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Integration of DFIG based Wind System and Solar PV Feeding Electric Vehicle Charging Station with Hybrid Energy Storage System

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Abstract-— This paper proposes a highly efficient Electric Vehicle Charging Station (EVCS) to generate the power for charging the Electric Vehicle (EV). The EVCS uses renewable energy sources such as solar Photo Voltaic (PV) and Doubly Fed Induction Generator (DFIG) based Wind Turbine (WT) system. The objective of this paper is to provide sustainable power for the electric vehicle and to maintain the dc link voltage constant for DC busbar at various irradiation conditions. The proposed system consists of solar PV array, DFIG based WT system, AC grid and Hybrid Energy Storage System (HESS) connected to a common DC busbar. The HESS consists of a Lithium-ion battery and a Supercapacitor (SC) which are connected to the bidirectional DC-DC converters. There are other Unidirectional DC-DC converters (Boost, Buck) connected to the solar PV array, Diode Bridge Rectifier (DBR) and to the EV Battery. Initially the power generated from the solar PV and DFIG based WT system is used to feed the electric vehicle and also charges the HESS, when the PV and DFIG based WT system could not supply enough power to charge the EV, then the power from the HESS is utilized. To support the load demand and to maintain the dc link voltage at 500 Volts during low irradiation conditions, the ac grid is connected in parallel to the WT-DFIG followed by the Diode Bridge Rectifier (DBR). The system performance is compared with and without using DFIG based WT system using MATLAB-Simulink software. The obtained results show that the proposed renewable charging mechanism is suitable for EV charging thus creating pollution free environment.

Keywords ---Bi-directional DC-DC converters, Charging station, Doubly Fed Induction Generator, Electric Vehicle, Hybrid Energy Storage System, Solar Photovoltaic, Wind Turbine.

I. INTRODUCTION

The use of fossil fuels such as petrol, diesel for conventional automobiles leads to causing air pollution which is one of the dangerous consequences. The increasing usage of renewable resources in vehicle system is advisable to get pollution free environment [1]. EVs of today are evolving into a reliable and marketable product. By 2022 it can be assumed that EVs will be more than 35 million all over the world. If all the Internal Combustion (IC) engines were to be substituted by EVs at large, then the high penetration causes heavy electricity demand to the power grid and the electric grid will black out unable to withstand the load demand [2], [3], [4]. Since Indian government has been concentrating over environmental friendly ecosystem to reduce the carbon emission from the transport sector, the distribution of EVs and installation of EVCS has become easy due to the reduced taxes [5]. The increase in demand of energy and the exhaustion of fossil fuels has become a circumstance that there is a need to use the renewable energy sources. Thus, the inexhaustible solar and wind energy has become an interesting topic for the generation of sustainable power. The hybrid is a combination of two or more energy sources which produces efficient energy power. Among many hybrid systems, the solar and wind energies give better results but the drawback is that they are intermittent in nature which leads to unreliability. However, the reliability of the system is enhanced when solar and wind energies are combined [6]. The intermittent behavior of the solar irradiation makes the solar PV generation as an unreliable power source. Due to the unavailability of PV power during the night and cloudy days, it is the major challenge to use PV system as a main power supply [7], [8]. Thereby the integration of the DFIG Wind system is necessary to lessen the uncertainty of the sustainable generation. There are many fixed-speed wind generators accessible in the world for the WECS, but presently for wind energy

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applications, the doubly fed induction generator (DFIG) is suitable generator [9]. Robustness, design simplicity, cost and the possibility to control active and reactive power are the main reasons for using DFIG for a variable speed wind turbine [10].

By using the storage devices such as battery and SC banks, ensures that power supply is available to the load even when the renewable sources unavailable. The battery banks provide long term power back up and SCs are beneficial in supplying momentary high power surges. Hence batteries possess high energy density and SCs possess high power density [11], [12].

To address the intermittency problem of using the solar PV and HESS system, this paper presents an integrated power generation of PV-DFIG based WT and HESS for feeding electric vehicle charging station (EVCS). Each of the battery and the SC energy storage systems are connected to the DC bus through a bi-directional DC-DC converter. The solar PV array is connected to the DC bus through a Unidirectional Boost converter and DFIG based wind turbine is connected to the same DC busbar through a Diode Bridge Rectifier (DBR) followed by a unidirectional Buck converter. Also, the ac grid is connected in parallel to the DFIG wind turbine which acts as backup source. Solar PV acts as the primary source to charge the EV. When there is low PV power at night, the DFIG-WT generates the power to feed the EV and battery-Supercapacitor HESS (BSHESS). Whenever there is a deficiency in the solar output power or DFIG-WT to charge the EV, then required amount of power is taken from the BSHESS and if all these sources have deficit power supply, then the power from the ac grid is taken to charge the EV to ensure the continuous operation of charging station throughout the day.

In the proposed work, there are six sections. The section I consists of introduction and section II consist of system description and modeling. The section III describes about circuit topology. The section IV describes the control strategy about proposed system and section V consists of simulation results which is explained in detail. The section VI contains the conclusion.

II. SYSTEM DESCRIPTION AND MODELING

The main objective of this paper is to design and model the solar PV-DFIG based wind turbine system fed electric vehicle charging station with HESS. The paper also aims to stabilize the dc link volage during low irradiation conditions. Due to the absence of central energy management system, the DFIG based WT and ac grid has been introduced to maintain the dc bus voltage constant (at 500v) during various irradiation conditions.

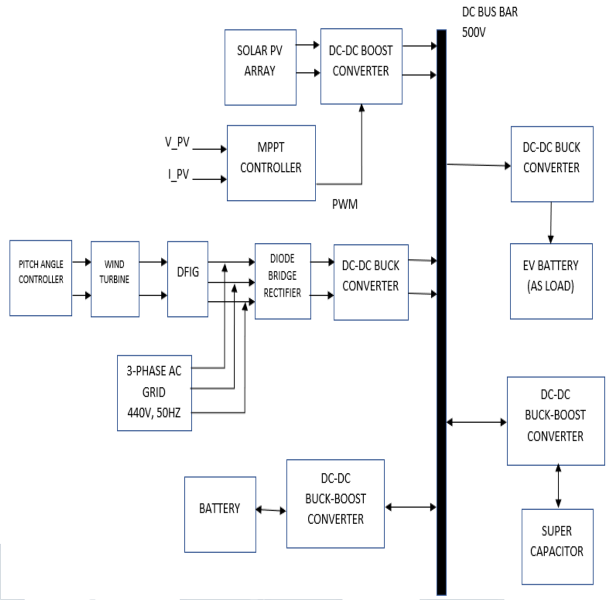

Fig. 1. Block diagram of proposed system

In Fig. 1 Block diagram of the proposed system is represented. This system consists of a solar photovoltaic (PV source), DFIG based WT system, the HESS, EV battery (acts as a load) and ac grid, all are connected to a common DC bus-bar. A uni-directional boost converter is connected to the PV source in order to connect to the DC bus-bar. This converter is having 2 roles in the system: 1) it steps up the PV voltage to the DC bus voltage and 2) it allows to achieve the maximum produced power by applying a MPPT (Maximum Power Point Tracking) algorithm [8]. The HESS comprised of lithium-ion battery and supercapacitor which are connected to dc busbar via dc-dc bidirectional converters. The Supercapacitor (SC) has rapid dynamics which will be used to smoothen quick fluctuations of the PV power and the load in short-term (from seconds to minutes). The dynamics of the battery is slower than the SC, therefore the batteries are used to smooth out the difference between the PV power produced and load demand in the long-term (from minutes to hours). [8]

Initially the PV source supplies the power to the electric vehicle and charges the battery as well as the supercapacitor. When it cannot produce enough power to feed the load (EV battery) then the DFIG based wind turbine generates the power so that it can feed the load as well as the other energy devices efficiently. However, if the solar-wind energy systems cannot supply enough power then the battery and SC comes into the picture.

