rotor and generator to optimize power output and protect the turbine from damage in high winds.

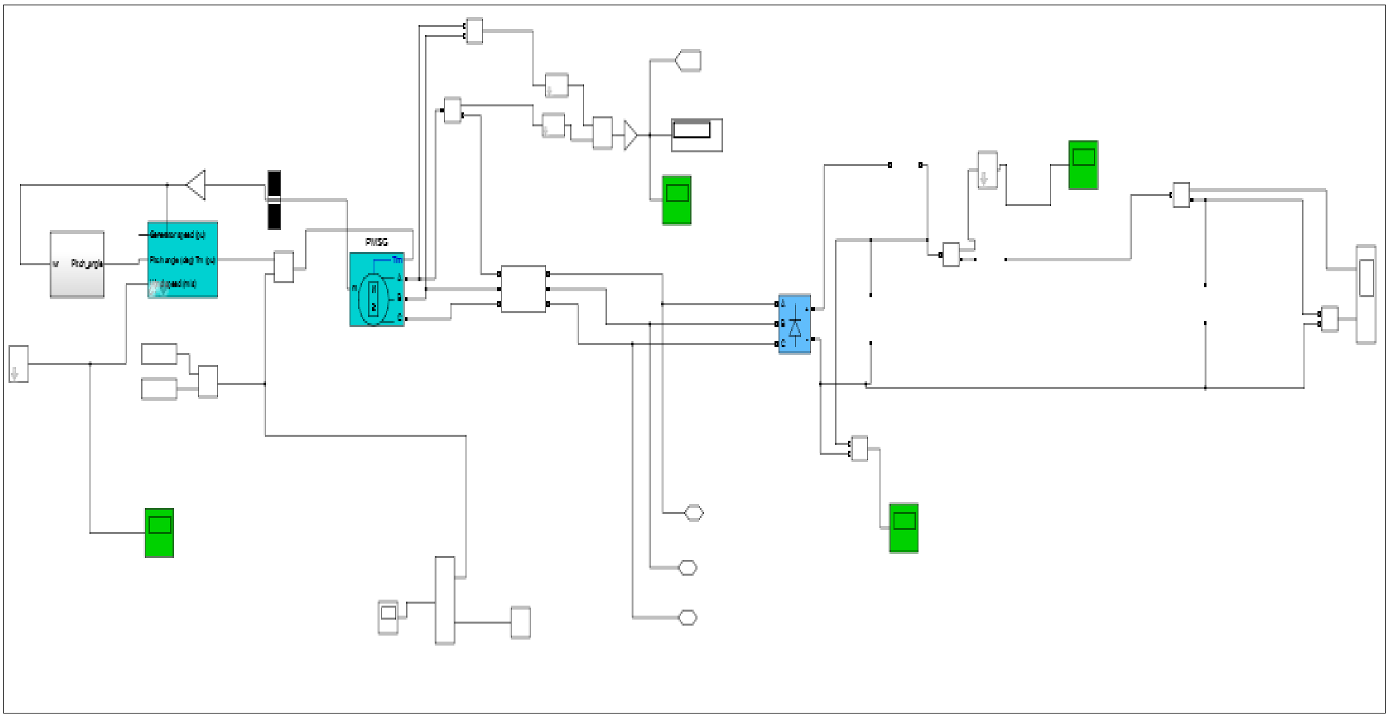

Fig.5 Wind Turbine Model

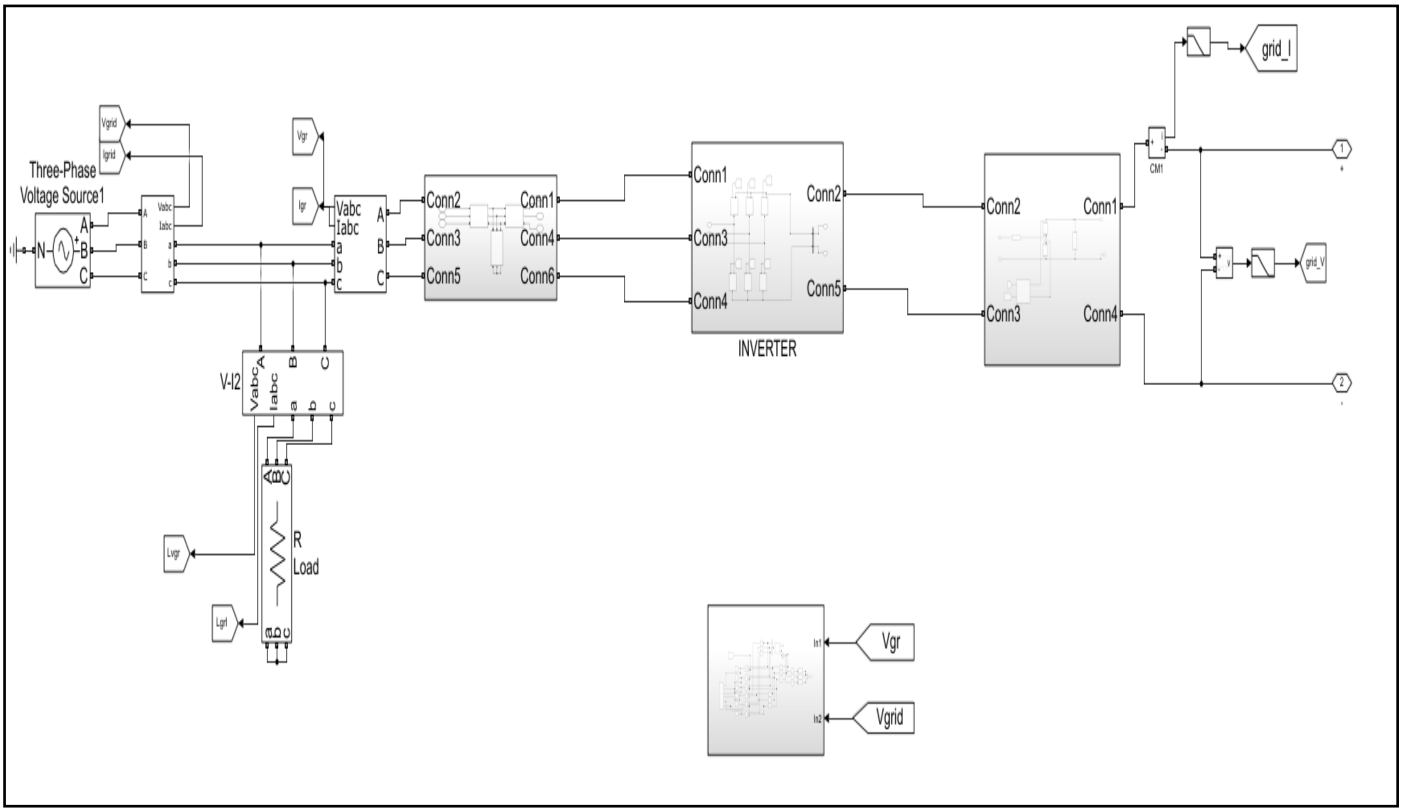

Fig.6 Grid System

A grid system can be interconnected with a Vienna rectifier converter to create a comprehensive power electronics simulation. The grid system component represents the utility grid or any power source, while the Vienna rectifier converter acts as an interface between the grid and the load. The Vienna rectifier topology is advantageous for its ability to provide bidirectional power flow and low harmonic distortion. By integrating these elements within Simulink, engineers can design and analyze complex power systems, investigate control strategies, and evaluate the performance of various grid-connected applications such as renewable energy systems or electric vehicle charging stations.

