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ANALYSIS AND DESIGN OF A GRID-INTEGRATED HYBRID RENEWABLE ENERGY ELECTRIC VEHICLE CHARGING SYSTEM

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ABSTRACT
The need for reliable and sustainable renewable energy sources (RES) is increasing. Wind and solar energy are the most promising renewable energy sources due to their quantity and accessibility. Renewable energy solutions for both on-grid and off-grid applications are widely explored. A RES application refers to a system for charging electric vehicle batteries. Escalating energy expenses and the exhaustion of fossil fuels are propelling the demand for electric vehicles. The battery and power electronic converters used in battery chargers influence cost, weight, and reliability. These systems convert power from renewable sources or the grid and provide it to the EV battery. Research is being conducted on the use of power electronic converters in renewable energy storage systems for electric vehicles. It intends to construct an electric vehicle battery charger equipped with a supplementary photovoltaic array battery bank. These converters provide uninterrupted charging of electric vehicle batteries in constant voltage mode, regardless of the intermittency of the photovoltaic array. Simulations and experiments are used to assess the efficacy of the proposed system. During peak sunlight hours, a bidirectional DC-AC converter transmits excess photovoltaic electricity to the single-phase utility grid while simultaneously charging the electric vehicle battery. The electric grid enabled EV battery recharge during periods of low sunlight. The proposed charging system's distinctive bidirectional DC-AC converter design facilitates self-grid synchronization, therefore lowering control complexity. We provide an independent wind energy converter supplying an electric vehicle battery charger. An alternating current generator charges an electric vehicle (EV) with a constant voltage that is unaffected by wind speed. Simulation and testing are used to validate the efficacy of the proposed system. This is a grid-integrated hybrid renewable energy electric vehicle battery charging system. An automated controller is proposed for this charging system to guarantee efficient power transfer between renewable energy sources and loads. Notwithstanding the intermittent characteristics of RES, the proposed method enables continuous EV charging. Excess renewable energy source power is also sent back into the system.

Keywords: Electric Vehicle battery charger, Renewable energy sources, Bidirectional interleaved dc-dc converter, Bridgeless cuk converter, Bidirectional line commutated converter, Backup battery bank.

I. Introduction
Currently, cars are seen essential for personal mobility and the transportation of products, as shown by the persistent need for petroleum. The demand, along with escalating fuel prices and growing worldwide apprehensions over environmental issues stemming from air pollution and climate change, has generated worries. Consequently, certain governments have urged automobile manufacturers to provide eco-friendly and low-emission transportation options [1]. In this context, Electric Vehicles (EVs) have been designed and used to decrease reliance on fossil fuels, leading to a reduction in greenhouse gas emissions and other pollutants. Moreover, car emission rules have been established to prevent environmental degradation resulting from traditional automobiles. The suggested system incorporates a photovoltaic array, wind energy conversion system, backup battery bank, and grid as available power sources, ensuring continuous charging of the electric vehicle battery despite the intermittent nature of renewable energy sources. A comprehensive analysis of the proposed system is provided in the following sections.

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II. Methodology

2.1 Description of the Proposed Charger

The proposed grid-tied hybrid RES based EV battery charger consists of PV array, WECS, Sepic converter, Bidirectional dc-dc converter, Bridgeless cuk converter, Bidirectional line commutated converter, relays, single phase utility grid, EV battery and backup battery bank as shown in Fig. 1 An automatic controller generates gate pulses to the switches of converters and also generates the control signals for the relays presented in the proposed charger. The working of the proposed charger is explained in 9 modes in the following section.

2.2 Modes of Operation of the Proposed Charger

The different modes of operation of the proposed charger depend on the power generated from the available sources as depicted in Table 1 and are explained in detail as follows:

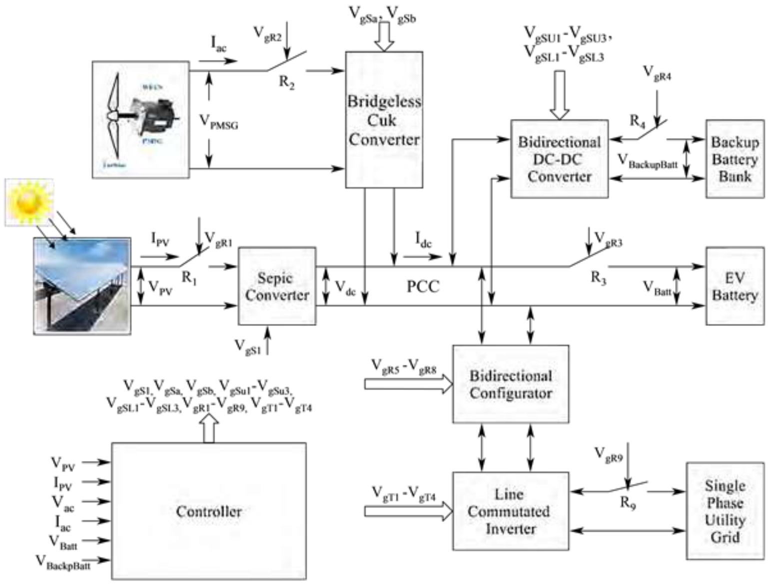

Figure 1: Progression of sensors

Table 1: Operating modes of the proposed charger

Predominant Sources	PV Array Power	WECS Power	Modes
PV Array	$P_L < P_{PV} \le P_U$	$P_W < P_L$	Mode 1: $PV - EV$
	$P_{PV} > P_U$	$P_W < P_L$	Mode 2: $PV - VB$
WECS	$P_{PV} < P_L$	$P_L < P_W \le P_U$	Mode 3: $WT - EV$
	$P_{PV} < P_L$	$P_W > P_U$	Mode 4: $WT - VB$
PV Array & WECS	$P_L < P_{PV} \le P_U$	$P_L < P_W \le P_U$	Mode 5: $PW - VB$
	$P_{PV} > P_U$	$P_L < P_W \le P_U$	Mode 6: $P_XW - VBG$
	$P_L < P_{PV} \le P_U$	$P_W > P_U$	Mode 7: $PW_X - VBG$
Grid	$P_{PV} < P_L$	$P_W < P_L$	Mode 8: $G - VB$
Backup Battery	$P_{PV} < P_L$	$P_W < P_L$	Mode 9: $B - V$

2.3 Design of Proposed Controller

Controller of the proposed grid-tied hybrid RES based EV battery charger generates gate pulses to the sepic converter, bidirectional interleaved dc-dc converter, bridgeless cuk converer and generates firing pulses to the SCR switches in the bidirectional line commutated converter as discussed in the previous chapters. Also, it controls the relays, R1 - R9 depending on the reference power lower and upper limits PL and PU respectively. Operating conditions of relays in the proposed charger are provided in Table 2 for different modes of operation and the relay controller diagram is shown in Fig 2.

Table 2: Operation of relays in the proposed charger Relay conditions: 1 - closed, 0 – open

Modes	Relays					Bidirectional Configurator Relays	
	R_1	R_2	R_3	R_4	R_9	R_5 & R_7	R_6 & R_8
Mode 1: $PV - EV$	1	0	1	0	0	0	0
Mode 2: $PV - VB$	1	0	1	1	0	0	0
Mode 3: $WT - EV$	0	1	1	0	0	0	0
Mode 4: $WT - VB$	0	1	1	1	0	0	0
Mode 5: $PW - VB$	1	1	1	1	0	0	0
Mode 6: $P_XW - VBG$	1	1	1	1	1	1	0
Mode 7: $PW_X - VBG$	1	1	1	1	1	1	0
Mode 8: $G - VB$	0	0	1	1	1	0	1
Mode 9: $B - V$	0	0	1	1	0	0	0

