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Electric Vehicle Battery Charging System Based on Grid-Tied Hybrid Renewable Energy

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Abstract-- The need for reliable and environmentally 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 options, both on and off the grid, are being widely researched. A RES application is a battery charging system for electric vehicles. Demand for electric vehicles is being driven by rising energy prices and the depletion of fossil resources. The battery and power electronic converters used in battery chargers have an impact on cost, weight, and reliability. These technologies convert and feed power from renewable sources or the grid into the EV battery. Power electronic converters are being investigated for application in renewable energy storage systems for electric vehicles. It intends to construct an EV battery charger together with a backup PV array battery bank. Regardless of PV array intermittency, these converters allow uninterruptible charging of EV batteries in constant voltage mode. The efficacy of the suggested system is evaluated using simulation and experimentation. A bidirectional dc-ac converter provides excess PV power back to the single-phase utility grid while charging the EV battery during peak solar hours. EV battery charging was made possible by the electric grid during non-sunny hours. The unique bidirectional dc-ac converter design of the proposed charging system enables self-grid synchronisation, decreasing control complexity. A solo wind energy converter is seen feeding an EV battery charger. A constant voltage, wind-independent alternating current generator is used to charge an electric vehicle (EV). Simulation and testing are used to show the efficacy of the proposed system. This is a hybrid renewable energy EV battery charging system that is grid-connected. For this charging system, an automated controller is recommended to provide optimal power transfer between RES and loads. Despite the intermittent nature of RES, the proposed technique enables for continuous EV charging. Surplus renewable energy 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. INTRODCUTION

Nowadays, vehicles are considered vital elements in everyday life for personal mobility and transport of goods as reflected by the continuous demand for petroleum. Along with such a demand, the rise in fuel costs and increasing global concerns over the environment because of air pollution and climate change have elicited apprehensions. Consequently, certain governments have encouraged car manufacturers to create environmentally friendly and low-emission transportation alternatives [1]. In this context, Electric Vehicles (EVs) have been developed and utilized to minimize dependency on fossil fuels; this has resulted in the reduction of emissions of greenhouse gases and other pollutant [2]. Furthermore, vehicle emission standards have been imposed to avert environmental damage caused by conventional vehicles. As the proposed system has PV array, WECS, backup battery bank and grid as the available sources of power, EV battery is charged uninterruptedly irrespective of the intermittent nature of the renewable energy sources. Detailed discussion on the proposed system is presented in the following sections.

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:

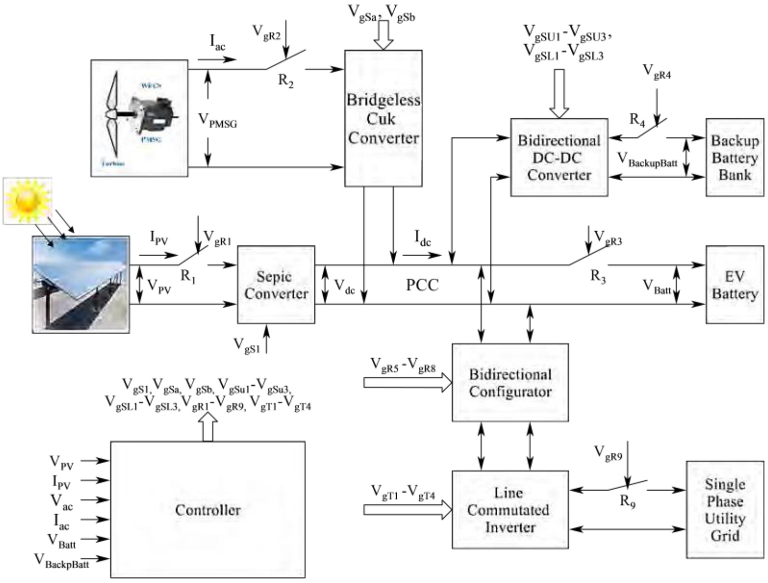

Figure 1: Proposed configuration of grid-tied hybrid RES based EV battery charger