Meanwhile, the ac grid supports the load demand and stabilizes the dc link voltage (V_{dc}) during low irradiation conditions when all of the above sources have deficit power supply.

Solar PV System

Photovoltaic (PV) cell is a semiconductor device which converts the light energy into electrical energy. The number of PV cells are connected in series and parallel to get more amount of voltage and current known as PV module and if these modules are connected for any application to get desired amount of current and voltage then it is called as PV array [13]. The most widely used modules are based on polycrystalline or monocrystalline technology. The behavior of a PV system under varying irradiance (G) and temperature (T) can be understood by examining its current–voltage (I–V) and power–voltage (P–V) characteristics [14].

The solar PV array output is connected to the input of the boost converter which steps up the voltage at 500 volts for dc bus by using Perturb & Observe MPPT technique [15] and Simulink model of P&O MPPT technique is shown in Fig. 2.

In Simulink model the PV array of 98KW at 65.1V as open circuit voltage is considered for the charging station.

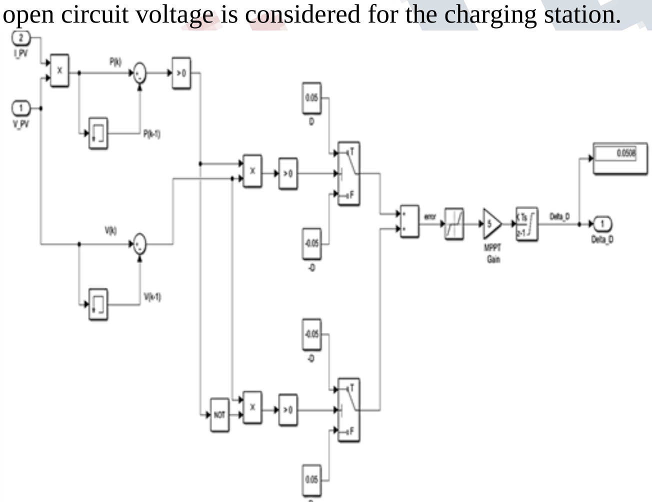

Fig. 2. Simulink model of P&O MPPT technique

Doubly Fed Induction Generator based Wind Turbine

The DFIG is coupled with a wind turbine and a slipring induction generator block is taken in Simulink as shown in Fig. 3. The wind turbine converts the kinetic energy of wind into mechanical energy transmitted by the shaft. The pitch angle controller is used to limit the rated power at high wind and accelerates the turbine faster during low winds. To maintain the rated value at $\omega^{ref} = 1.1$pu, the pitch control comes into picture when the generator speed increases beyond the rated speed [6]. The explanation of DFIG based wind turbine is done in [6], [10], [16]. The ac grid is connected in parallel to the stator of the DFIG so that it can supply power to the DFIG to operate and to stabilize the dc link voltage during variable irradiation conditions.

In Simulink model the rating of DFIG wind turbine is taken as 150KW, 440V, 50Hz with the wind speed of 12m/s and nominal voltage as 1975Vrms.

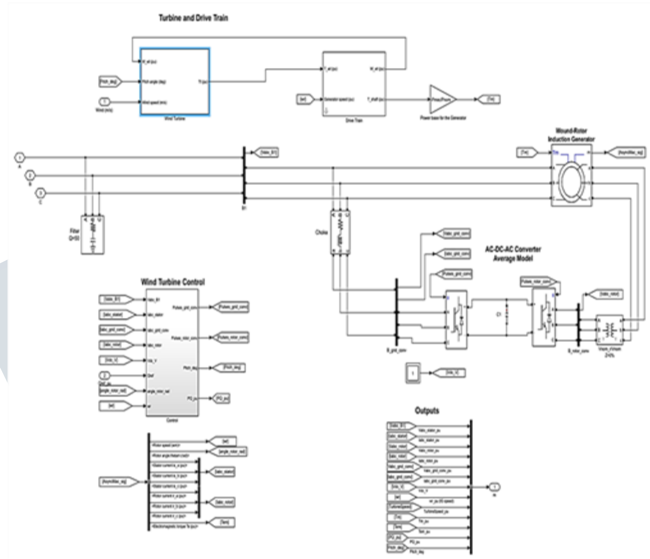

Fig. 3. Simulink model of DFIG based wind turbine

Battery-Supercapacitor Hybrid Energy Storage System

In this paper full active HESS topology is used which actively controls the power flow of battery and SC via bidirectional DC-DC converters. Hence, this enhances the flexibility of HESS and improves the overall performance of the system and life cycle. Generally, two types of full active HESS topologies (parallel active HESS topology, cascaded active HESS topology) are common to use. Among them we are using parallel active HESS topology. In this, both battery and SC are isolated from the DC bus-bar by bidirectional DC/DC converters [17]-[18] as shown in Fig. 4. The control of this HESS system is explained in detail in the paper [12].

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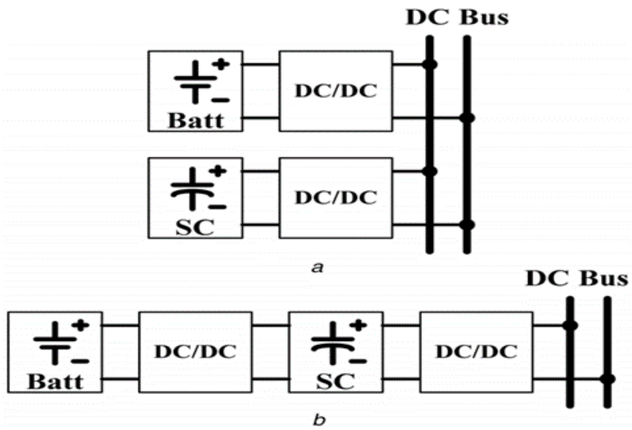


Fig. 4. Active HESS topologies (a) Parallel active HESS topology, (b) Cascaded active HESS topology

The BSHESS is used to store the surplus power from the solar PV for charging the EV battery. The charging and discharging operation of BSHESS is controlled by the bi-directional DC-DC converter. For supplying maximum energy to the EV battery 200V 100Ah lithium-ion battery with SOC of 90% and 10 Farads 250V Supercapacitor is used for the charging station in Simulink.

