Analysis and Design of Multi Input Dc–Dc Converter for Integrated Wind PV Cell Renewable Energy Generated System

S. Ramya, T. Manokaran

Abstract: The objective of this paper is to propose a multi-input power converter for the hybrid system in order to simplify the power system and reduce the cost. The proposed converter interfaces two unidirectional input ports and a bidirectional port for storage element in a unified structure. It also utilizes four power switches that are controlled independently with four different duty ratios. The renewable power system hybridizes PV and Wind as main source & Battery Power for backup energy source. Three different power operation modes are defined for the converter based on utilization state of the battery as follows: 1) An operation type wherein power is delivered to load from hybrid renewable energy sources; 2)A single type wherein only one renewable energy source supplies power to the load with battery discharging; 3) An operation type wherein power is delivered to load from renewable sources along with battery charging. A simple and cost effective control with DC-DC converter is used for maximum power point tracking (MPPT) and hence maximum power is extracted from the source .The integration of the hybrid renewable power system is implemented and simulated using MATLAB/SIMULINK.

Index Terms: Photovoltaic (PV)/Wind/Battery sources, hybrid power system, State Of Charge(SOC), Multi input power converter, Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

The energy consumption of the world is increasing dramatically with the rapid increase of population. Renewable energy resources are holding the predominant place for satisfying the future energy demand .Among the available renewable sources, wind and solar are predominant ones, since they have more advantages on production, maintenance, etc. when compared with others. However, the renewable energy generation has a drawback that the change of the output characteristic becomes intense because the output greatly depends on climatic conditions, including solar irradiance, wind speed, temperature, and so forth. Many researches are still going on this field to improve the efficiency of this type of systems having wind and solar as resources [1]. Batteries are usually taken as storage mechanism for smoothing output power, improving startup transitions and dynamic characteristics, and enhancing the peak power capacity [2]. Combining the photovoltaic generation with wind power generation, the instability of an output characteristic each other was compensated. Combining such energy source introduces a PV/WIND/battery hybrid power system. In comparison with single-sourced systems, the hybrid power system has the potential to provide high quality, more reliable, and efficient power. In these systems with a storage element, the bidirectional power flow capability is a key feature at the storage port. [3] Further, the input power sources should have the ability of supplying the load individually and simultaneously. Many hybrid power systems with various power electronic converters have been proposed in the literature up to now. However, the main shortcomings of these integrating methods are complex system topology, high count of devices, high power losses, expensive cost, and large size.[4]. In [5]–[8], three multi input converters are proposed based on structure of the dc–dc boost converter. The dc–dc boost converter in [5] is useful for combining several energy sources whose power capacity or voltage levels are different. The multi-input dc–dc converter proposed in [9] has the capability of operating in different converter topologies (buck, boost, and buck–boost) in addition to its bidirectional operation and positive output voltage without any additional transformer. Further, phase-shift control method is used to manage the power flow among the three ports in addition to soft switching for all switches over a wide input range.[10] Although the circuit efficiency is greatly developed, the converter does not provide bidirectional functionality and is not able to boost the input voltage to a higher level. Moreover, the summation of duty ratios should be greater than one and the two input voltages should be in the same level in the dual-power-supply operation state.[11-13]. In [14] power control strategies designed manage the charge balance of the battery in order to regulate the output voltage. In these systems, the PV is exploited in MPPT conditions with FC/Battery interfacing.

II. PROPOSED SYSTEM

In this paper, combining the photovoltaic generation with wind power generation, the instability of an output characteristic each other was compensated. The proposed system is applicable for hybrid power system. As shown in Fig. 1, the proposed converter interfaces two unidirectional ports for input power sources, a bidirectional port for a storage element, and a port for output load in a unified structure. The Input power source1 is Photovoltaic (PV) cell , power source2 is the Wind and the storage element is the battery. The converter is of current-source type at the both input power ports and is able to step up the input voltages.

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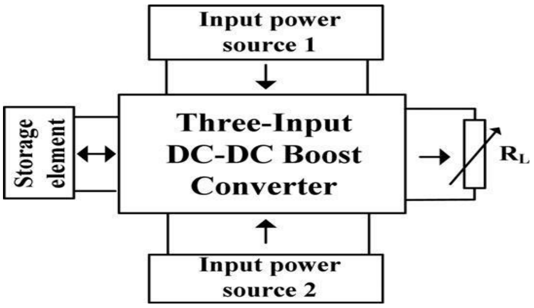


Fig. 1 Proposed system overview.