Table 1: Operating modes of the proposed charger

Predominant Sources	PV Array Power	WECS Power	Modes
PV Array	$P_L < P_{PV} \leq P_U$	$P_W < P_L$	Mode 1: $PV - EV$
	$P_{PV} > P_U$	$P_W < P_L$	Mode 2: $PV - VB$
WECS	$P_{PV} < P_L$	$P_L < P_W \leq P_U$	Mode 3: $WT - EV$
	$P_{PV} < P_L$	$P_W > P_U$	Mode 4: $WT - VB$
PV Array & WECS	$P_L < P_{PV} \leq P_U$	$P_L < P_W \leq P_U$	Mode 5: $PW - VB$
	$P_{PV} > P_U$	$P_L < P_W \leq P_U$	Mode 6: $P_XW - VBG$
	$P_L < P_{PV} \leq P_U$	$P_W > P_U$	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, R_1 - R_9 depending on the reference power lower and upper limits P_L and P_U 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 nfigurator 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

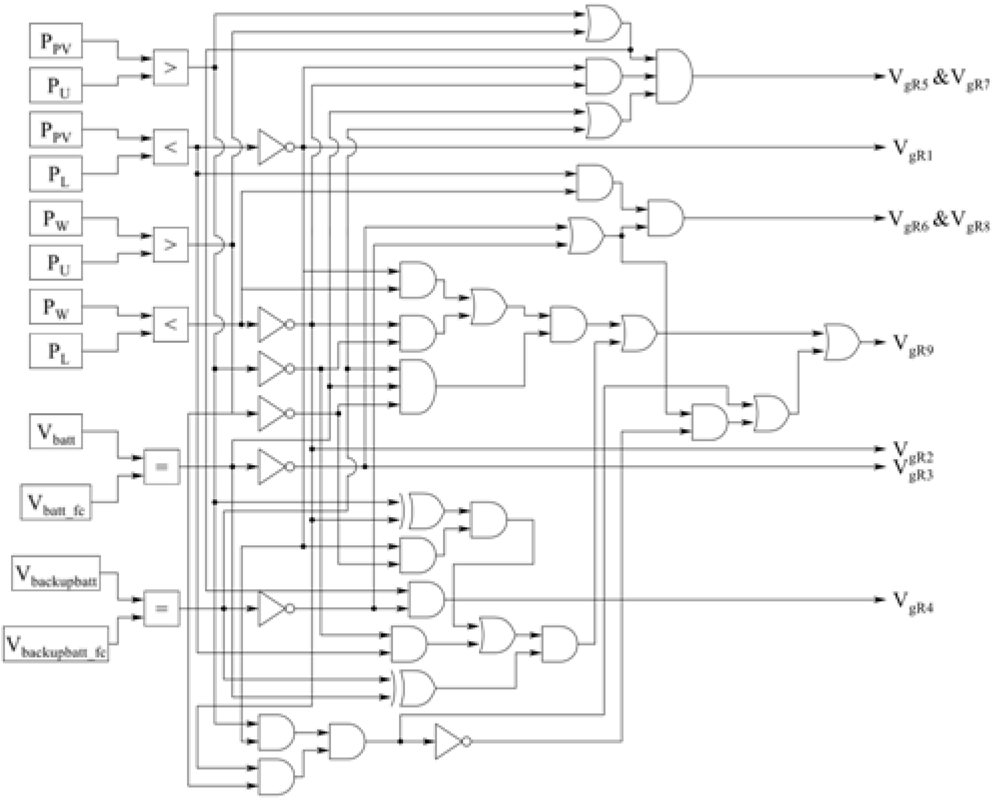

Figure 2: Controller diagram for operating relays in the proposed charger

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 ($PW - VB$) at PV array irradiation of 550 W/m^2 & wind speed of 8 m/s, mode 6 ($P_XW - VBG$) at an irradiation of 850 W/m^2 & wind speed of 8 m/s and mode 7 ($PW_X - VBG$) at an irradiation of 550 W/m^2 & 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 $PW - VB$ mode, out of 480 W input power, 248 W is contributed from the PV array voltage, V_{PV} of 23.65 V and current, I_{PV} of 10.5 A as shown in Fig. 3 and around 232 W is contributed from the WECS output ac voltage, V_{PMSG} of 55.02 V and current, I_{PMSG} 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

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

through bridgeless cuk converter. The dc bus voltage of 27.2 V and current of 17.14 A is depicted in Fig. 5. 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, V_{dc} 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.