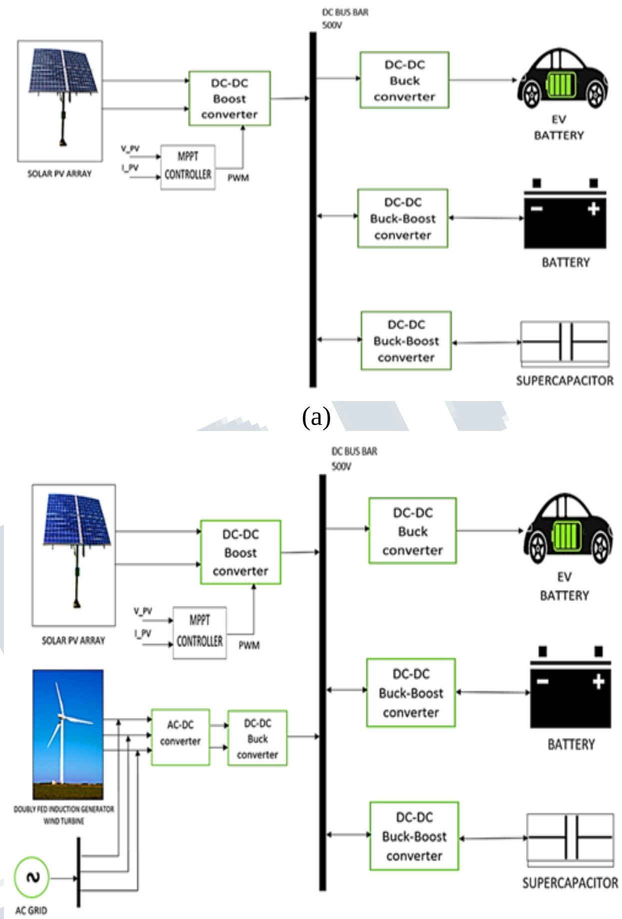
Electric Vehicle Battery as load

For the simulation, it is assumed that the EV battery with a rating of 100Ah, 32KWh power rating, 320V with SOC of 20% is considered. Tata Nexon is considered as EV. The buck converter is used at EV battery to step down the 500V DC bus voltage into 320V DC.

Grid with Rectifier

The 440V 50Hz ac grid is considered for the charging station to get the additional power requirement. In MATLAB/Simulink, a 440V AC source is considered as grid and the Diode Bridge Rectifier (DBR) is used to convert 440V AC into 622V DC. Further the buck converter is used to step down the voltage from 622V DC to 500V DC.

III. CIRCUIT TOPOLOGY



(a)

(b)

Fig. 5. (a) Conventional System (b) Proposed System

From Fig. 5 it is assumed that in conventional system for various irradiation conditions the dc link voltage leads to instability and also it cannot produce enough power to feed the electric vehicle. However, by introducing DFIG wind turbine into the system, the stability of dc bus-bar voltage is maintained and the load gets enough power to operate continuously without any discontinuity.
Simulink diagram of PV-HESS system is shown in Fig.6 and Simulink diagram of PV-Wind-HESS system is shown in Fig. 7.

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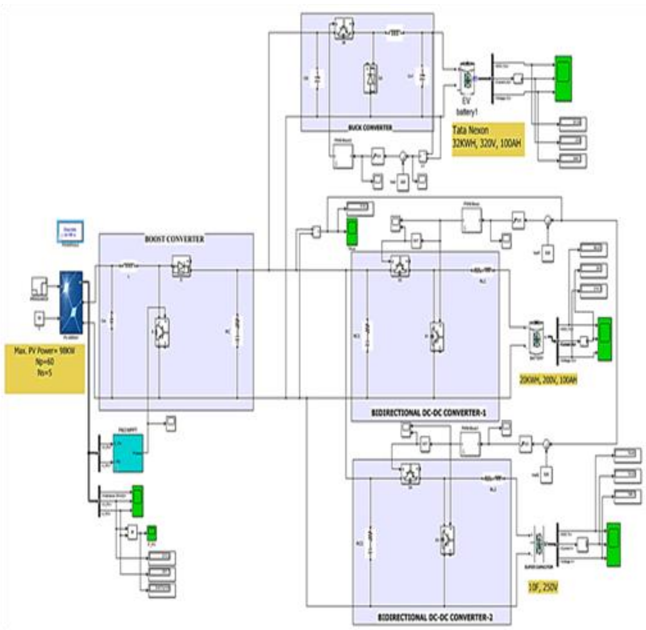

Fig. 6. Simulink diagram of PV-HESS System

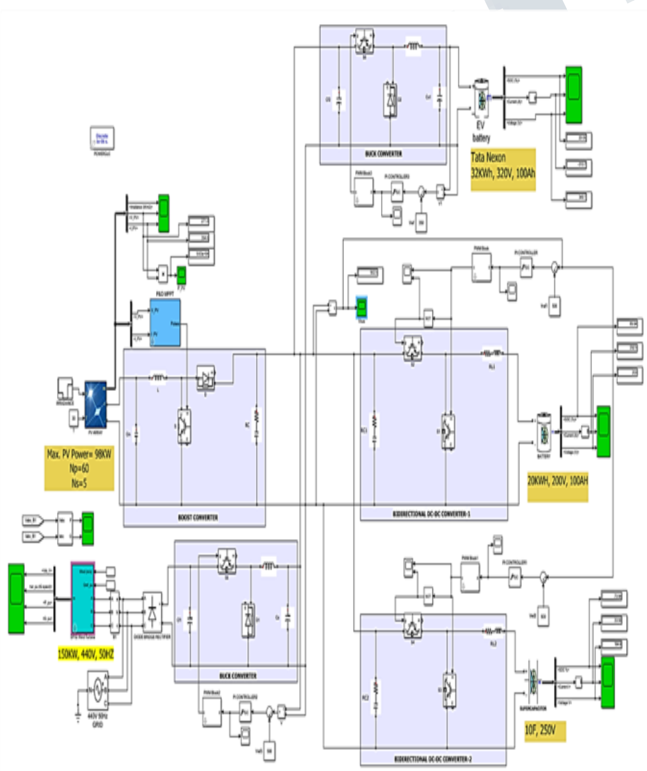

Fig. 7. Simulink diagram of proposed PV-WIND-HESS system

IV. CONTROL STRATEGY FOR PROPOSED SYSTEM

The control strategy of boost converter can be seen in Fig. 8. The duty ratio obtained by the P&O method for the converter is noted as $Delta\_D$ and is compared with duty ratio ($Dinit$) which is taken as 50%, the obtained error is given to the PWM generator through the saturation block. Then the obtained pulses are fed to the boost converter to get the maximum power from the solar PV by keeping DC bus voltage constant.

The control scheme of Buck converter at DBR side is shown in Fig. 9. By using the PI controller, the voltage at the DC bus-bar is made constant at 500V by comparing it with actual bus voltage ($Vbus\ act$) and reference bus voltage ($Vbus\ ref$). The S5 is the IGBT switch of the buck converter at the DBR side.