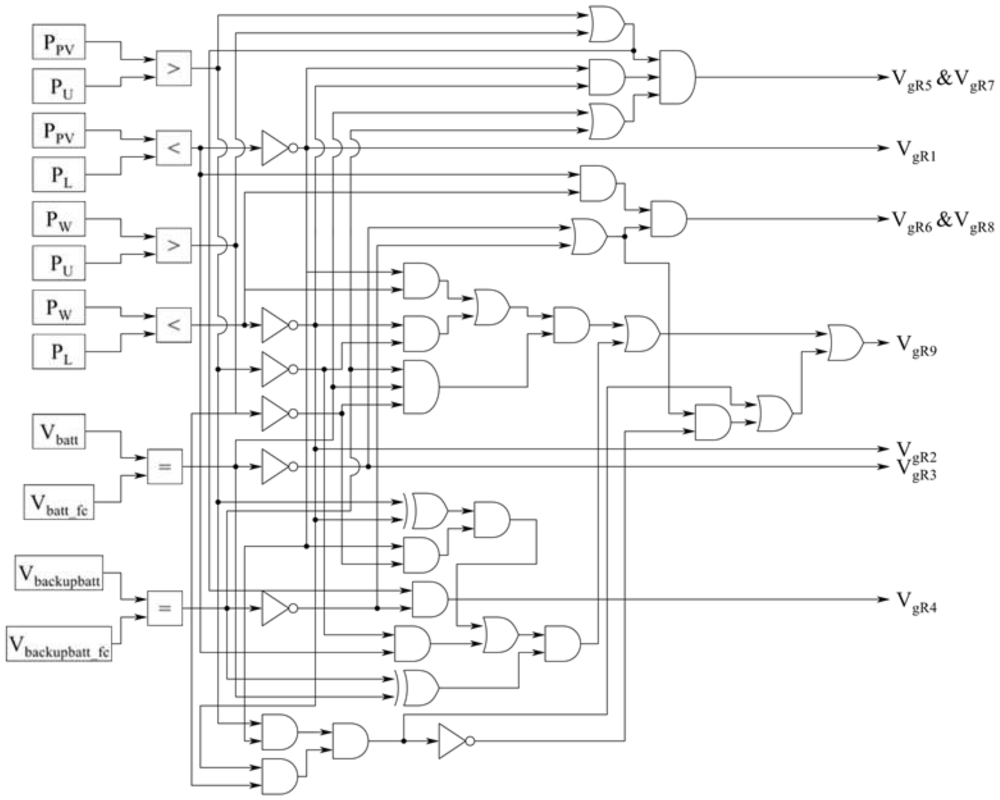

Figure 2: Controller diagram for operating relays in the proposed charger

III. Simulation Results of the Proposed Grid-tied Hybrid RES based EV Battery Charger

Simulation studies of the proposed charger are carried out in MATLAB/Simulink software. The converters employed in the proposed charger is modeled using Power MOSFETs, Thyristors, step up transformer, inductors and capacitors and the proposed controller is developed using PWM generator, pulse generator, logic gates, comparator, multiplier and PI controller available in the SimPowerSystem blockset in Simulink library. PV array model and Wind turbine along with PMSG, battery model available in the library are integrated with the modeled converters to develop the proposed charger and the parameters of each component are presented in Table 3.

Dynamic response of the proposed charger was investigated using the developed simulation model in mode 5 (PW −V B) at PV array irradiation of 550 W/m2 & wind speed of 8 m/s, mode 6 (PXW −V

BG) at an irradiation of 850 W/m2 & wind speed of 8 m/s and mode 7 (PWX −V BG) at an irradiation of 550 W/m2 & 12 m/s wind speed. Figure 3 to 8 depicts the simulated dynamic voltage and current waveforms of PV array, WECS, dc bus, EV battery, backup battery and utility grid respectively for the corresponding solar irradiation and wind speed values. In PW − V B mode, out of 480 W input power, 248 W is contributed from the PV array voltage, VPV of 23.65 V and current, IPV of 10.5 A as shown in Fig. 3 and around 232 W is contributed from the WECS output ac voltage, VPMSG of 55.02 V and current, IPMSG of 4.371 A as shown in Fig. 4. Out of 480 W input power from RES, 466 W of power is transferred to the dc bus from PV array through the Sepic converter and from WECS through bridgeless cuk converter. The dc bus voltage of 27.2 V and current of 17.14 A is depicted in Fig. 5.

Table 3: Specifications of the proposed charger

Components	Specifications	Components	Specifications
PV Array (2 Panels in Parallel, each of 250 W)		**Wind Turbine Generator**	
Open circuit voltage, V_{oc}	37.25 V	Nominal Mechanical power	600 W
Short circuit current, I_{sc}	17.5 A	Base wind speed	12 m/s
SEPIC Converter		**Bridgeless Cuk Converter**	
Inductors, L_a & L_b	1 mH, 20 A	Inductors, L_{in1} & L_{in2}	1 mH, 20 A
Capacitor, C_a	1000 μF, 250 V	Inductors, L_{01} & L_{02}	8 μH, 20 A
Capacitor, C_b	600 μF, 150 V	Capacitor, C_1 & C_2	1 μF, 160 V
BIDC Converter		Capacitor, C_0	4700 μF, 25 V
Inductors, L_1, L_2 & L_3	85 μH/ 15 A	**BLCC Converter**	
Capacitor, C_L	1 μF/ 450 V	Inductor, L_{dc}	5 mH, 20 A
Capacitor, C_H	100 μF/160 V	**Transformer turns ratio**	1:5
EV Battery (2 batteries in series)		**Backup Battery Bank (5 batteries in series)**	
Battery	12 V, 35 Ah	Battery	12 V, 100 Ah