IV SIMULATION RESULT AND DISCUSSION

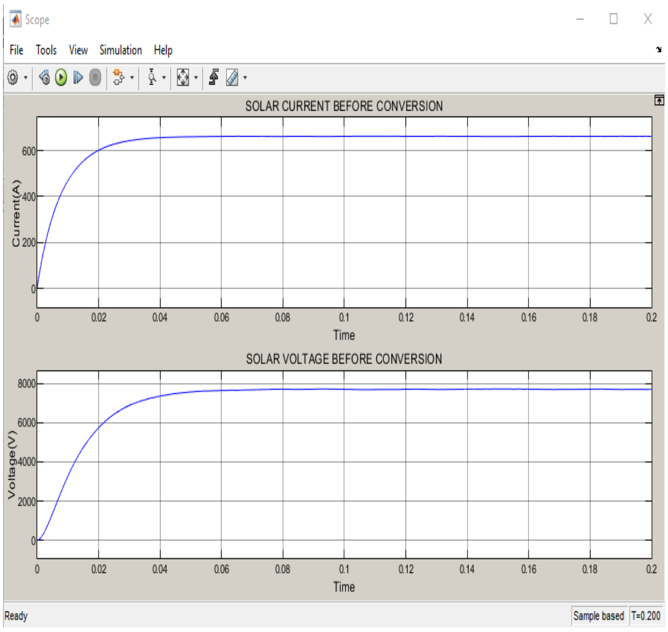

Fig.7 Solar voltage and current waveform before the converter

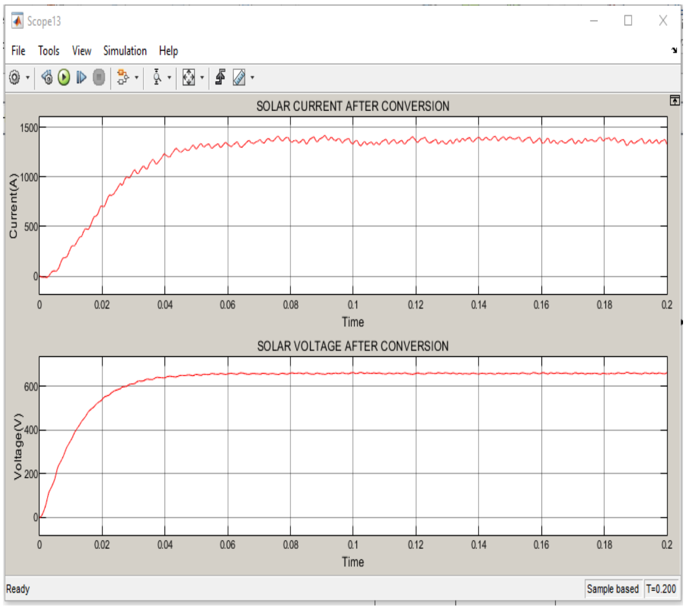

Fig.8 Solar voltage and current waveform after the converter

Fig 7 Solar voltage and current waveform before the converter, the current generated 660 A, Where Voltage generated 7800V from the solar. Fig 8 showing the solar voltage and current waveform after the converter, the current generated 1470 A; Where the Voltage generated 650V from the solar.

Table 1 SOC Charging condition

NO.1	SOC	Status	Action
1	Less than 25%	charge	Disconnected from load only charging of battery
2	25 % < SOC < 50%	charge	V2G avoided charging done
3	50% < SOC < 50%	charge	Vehicle to grid perform, charging
4	SOC = 100%	**dis**charge	Grid perform, no charging

In the simulation 4 SOC condition check to check the SOC of the battery in the first case If SOC is between 0 to 25%, it will charge showing in Figure 7.

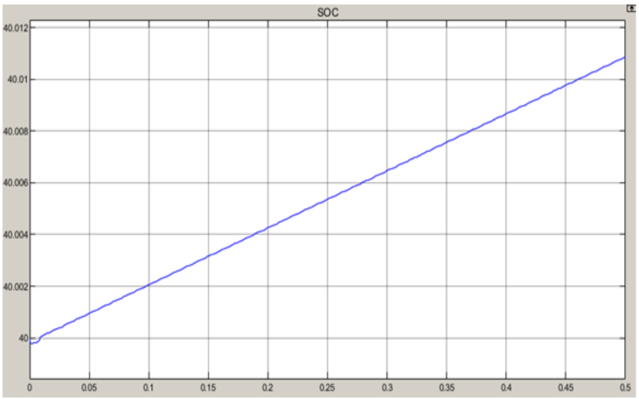

Fig.9 SOC charging at 40%

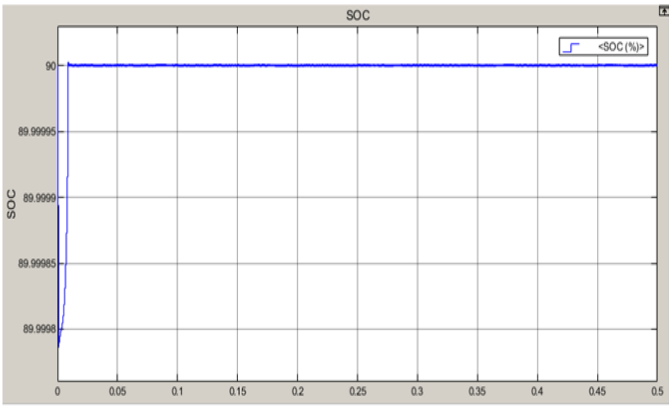

Fig.10 SOC charging at 90%

In the third case if soc between 50% to 90%, it will charge showing in fig.9 in the third case if soc is between 50% to 90%, it will charge showing in fig.10.

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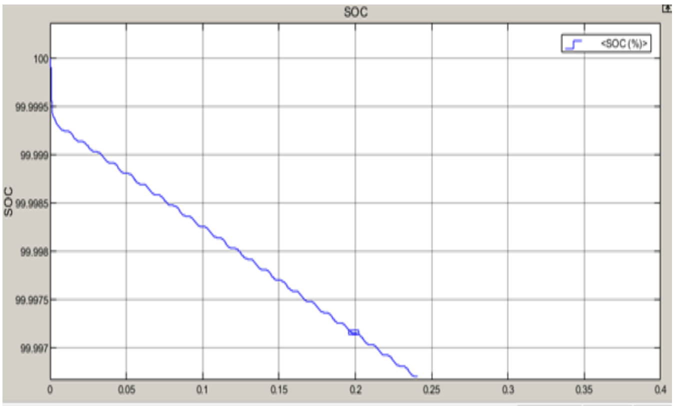