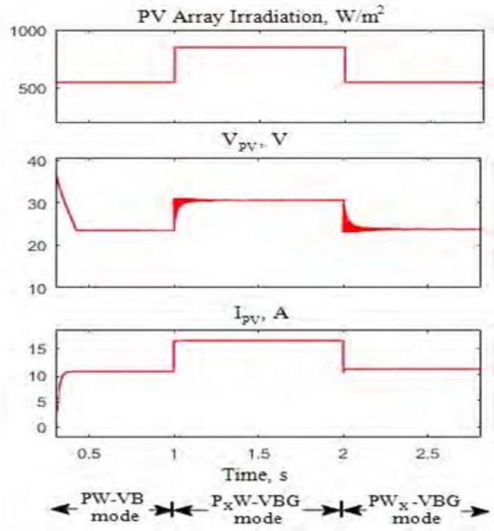

Fig. 3 Dynamic response of PV array irradiation, voltage and current waveforms In $P_XW - VBG$ mode, 472 W of power is generated from the PV array at an irradiation of 850 W/m^2 and the corresponding PV array voltage of 30.82 V and current of 15.34 A is shown in Fig. 3. Power of 232 W is generated from 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

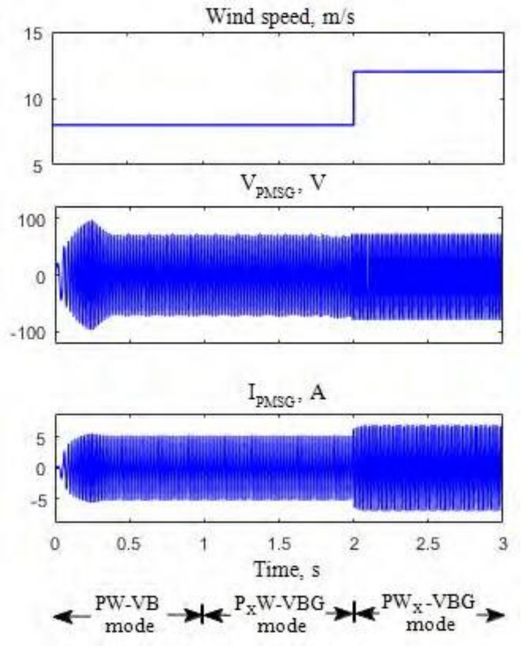

Fig. 4 Dynamic response of Wind speed, WECS output voltage and current waveforms fed to the single phase utility grid with the voltage of 230 V and current of 0.92 A as shown in Fig. 8. In this mode also, both batteries are charged which is indicated by the increase in their SOC in Fig. 6 & 7 respectively.

In $PW_X - VBG$ mode, PV array generates the voltage of 23.65 V and current of 10.5 A at an irradiation of 550 W/m^2 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 $P_XW - VBG$ & $PW_X - VBG$ modes.

Also, simulation studies of the proposed charger are carried out when both renewable energy sources are not available to charge EV battery. During $G - VB$ & $B - V$ 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