By using gate pulses from the PI controller circuits, the switches S1, S2 are triggered at the battery side and S3, S4 are triggered at the Supercapacitor side. Here constant voltage control method is used for BSHESS as shown in Fig. 10, Fig. 11 and the control operation is explained in detail in [12].

The control scheme of EV battery is shown in Fig. 12. Here, the constant voltage control method is used. The error signal obtained by comparing EV battery actual voltage with EV battery reference voltage is fed to the PI controller from which the gate pulses are obtained and the switch S6 is triggered for the operation of the buck converter.

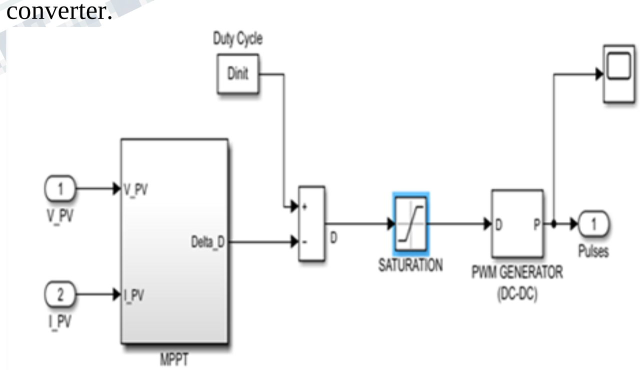

Fig. 8. Pulses to the gate terminal of the boost converter switch (S)

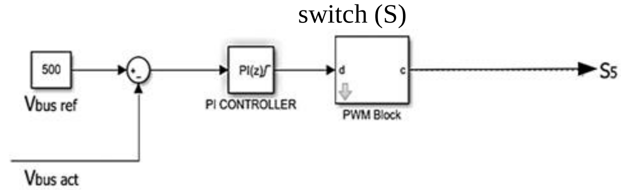

Fig. 9. Control scheme of Buck converter at DBR side

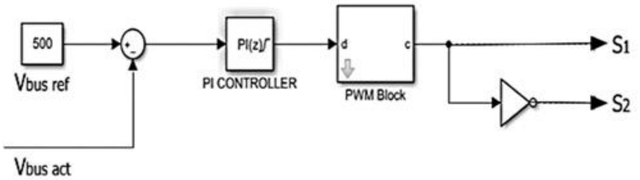

Fig. 10. Control scheme of battery

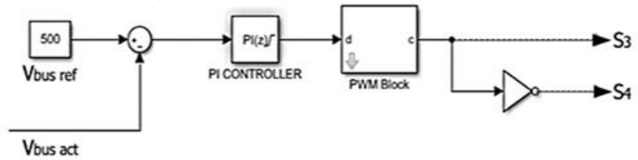

Fig. 11. Control scheme of Supercapacitor

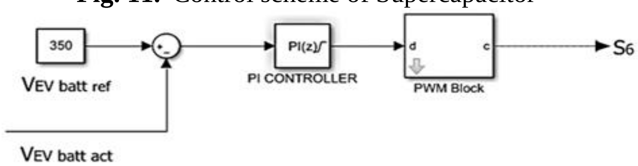

Fig. 12. Control scheme of EV battery

V. SIMULATION RESULTS

The proposed Electric Vehicle Charging Station can charge the EV continuously under various irradiation conditions of solar PV generated power because of the presence of DFIG wind system. Therefore, the dc bus voltage can be maintained constant at 500V. The battery and SC are connected to the Bidirectional DC-DC converter, which is decided by the modes of operation i.e. either charging or discharging based on solar PV power applied during that instant. The comparison of PV-HESS system and PV-Wind-HESS system is done for DC busbar voltages under charge/discharge modes of operation of BSHESS. From Figures 21 to 24 we can see that DC busbar voltage is maintained constant at 500V under various irradiation conditions during Charge/Discharge modes of operation of HESS for PV-Wind-HESS system when compared to PV-HESS system. Also, the EV gets continuous power supply in case of PV-Wind-HESS system compared to the PV-HESS system. In the simulation model the sample time is taken as 1µs.

From the Figures 29 to 32 it is seen that the power of EV battery is maintained constant at various irradiations irrespective of the battery and SC charge/discharge operations in PV-Wind-HESS system. Whereas, from Figures 25 to 28 it is seen that the EV battery power is varying at low irradiation conditions under different charge/discharge operations of battery and SC which is undesirable in PV-HESS system. Therefore, the charging station with solar-wind system is giving better results than the charging station with solar system alone.