Increase in SOC of EV battery and its negative current of 8.7 A shown in Fig. 6 indicate that the EV battery is charged with the voltage of 26.34 V in this mode. BIDC operates as boost converter in forward direction in this mode, boosting the dc bus voltage, Vdc of 27.2 V to 60.8 V to charge the backup battery which is indicated by the increase in SOC as presented in Fig. 7. As the input power is sufficient to charge EV battery and backup battery alone, grid is isolated from the charger in this mode and it is depicted by 0 A dc link current and grid current in Fig. 8.

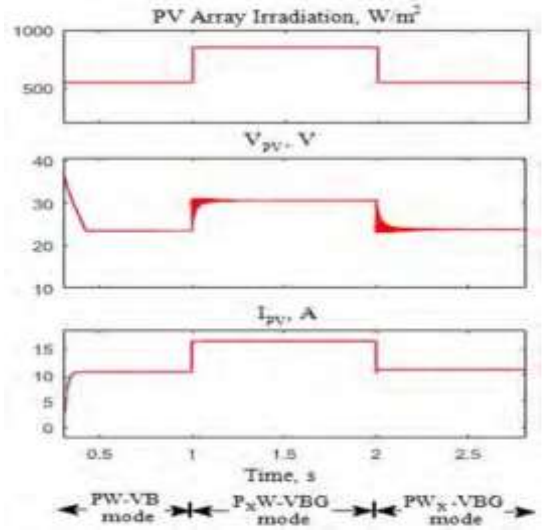

Figure 3: Dynamic response of PV array irradiation, voltage and current waveforms

In PXW − V BG mode, 472 W of power is generated from the PV array at an irradiation of 850 W/m2 and the corresponding PV array voltage of 30.82 V and current of 15.34 A is shown in Fig. 3.

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Power of 232 W is generated from the WECS at the wind speed of 8 m/s and the generated ac voltage of 55.02 V and current of 4.371 A is shown in Fig. 4. Out of 704 W total input power from PV array and WECS, 685 W of power is transferred to the dc bus with the voltage of 27.2 V and current of 25.2 A as shown in Fig. 5. Out of the power at PCC of dc bus, 229 W power is used to charge the EV battery with the voltage of 26.31 V and current of 8.719 A as shown in Fig. 6 and 232 W power is used to charge the backup battery bank with the voltage of 60.86 V and current of 3.807 A as shown in Fig. 7 and the remaining power of 207 W is fed to the single phase utility grid with the voltage of 230 V and current of 0.92 A as shown in Fig. 8. In this mode also, both batteries are charged which is indicated by the increase in their SOC in Fig. 6 & 7 respectively.

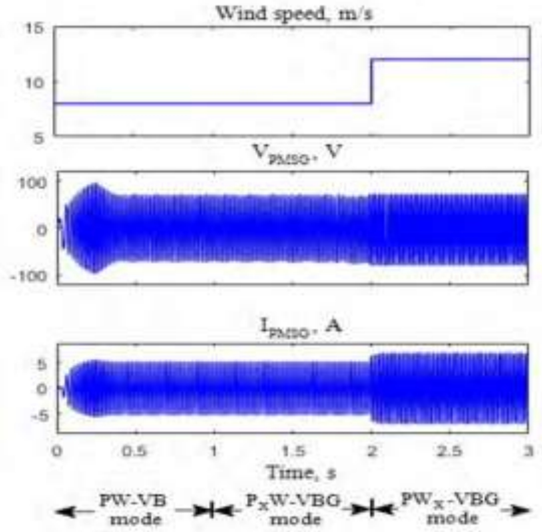

Figure 4: Dynamic response of Wind speed, WECS output voltage and current waveforms