Fig.11 SOC discharging at 100%

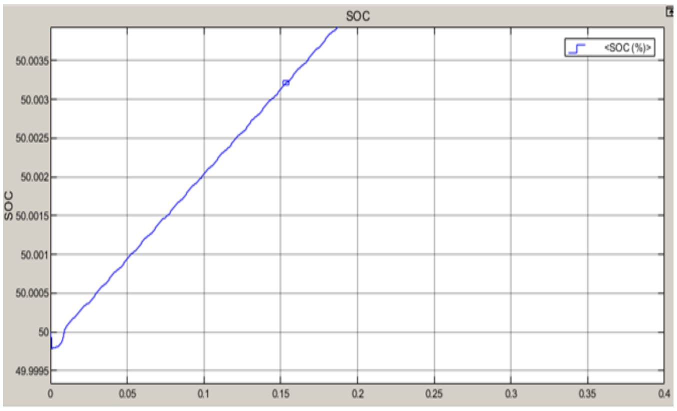

Fig. 12 SOC charging at 50%

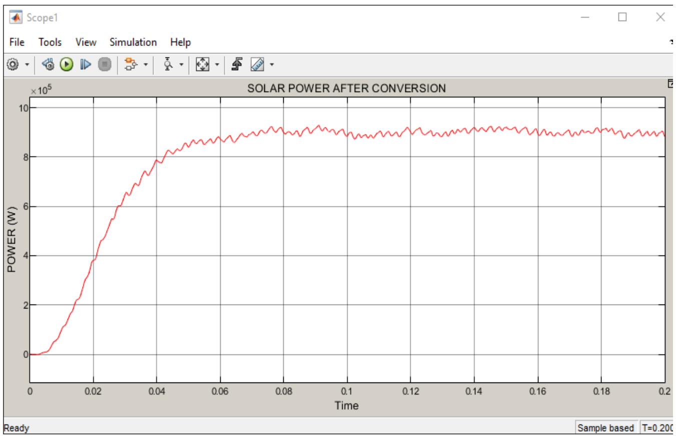

Fig.13 showing the solar power waveform after the converter

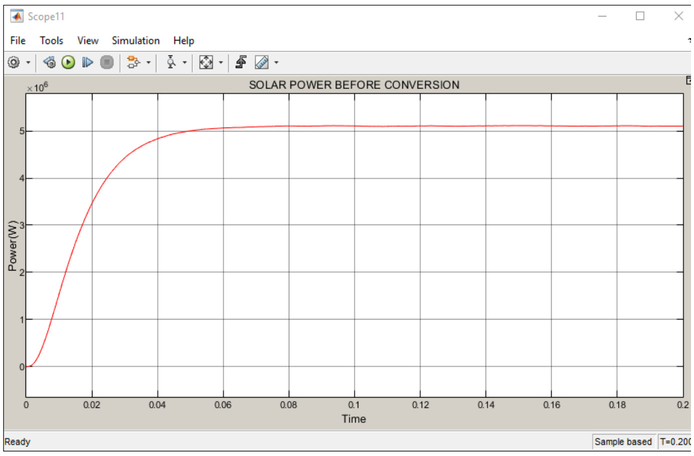

Fig 14 showing the solar power waveform before the converter

Fig.13 showing the solar power waveform after the converter, approx. 5MegaWatt power generated from the solar.