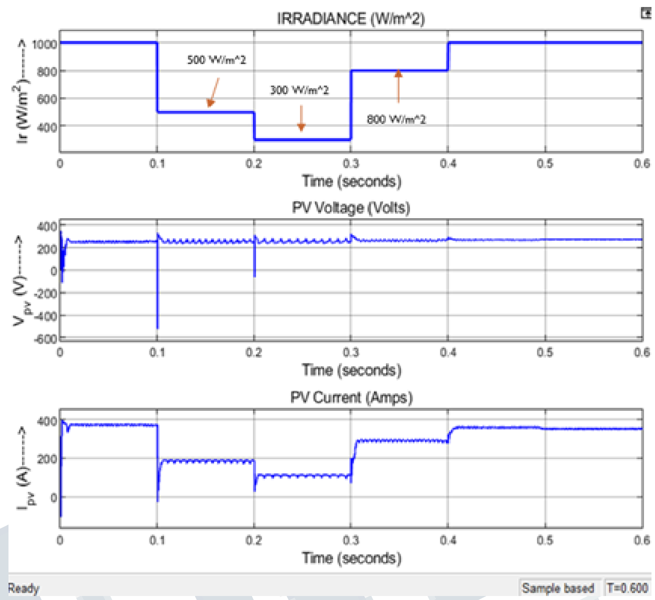

Fig. 13. PV voltage and current waveforms for various irradiations

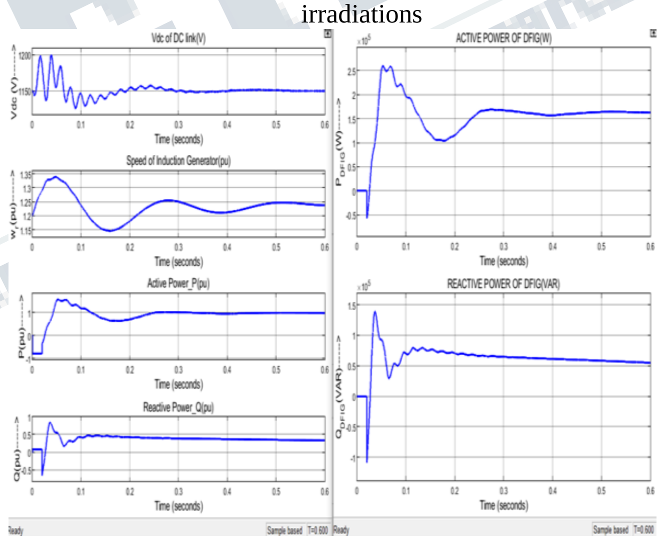

Fig. 14. Output waveforms of DFIG based WT system

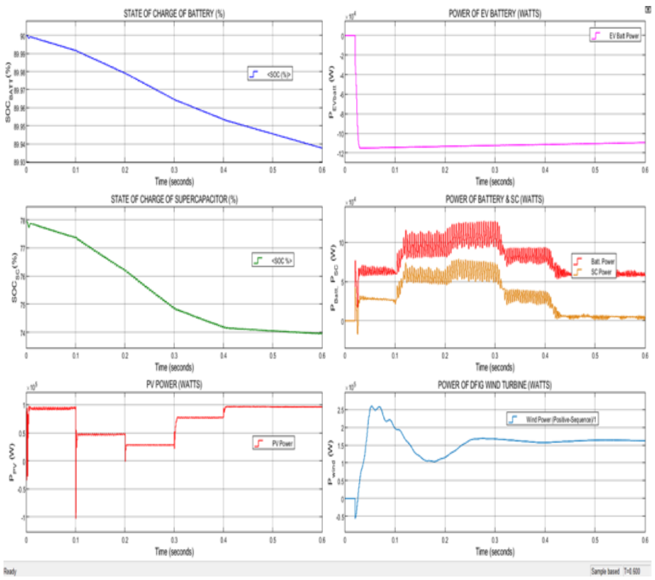

Fig. 15. SOC of HESS & Powers of PV, EV battery, HESS and DFIG-WT for PV-Wind-HESS system (when both battery and SC are discharging)

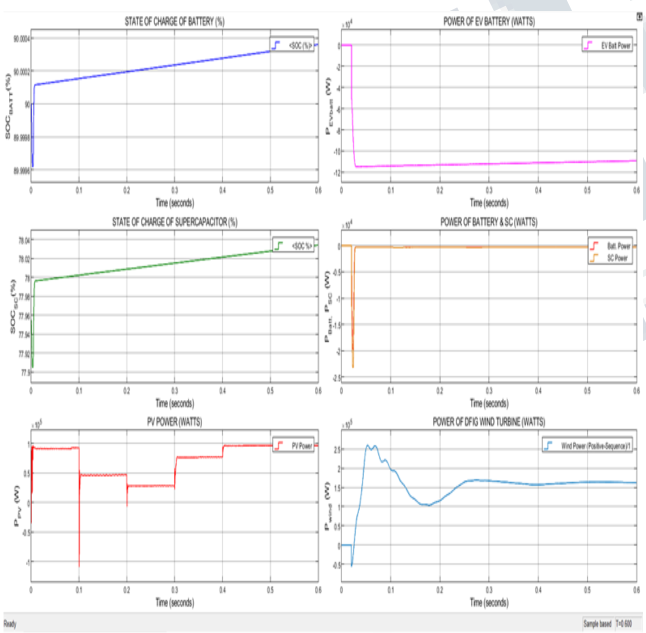

Fig. 16. SOC of HESS & Powers of PV, EV battery, HESS for PV-Wind-HESS system (when both battery and SC are charging)

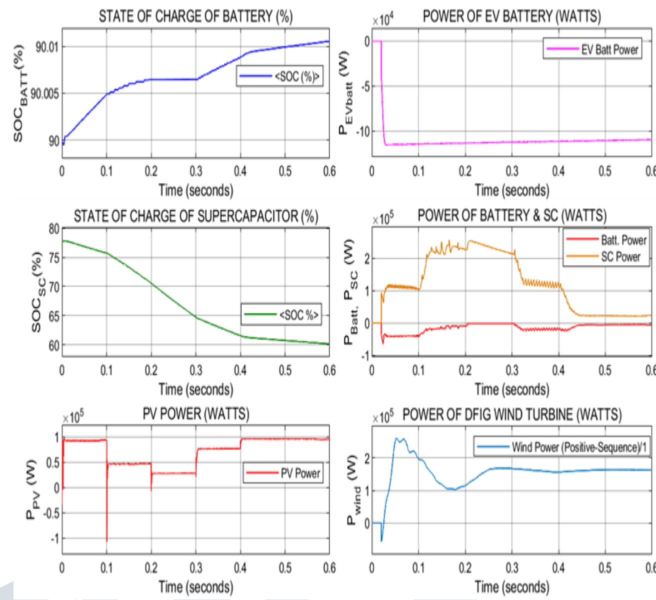

Fig. 17. SOC of HESS & Powers of PV, EV battery, HESS and DFIG-WT for PV-Wind-HESS system (when battery is charging and SC is discharging)

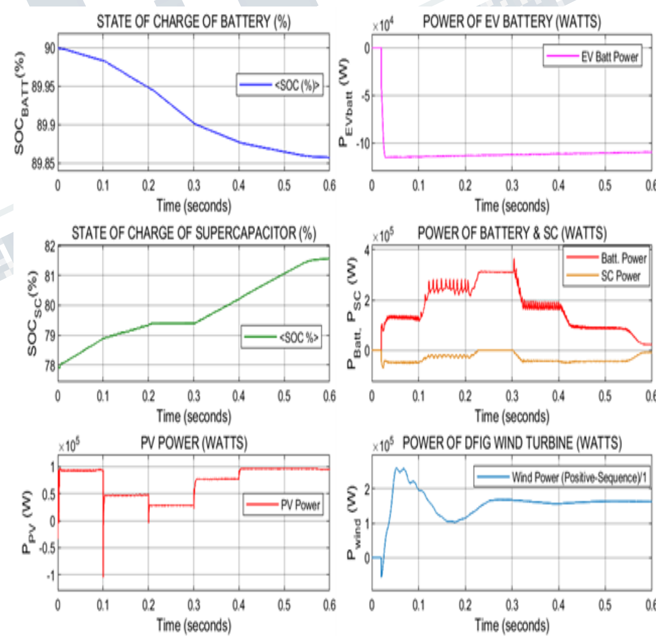

Fig. 18. SOC of HESS & Powers of PV, EV battery, HESS and DFIG-WT for PV-Wind-HESS system (when battery is discharging and SC is charging)

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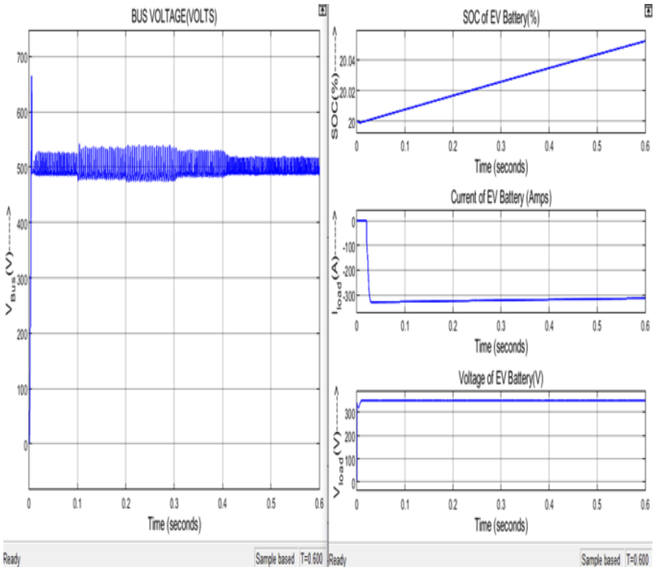