In PWX − V BG mode, PV array generates the voltage of 23.65 V and current of 10.5 A at an irradiation of 550 W/m2 as shown in Fig.3 and WECS generates the ac voltage of 57.08 V and current of 8.398 A at a wind speed of 12 m/s as depicted in Fig. 4. PV array and WECS contributes the total input power of 718 W. Out of this input power, 683 W power is fed to the dc bus with the voltage of 27.2 V and current of 25.1A as shown in Fig. 5. In this mode, EV battery is charged with the voltage of 26.34 V and current of 8.72 A contributing to the power of 230 W as shown in Fig.
6 and backup battery is charged with the power of 232 W as depicted in Fig. 7. In this mode also, 207 W of power is fed to the single phase utility grid with the voltage of 230 V and current of 0.92 A as shown in Fig. 8. The negative dc link voltage shown in Fig. 8 clearly depicts that BLCC operates as inverter and the power is fed to the utility grid during PXW − V BG & PWX − V BG modes.
Also, simulation studies of the proposed charger are carried out when both renewable energy sources are not available to charge EV battery. During G − V B & B − V modes, PV array along with sepic converter and WECS with bridgeless cuk converter are isolated from the charger and the dynamic voltage and curent waveforms of grid, dc bus, EV battery and backup battery are shown in Fig. 9 to Fig. 12 respectively. In G − V B mode, single phase utility grid supplies voltage of 230 V and current of 2.12 A contributed to the power of 483 W to charge EV battery and backup battery bank as shown in Fig. 9. Out of the grid power, 462 W is transferred to the dc bus with the voltage of 26.9 V and 17.17 A through BLCC and transformer as depicted in Fig. 10. Out of the power at PCC of dc bus, 230 W is used to charge EV battery with the voltage of 26.2 V and current of 8.77 A as shown in Fig. 11. Remaining power of 225 W is fed to charge backup battery with the voltage of 60.85 V and current of 3.7 A as shown in Fig. 12. The positive dc link voltage shown in Fig. 9 indicates that, BLCC operates as rectifier in G − V B mode.

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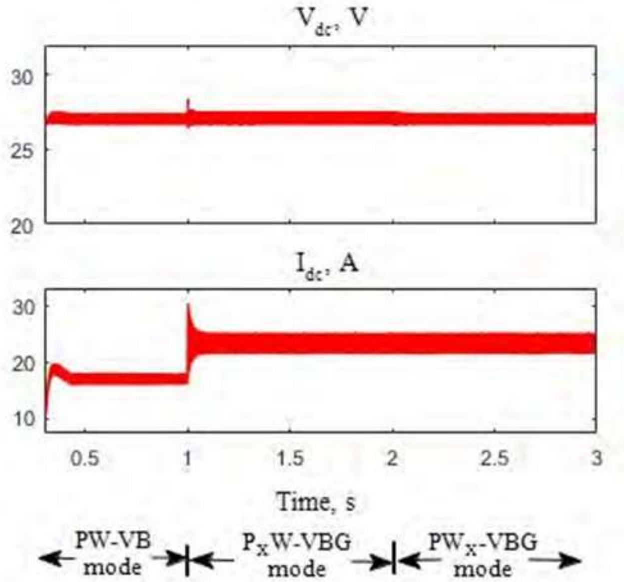