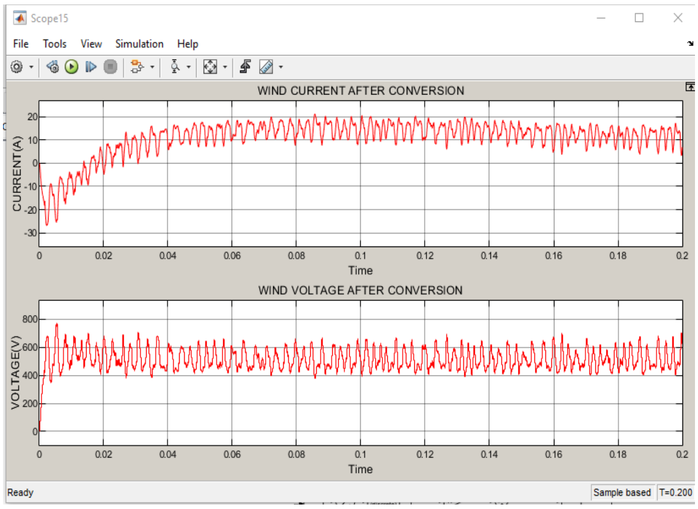

Fig.15 showing the wind system voltage and current waveform after the converter

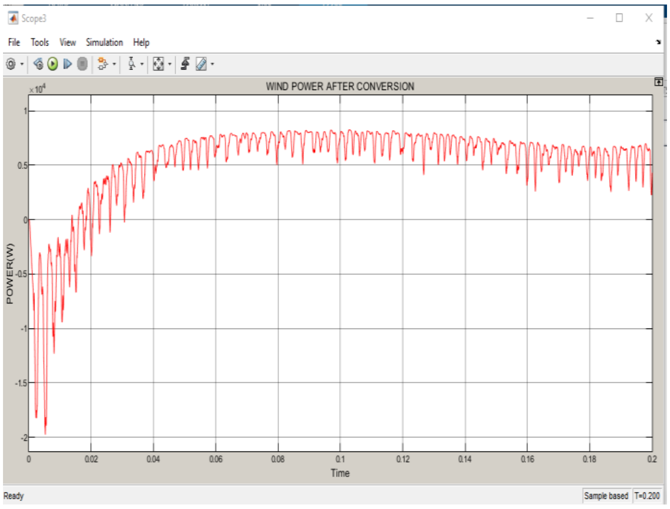

Fig.16 The wind system power waveform after the converter

Fig 15 showing the wind voltage and current waveform after the converter, the current generated 19 A, Where Voltage generated 640V from the wind system.