Fig. 19. Characteristics of dc busbar voltage and EV battery for PV-wind-HESS system during discharging mode of operation of HESS under various irradiation conditions

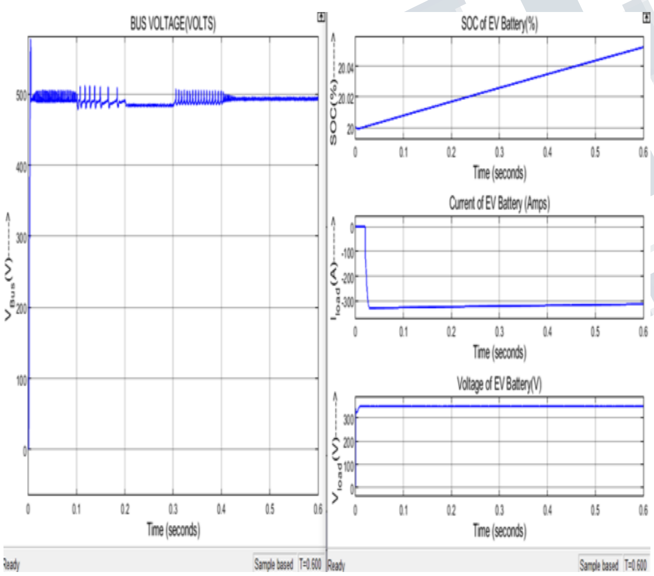
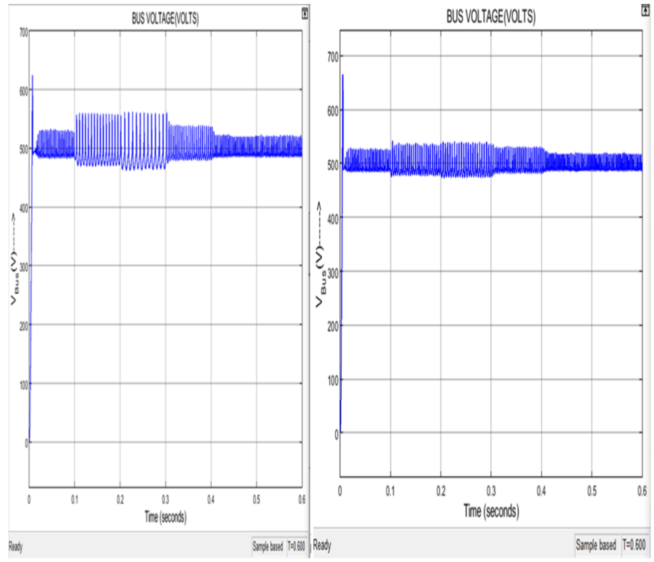
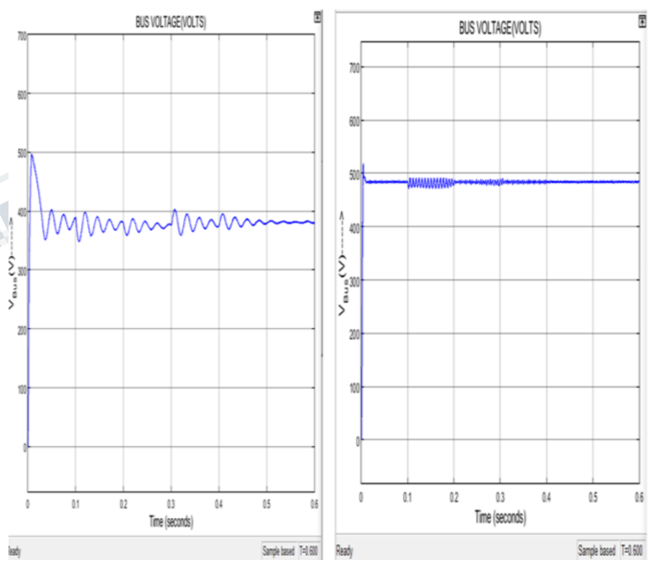


Fig. 20. Characteristics of dc busbar voltage and EV battery for PV-wind-HESS system during charging mode of operation of HESS under various irradiation conditions



(a) (b)

Fig. 21. DC Busbar voltage of (a) PV-HESS system (b) PV-Wind-HESS system during discharging mode of battery and SC under various irradiation conditions



(a) (b)

Fig. 22. DC Busbar voltage of (a) PV-HESS system (b) PV-Wind-HESS system during charging mode of battery and SC under various irradiation conditions

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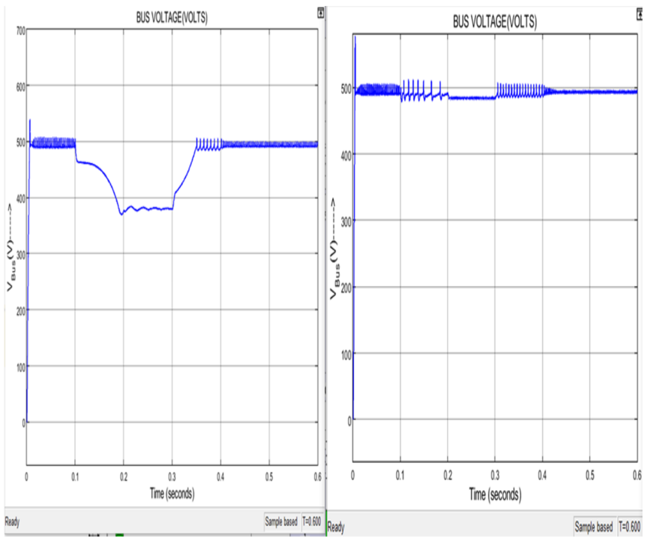


(a) (b)

Fig. 23. DC Busbar voltage of (a) PV-HESS system (b) PV-Wind-HESS system during charging mode of battery and discharging mode of SC under various irradiation conditions