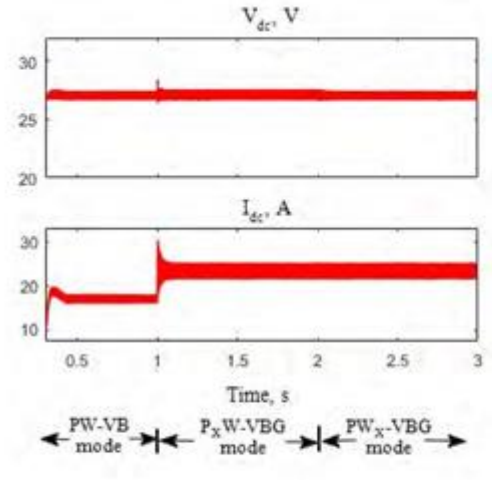

Fig. 5 Dynamic response of dc bus voltage and current waveforms

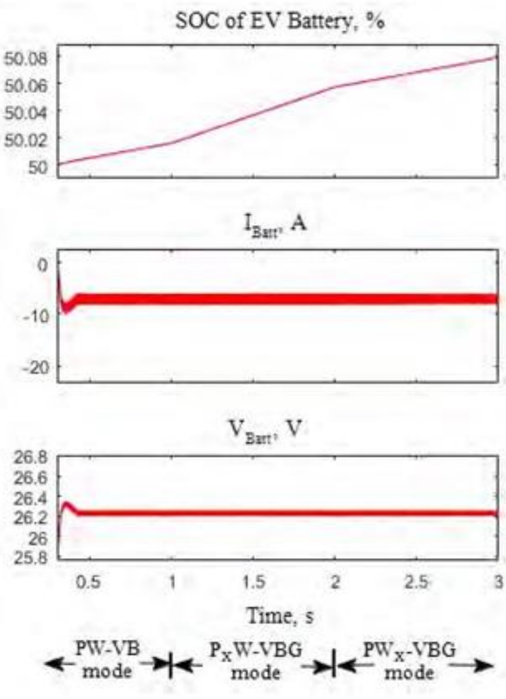

Fig. 6 Dynamic response of EV battery SOC, voltage and current waveforms

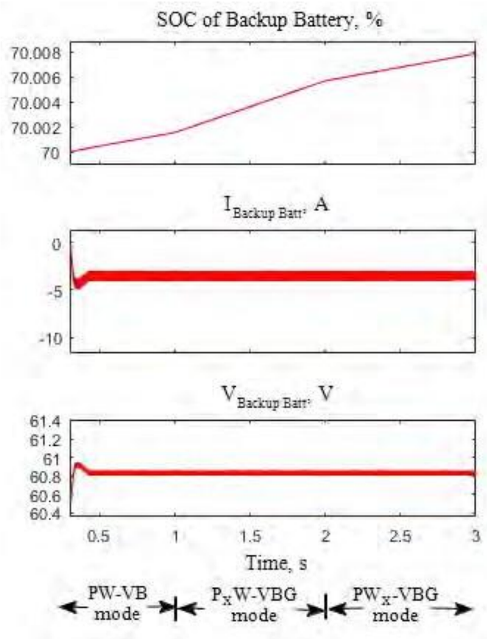

Fig. 7 Dynamic response of backup battery SOC, voltage and current waveforms

of grid, dc bus, EV battery and backup battery are shown in Fig. 9 to Fig. 12 respectively. In $G-VB$ 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.

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

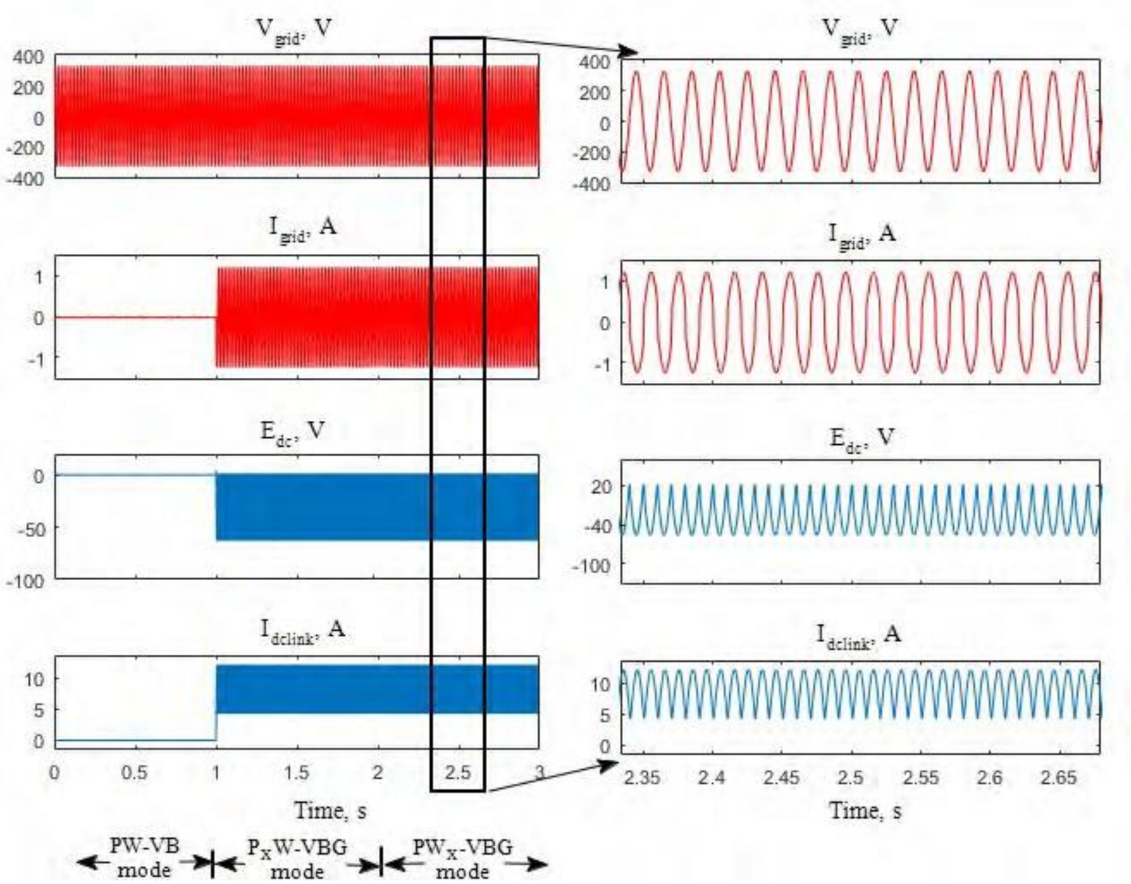

Fig. 8 Dynamic response of grid voltage & current and dc link voltage & current waveforms