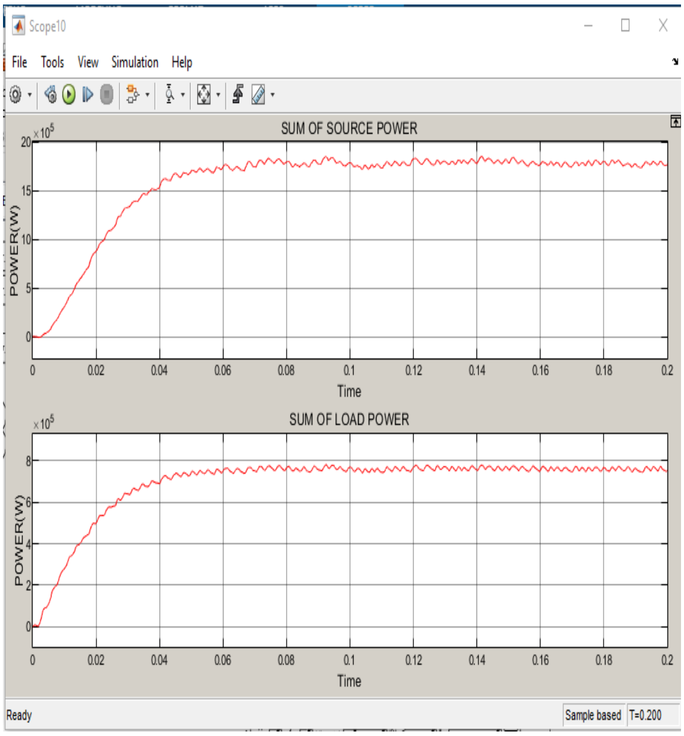

Fig.16 showing the sum of source power and sum of load power of the system

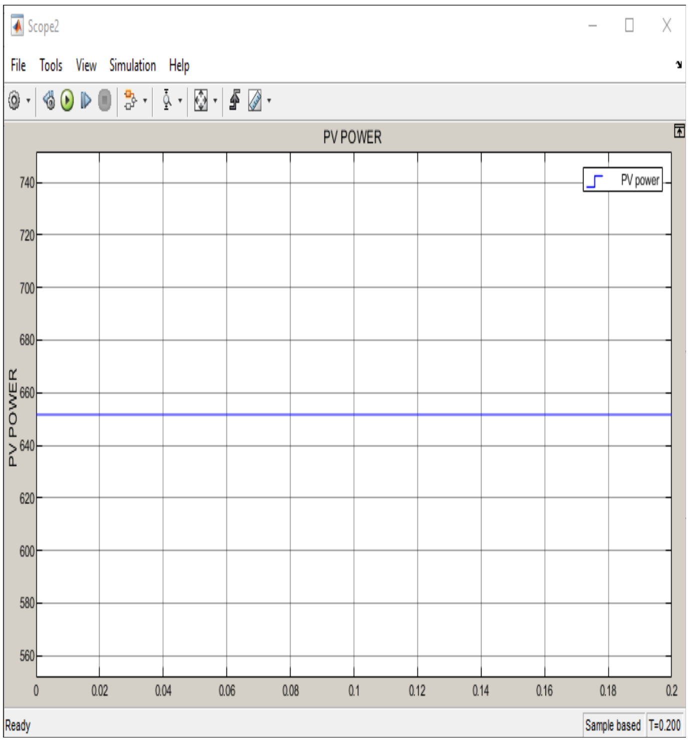

Fig.17 PV power

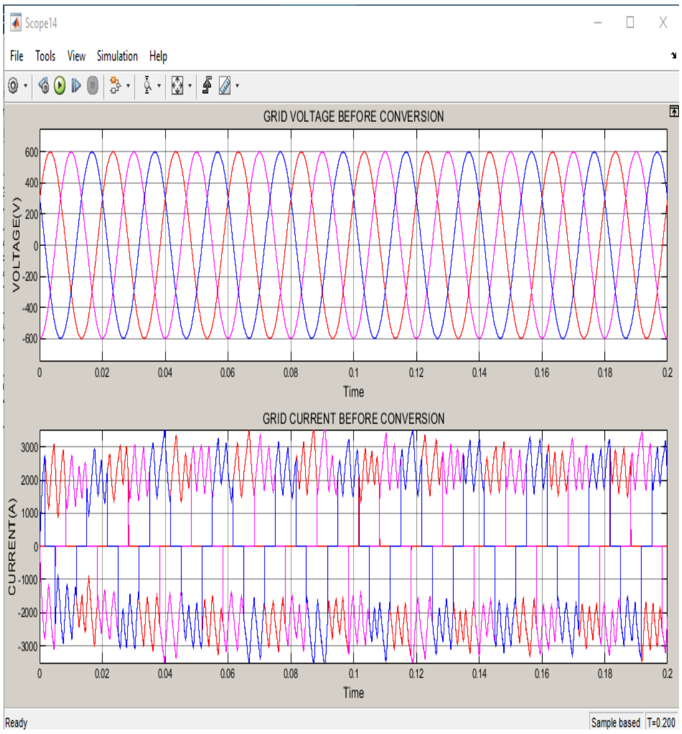

Fig.18 showing the grid voltage and current waveform before the converter

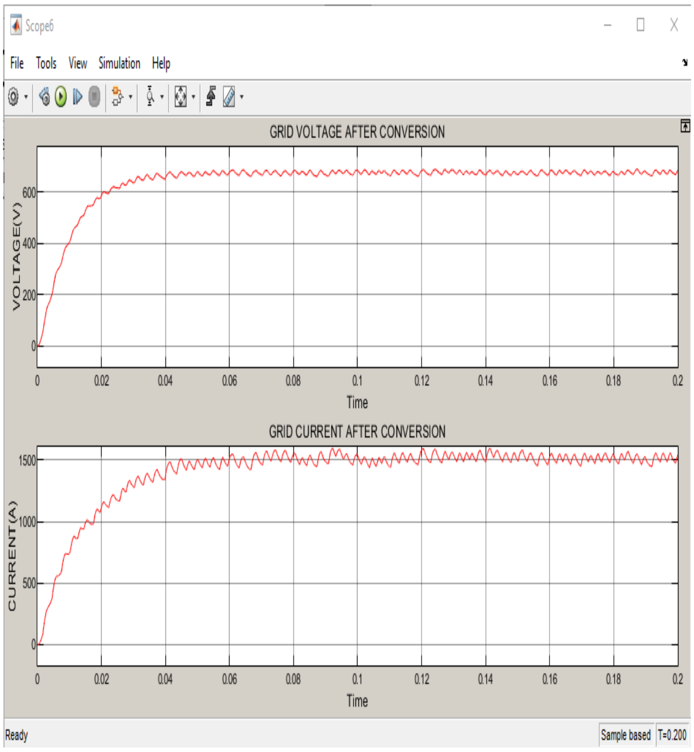

Fig.19 showing the grid voltage and current waveform after the converter

Fig 18 showing the grid voltage and current waveform before the converter, the current generated 2500 A, Where Voltage generated 600V.Fig 19 showing the grid voltage and current waveform before converter, the current generated 2500 A, Where Voltage generated 600V.