Figure 5: Dynamic response of dc bus voltage and current waveforms

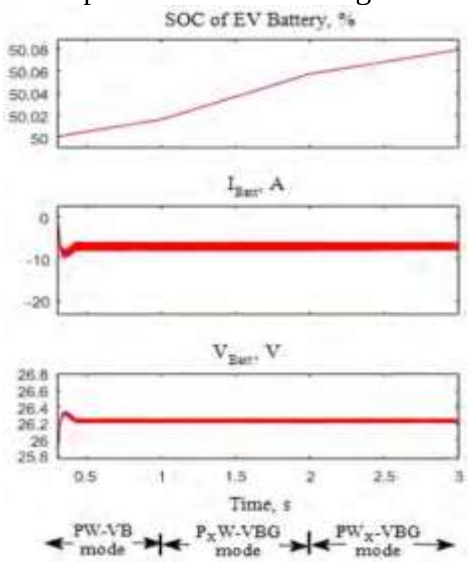

Figure 6: Dynamic response of EV battery SOC, voltage and current waveforms

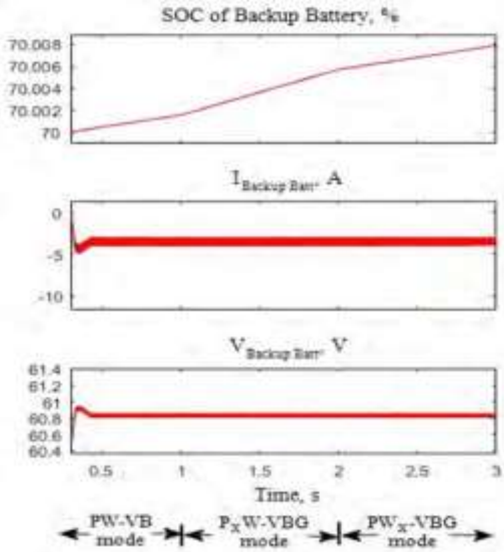

Figure 7: Dynamic response of backup battery SOC, voltage and current waveforms

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When the renewable energy sources and grid are not available to supply power to charge EV battery, backup battery bank discharges to charge the EV battery during B-V mode. In this mode, grid is also isolated from the charger which is indicated by the 0 A grid current and dc link current in Fig. 9. The positive backup battery current and decrease in SOC shown in Fig. 12 clearly depicts that the backup battery bank is discharged in order to charge the EV battery in this mode. Out of 228 W of backup battery power contributed from voltage of 60.42 V and current of 3.784 A, EV battery is charged with the power of 222 W contributed from the voltage of 26.2 V and current of 8.477 A as shown in Fig. 11. From Fig. 6 & Fig. 11, it is evident that EV battery is charged in all the modes irrespective of changes in solar irradiation and wind speed. Also, the dc bus voltage is maintained constant around 27 V in all the modes as shown in Fig. 5 & Fig. 10 in order to supply the EV battery in constant voltage charging method.

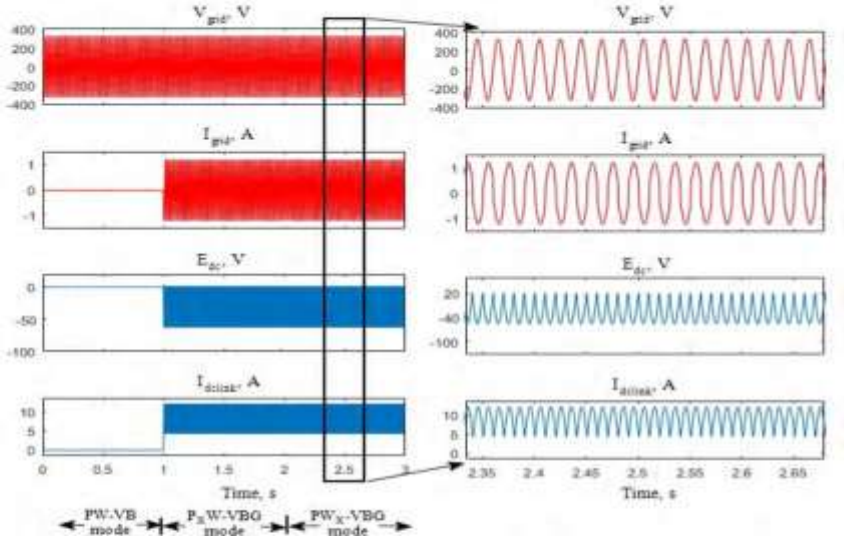

Figure 8: Dynamic response of grid voltage & current and dc link voltage & current waveforms