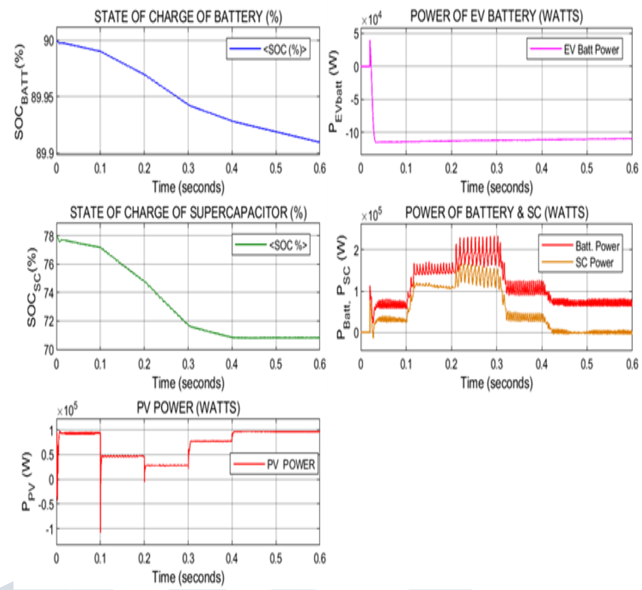
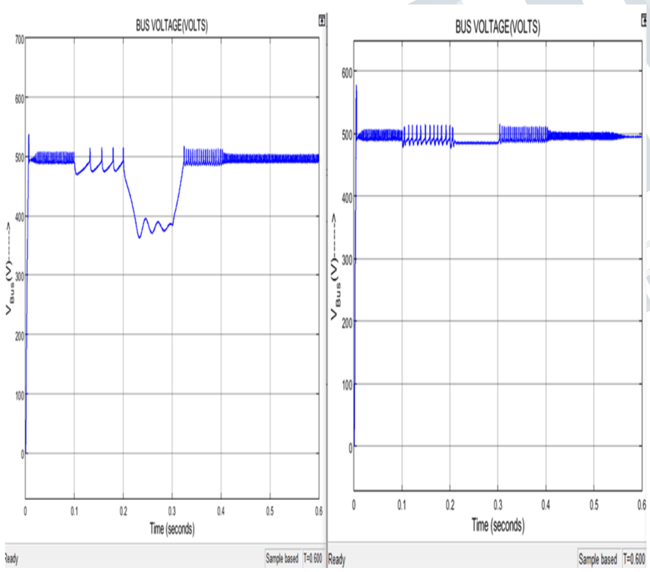


Fig. 25. SOC of HESS & Powers of PV, EV battery, HESS for PV-HESS system (when both battery and SC are discharging)



(a) (b)

Fig. 24. DC Busbar voltage of (a) PV-HESS system (b) PV-Wind-HESS system during discharging mode of battery and charging mode of SC under various irradiation conditions

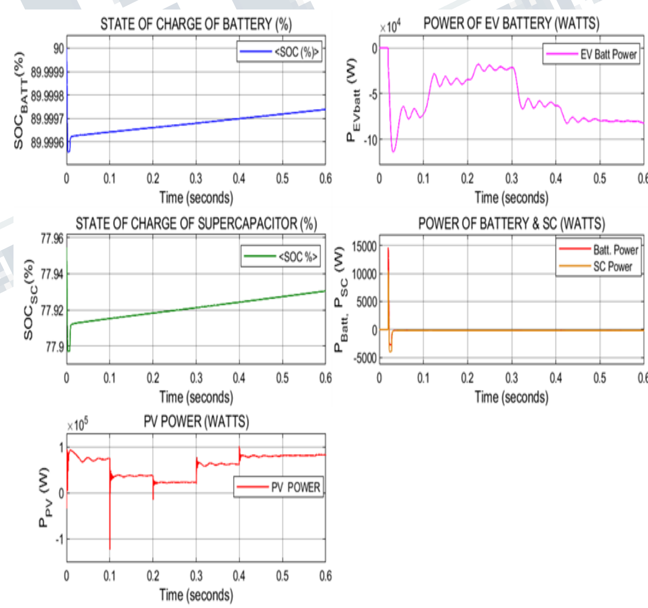


Fig. 26. SOC of HESS & Powers of PV, EV battery, HESS for PV-HESS system (when both battery and SC are charging)

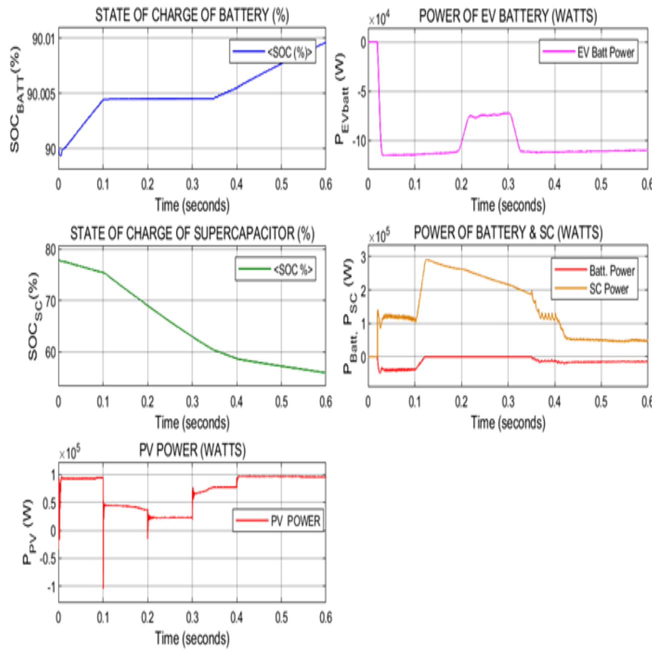


Fig. 27. SOC of HESS & Powers of PV, EV battery, HESS for PV-HESS system (when battery is charging and SC is discharging)

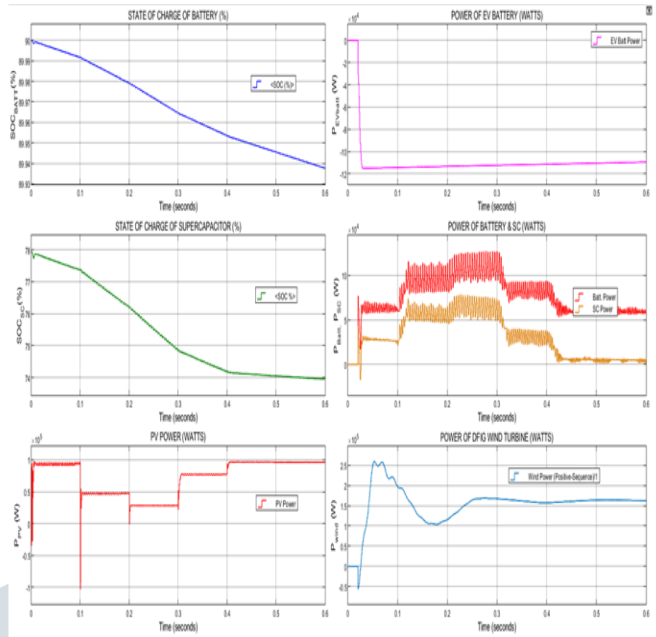


Fig. 29. SOC of HESS & Powers of PV, EV battery, HESS and DFIG-WT for PV-Wind-HESS system (when both battery and SC are discharging)