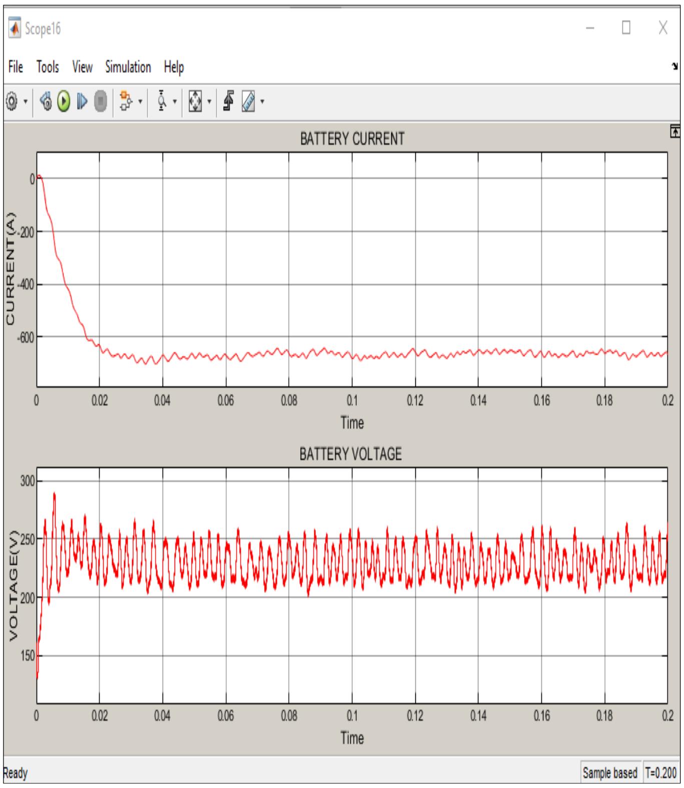

Fig.20 showing the battery power generate by the system

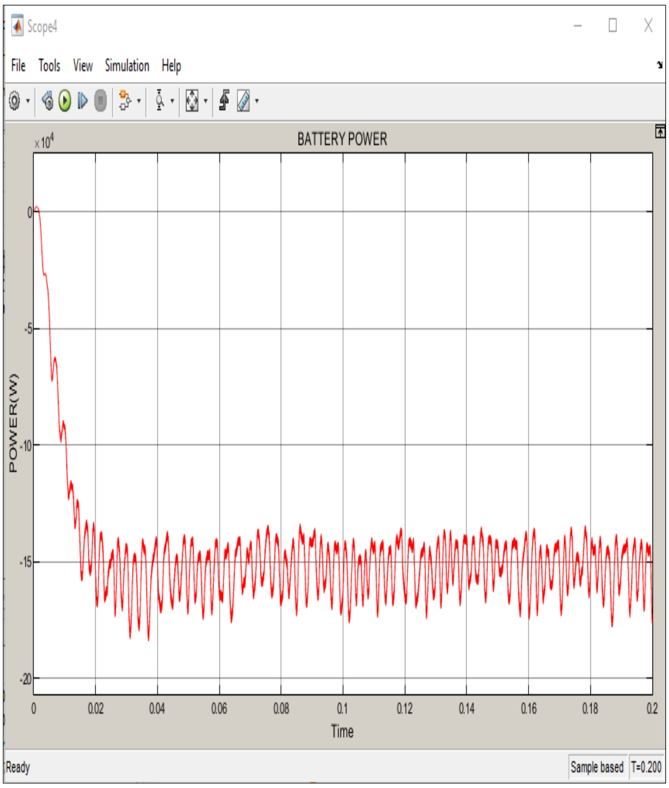

Fig. 21 showing the battery power generate by the system

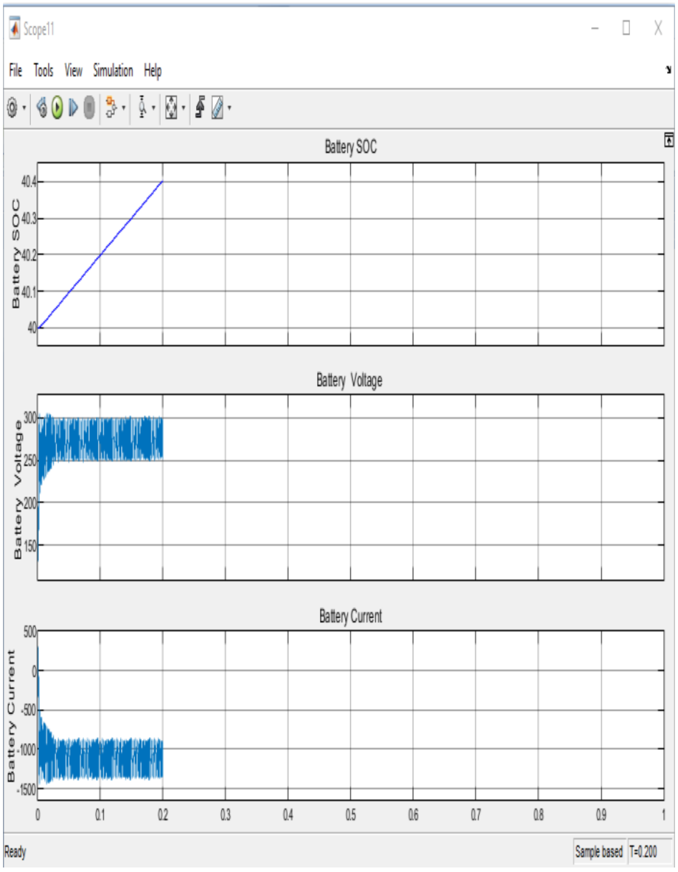

Fig. 22 Battery SOC, Battery voltage, and battery current for EV1 Station

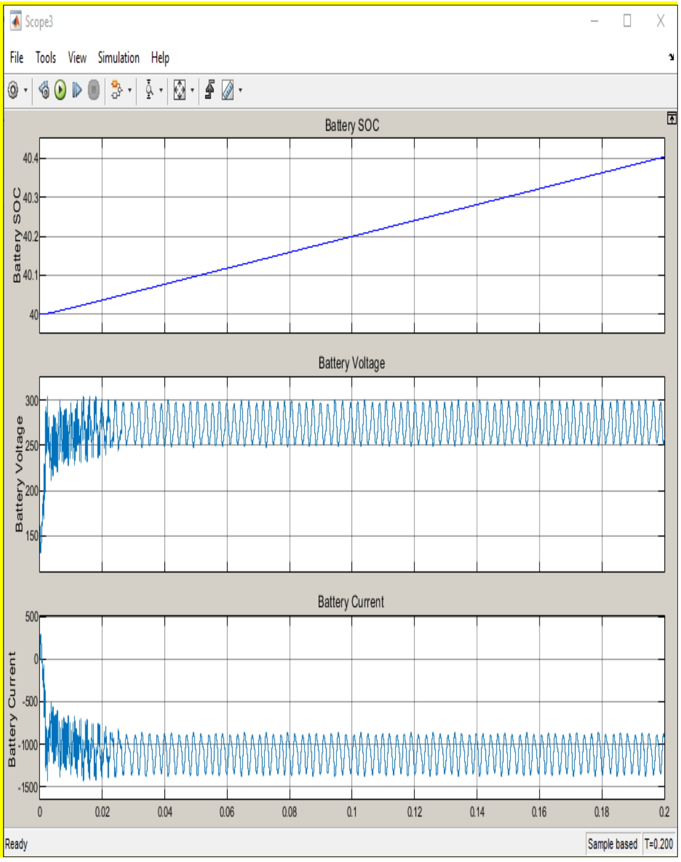

Fig. 23 Battery SOC, Battery voltage, and battery current for EV4 Station

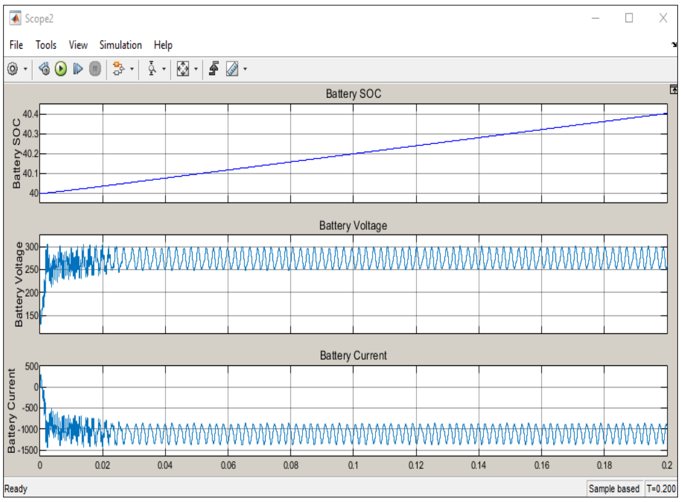

Fig.24 Battery SOC, Battery voltage, and battery current for EV3 Station

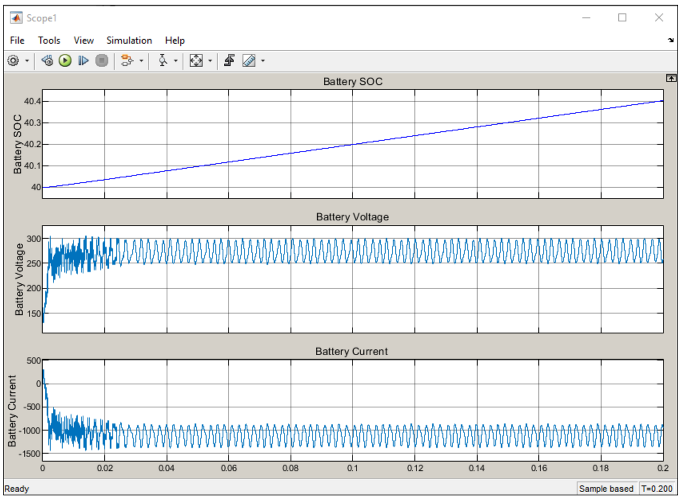

Fig.25 Battery SOC, Battery voltage, and battery current for EV2 Station

IV CONCLUSION

The development of the electric vehicle over the last few years has become an emerging move towards eco-friendly technology, and the usage of energy and storage sources has been improving over the years. the research has focused on the storage system and control system of the electric vehicle. for this research study, a specifically rated battery and renewable energy have been selected as sources, and converters like boost converters, Vienna converters and optimization algorithms have been simulated for four different EV stations designed with different soc conditions to regulate continuous charging supply to EVS. it also involves the design of a three-level inverter using MATLAB. Simulink concerning EV batteries being distributed in smart environments, there are technical issues that need to be addressed. energy management strategies and control of the integration of EVs into the grid are the keys to using EVs as shared storage, which need to be carefully examined.

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