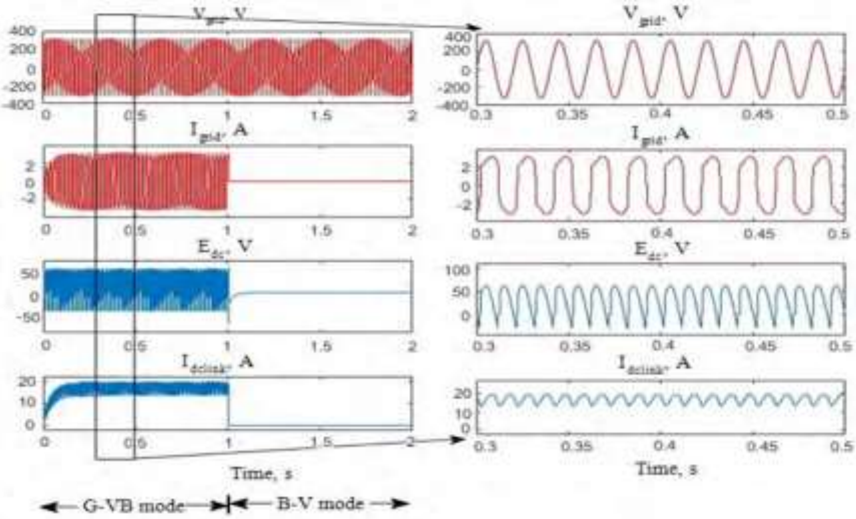

Figure 9: Dynamic response of grid waveforms during G-VB & B-V modes

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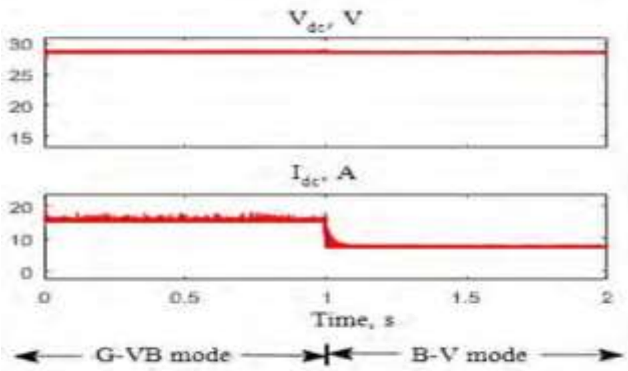

Figure 10: Dynamic response of dc bus waveforms during G-VB & B-V modes

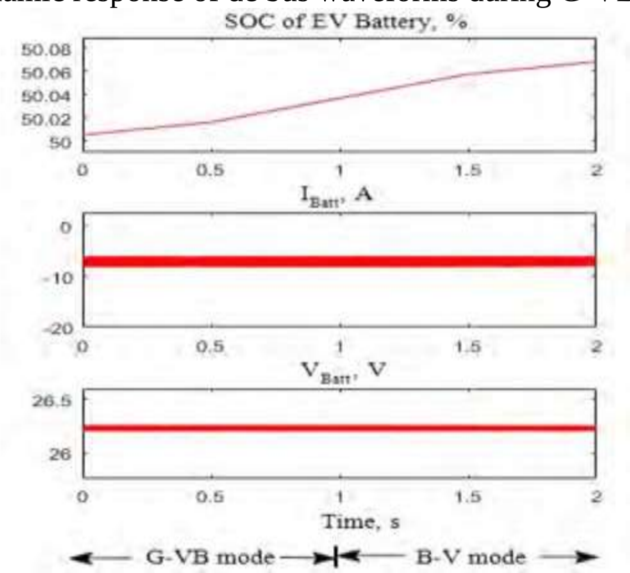

Figure 11: Dynamic response of EV battery waveforms during G-VB & B-V modes

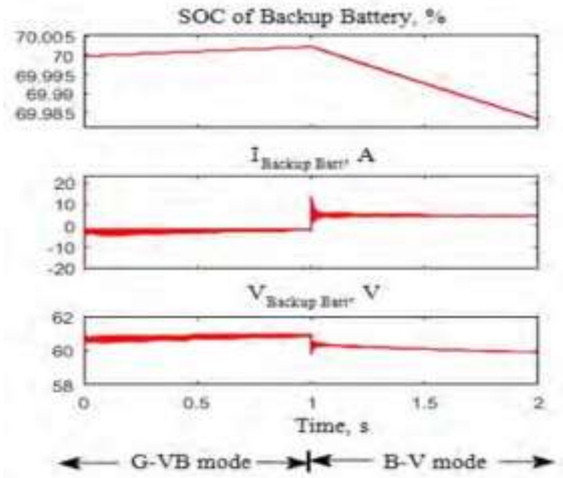

Figure 12: Dynamic response of backup battery waveforms during G-VB & B-V modes

Table 4: Simulation results of proposed EV battery charger

Parameters	$PW - VB$ mode	$P_XW - VBG$ mode	$PW_X - VBG$ mode	$G - VB$ mode	$B - V$ mode
Irradiation (W/m^2)	550	850	550	100	100
$V_{PV}(V)$	23.65	30.82	23.65	32.89	32.89
$I_{PV}(A)$	10.5	15.34	10.5	0	0