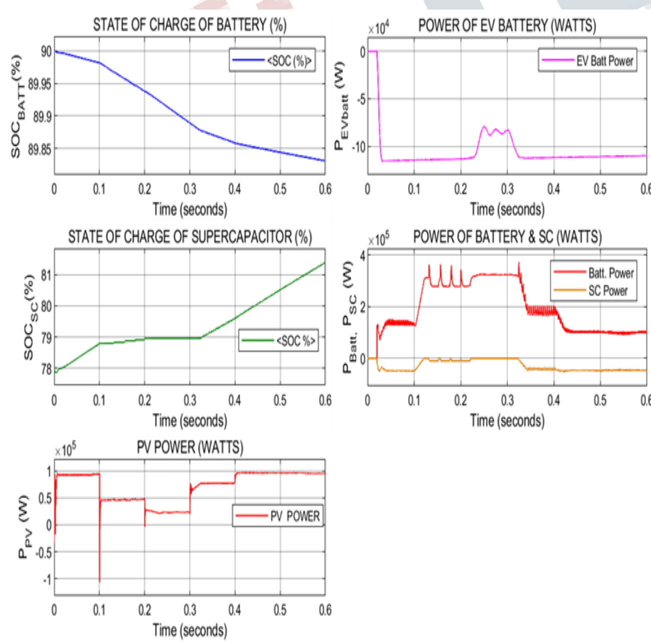


Fig. 28. SOC of HESS & Powers of PV, EV battery, HESS for PV-HESS system (when battery is discharging and SC is charging)

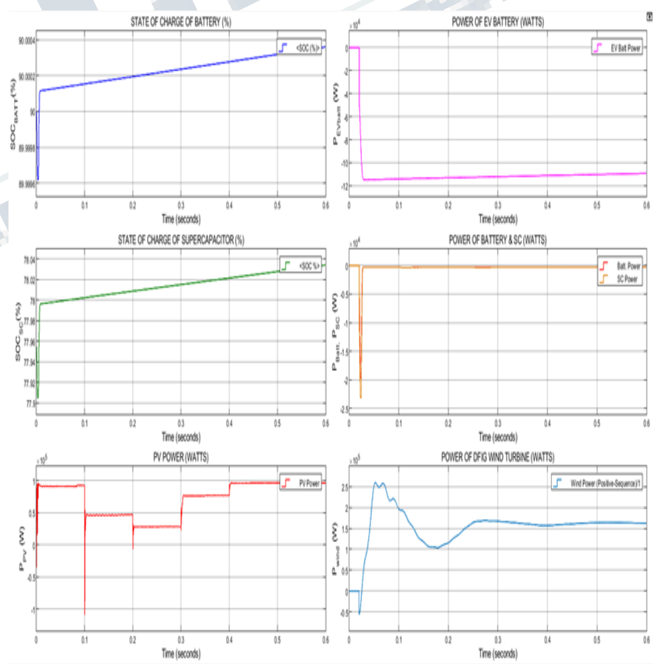


Fig. 30. SOC of HESS & Powers of PV, EV battery, HESS for PV-Wind-HESS system (when both battery and SC are charging)

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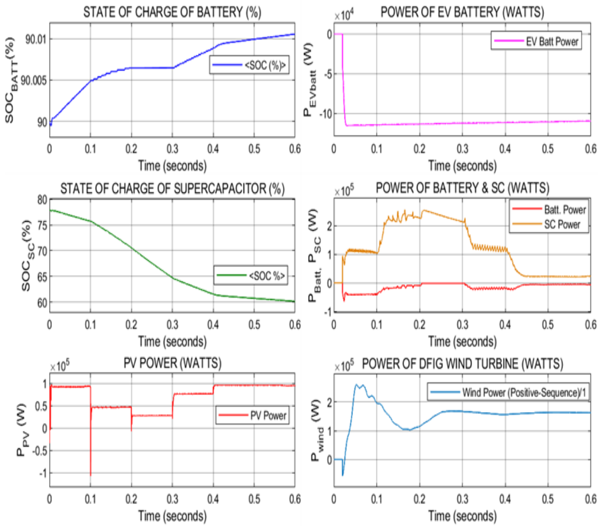

Fig. 31. SOC of HESS & Powers of PV, EV battery, HESS and DFIG-WT for PV-Wind-HESS system (when battery is charging and SC is discharging)

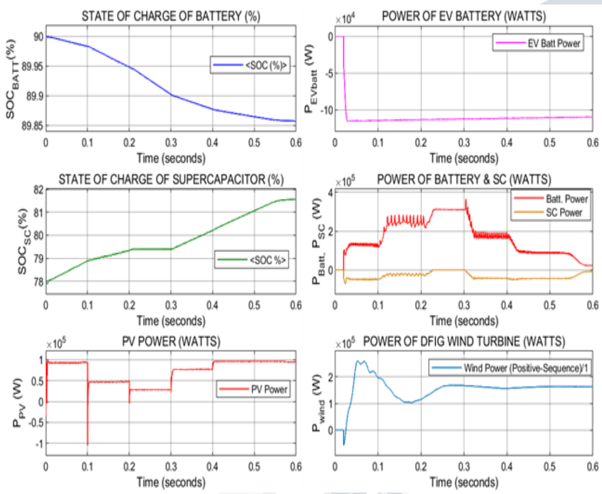

Fig. 32. SOC of HESS & Powers of PV, EV battery, HESS and DFIG-WT for PV-Wind-HESS system (when battery is discharging and SC is charging)

Table I: Solar panel parameters

Power	98KW
Maximum voltage (Vmax)	54.7V
Maximum current (Imax)	5.98A
Open circuit voltage (Voc)	65.1V
Short circuit current (Isc)	6.46A
Parallel strings (Np)	60
Series strings (Ns)	5
Temperature	30 degrees

Table II: Power circuit parameters

Boost Converter at solar PV:

Input capacitance (Cin)	47µF
Input inductor (L)	1µH
Output capacitance with resistor (RC)	5mΩ, 1000mF

Bidirectional converter for Battery and Supercapacitor:

RL1 and RL2	80mΩ, 161.95µH
RC1 and RC2	5mΩ, 220µF
Kp, Ki	0.1, 0.00023
Switching frequency (Fs)	10KHz

Buck converter for Wind system:

Capacitance (Cf1)	1000µF
Inductance (L)	1mH
Capacitance (C0)	12000µF
Kp, Ki	0.05, 0.00023

Buck converter at EV Battery:

Capacitance (Cf2)	1000µF
Inductance (L)	1mH
Capacitance (C01)	1000µF
Kp, Ki	0.8, 0.00023

VI. CONCLUSION

With the substantial increase of EVs on the road every year, the charging of EVs becoming major concern. A charging station with solar PV, DFIG wind system, Hybrid energy storage system and with additional ac grid is more promising solution for satisfying charging needs of EVs. By using the voltage control and PI controller, desired power is achieved by maintaining the DC busbar voltage constant for the charging station. Whenever solar PV power is surplus than the EV charging demand, the available power is used to charge the HESS. Likewise, during solar power inadequacy the DFIG wind system supports load. If both renewable sources cannot support, then HESS provides supply to the EV demand through discharging. If all above sources cannot provide the power then ac grid supplies to the EV demand.

By means of simulation, the effectiveness of this EV charging station is analyzed by changing solar irradiations and also compared with the PV-HESS system. It is found that the proposed PV-Wind-HESS system is much more reliable than the PV-HESS system.

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