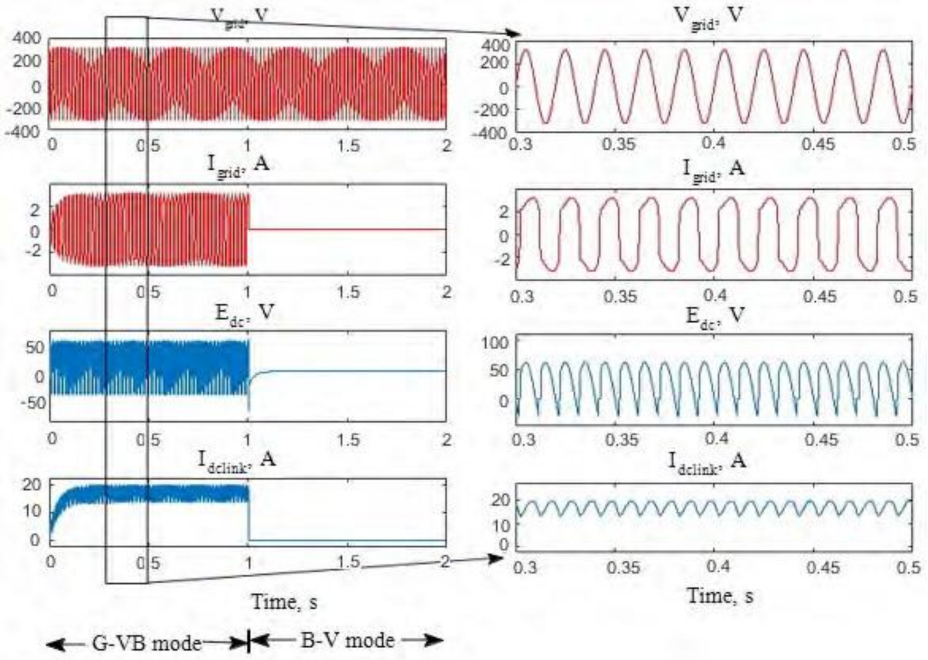

Fig. 9 Dynamic response of grid waveforms during G-VB & B-V modes

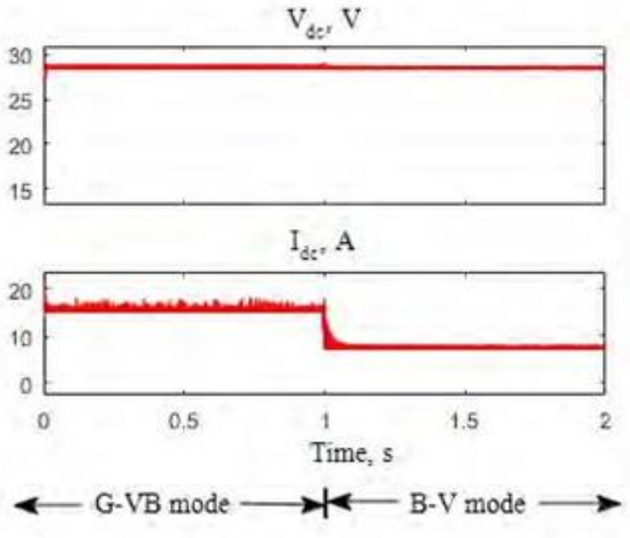

Fig. 10 Dynamic response of dc bus waveforms during G-VB & B-V modes

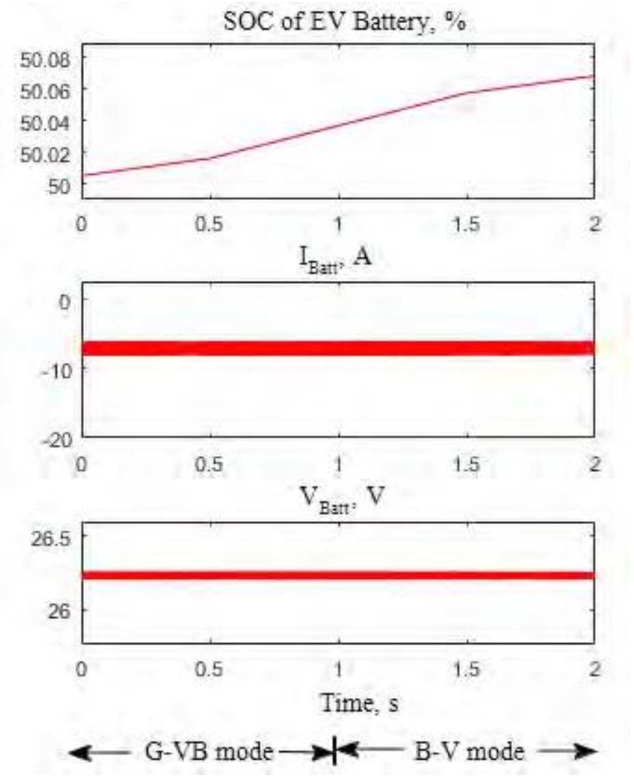

Fig. 11 Dynamic response of EV battery waveforms during G-VB & B-V modes

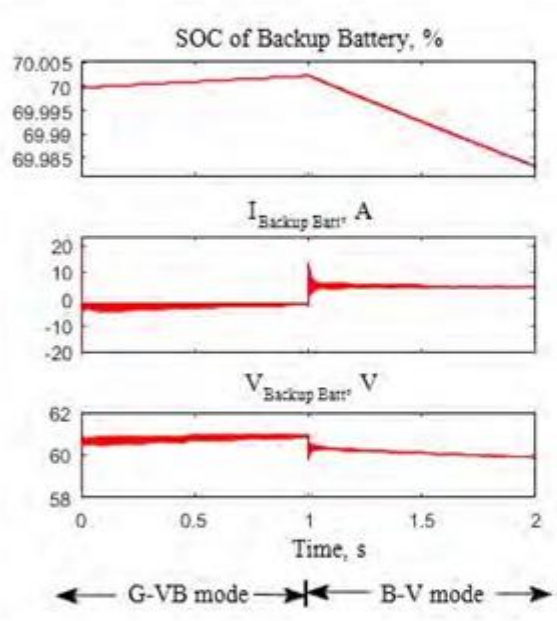

Fig. 12 Dynamic response of backup battery waveforms during G-VB & B-V modes battery is charged in all the modes irrespective of changes in solar irradiation and wind speed. Also, the dc bus voltage is maintained constant around 27 V in all the modes as shown in Fig. 5 & Fig. 10 in order to supply the EV battery in constant voltage charging method.

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
$VBackupBatt\,(V)$	60.8	60.86	60.79	60.85	60.42
$IBackupBatt\,(A)$	3.81	3.807	3.817	3.7	3.782
$PBackupBatt\,(W)$	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.

CONCLUSION & FUTURE SCOPE

4.1 Conclusion

A hybrid RES-based EV battery charger that is grid-connected. This charger's automated controller enables efficient power transfer from renewable energy sources to loads through relays and power converters. The dynamic response of the recommended charger clearly illustrates that the EV battery is charged constantly at constant voltage independent of solar irradiation or wind speed. Surplus RES power is supplied back into the grid in addition to charging EV batteries and backup batteries. The simulation results of this proposed charging method validate its performance in several modes.

Parking/charging stations, residential buildings, business buildings, and smart residences may all utilise the efficient charger to charge EV batteries in constant voltage mode, independent of the intermittent nature of renewable energy sources. All of the chargers recommended prevent trickle charging of EV and backup batteries, hence improving battery life. The proposed charging system is more efficient than present methods, has fewer components, is smaller, has a simpler control circuit, and can combine hybrid renewable energy sources and self-synchronized grids.

4.2 Future Scope

The suggested system provides a lot of room for future enhancement. Because the grid-connected RES-based EV battery charging system is a thriving field in the car industry, maximum power extraction from RES may be emphasised. Grid concerns such as sag, swell, and line failures may also be taken into account during the grid integration of the EV battery charging system. Improved converters may be offered to minimise component count and hence enhance the efficiency of the EV battery charger. In addition, constant current charging methods for EV batteries may be applied to optimise EV battery life cycle.

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