$P_{PV}(W)$	248.32	472.6	248.32	0	0
Wind Speed (m/s)	8	8	12	5	5
V_{PMSG} (V)	55.02	55.02	57.08	22.4	22.4
I_{PMSG} (A)	4.371	4.371	8.398	0	0
P_{PMSG} (W)	231.75	231.75	469.8	0	0
V_{dc} (V)	27.2	27.2	27.2	26.9	26.6
I_{dc} (A)	17.14	25.2	25.1	17.17	8.47
P_{dc} (W)	466.2	685.44	682.72	461.87	225.48
V_{Batt} (V)	26.34	26.31	26.34	26.2	26.2
I_{Batt} (A)	8.7	8.719	8.72	8.77	8.477
P_{Batt} (W)	229.15	229.4	229.6	229.77	222.09
$V_{BackupBatt}$ (V)	60.8	60.86	60.79	60.85	60.42
$I_{BackupBatt}$ (A)	3.81	3.807	3.817	3.7	3.782
$P_{BackupBatt}$ (W)	231.64	231.69	232.04	226	228.5
V_{grid} (V)	230	230	230	230	230
I_{grid} (A)	0	0.92	0.92	2.12	0
P_{grid} (W)	0	207.3	207.3	482.72	0
PF	-	0.98	0.98	0.99	-
Efficency (%)	96	95	93	94	97

Simulation results of the proposed charger in all modes of operation are presented in Table 4. From Table 4, it is evident that the average of overall system efficiency is around 95 %. Simulation results validate the performance of proposed grid-tied hybrid RES based EV battery charger.

Advantages of the integrated system over individual systems are that the integrated system inherits the advantages of all individual systems. EV battery can be charged round the clock since the power is generated from various RES. Thus, excess power generated from RES during sun shine hours is fed to the utility grid. Despite the advantages, the integrated system has some limitations such as control complexity is high compared with the individual systems. Maintaining constant dc bus voltage at the point of common coupling is more complex when both PV array and WECS are integrated to the proposed system. Transition from one mode to the other occurs often in the integrated system which necessitate an intelligent and automatic controller to track various parameters simultaneously in this proposed system. Installation and maintenance cost is also high. Hence, the proposed system can only be installed in the parking/charging stations, office buildings and residential buildings where more number of electric vehicles get charged. Whereas, individual systems can be installed in single residential plots with reduced power ratings for single EV users also. The proposed grid-tied hybrid RES based EV battery charger integrating all the individual system is presented. This chapter discusses the flexibility of the system to charge the EV battery constantly irrespective of the irradiation and wind speed conditions. The proposed system is designed and simulated in Simulink environment of the MATLAB software and the results are furnished for the different modes of operation. The simulation results emphasize the effectuality of the proposed charger.

IV. Conclusion & Future Scope

4.1 Conclusion

An electric vehicle battery charger that is grid-tied and utilizes a hybrid renewable energy system. This charger has an automated controller that facilitates efficient power transfer from renewable energy sources to loads using relays and power converters. The proposed charger's dynamic reaction unequivocally demonstrates that the EV battery is charged consistently at a constant voltage, irrespective of solar irradiation and wind velocity. Surplus renewable energy source power is sent back into the grid, in addition to charging electric vehicle batteries and backup batteries. The simulation results of this proposed charging mechanism validate its efficacy across several modes. The efficient charger enables parking and charging stations, residential buildings, business buildings, and smart homes to continuously charge electric vehicle batteries in constant voltage mode, irrespective of the intermittency of renewable energy sources. All recommended chargers inhibit trickle charging of electric vehicles and backup batteries, hence prolonging battery lifespan. The proposed charging system is more efficient than existing systems, has fewer components, is more compact, possesses a simpler control circuit, and may include hybrid renewable energy sources and self-synchronized grids.

4.2 Future Scope

The suggested system offers significant potential for future enhancement. The grid-tied renewable energy source (RES) based electric vehicle (EV) battery charging system is a burgeoning sector in the automotive industry, emphasizing the extraction of optimal power from RES. Additionally, grid complications like as sagging, swelling, and line faults may be taken into account during the integration of the EV battery charging system. An enhanced converter may be offered to decrease the component count, hence increasing the efficiency of the electric vehicle battery charger. The constant current charging methods for EV batteries may be used to enhance the battery's life cycle.

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