Supplying the output load, charging or discharging the battery can be made by the PV and the wind power sources individually or simultaneously. The proposed converter has the merits of including bidirectional power at the storage port, simple structure, low power components, low weight and high level of boosting.

III. STRUCTURE OF THE PROPOSED CONVERTER

The proposed Multi – Input power converter is shown in Fig. 2.

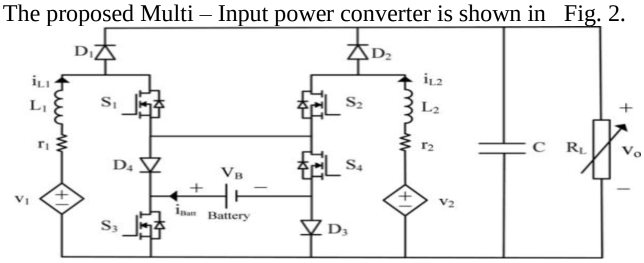


Fig. 2 Circuit topology of the proposed system.

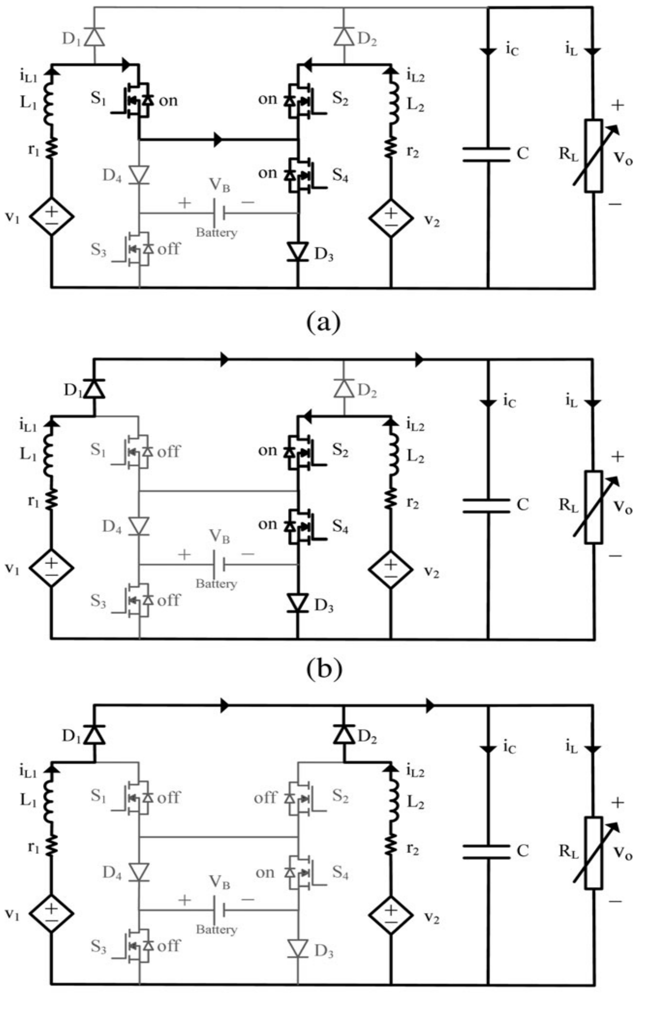
The proposed converter Interfaces two Input power sources v_1 and v_2 and a battery as the storage element. v_1 and v_2 are two dependent power sources, their output characteristics are determined by the Input power sources. In the proposed circuit, two Inductors L_1 and L_2 make the Input power ports as two current type sources. It results in drawing smooth currents from the sources. R_L is the load resistance and switches S_1 – S_4 are the main controllable element that controls the power flow of the hybrid power system. The d_1 – d_4 are the duty ratios controlling the switches S_1 – S_4 respectively. The diodes D_1 and D_2 conducts in complementary manner with switches S_1 and S_2. Turning ON S_3 and S_4, makes D_3 and D_4 to reverse bias by the V_{bat}. On the other hand, turn – OFF state of these switches makes diodes D_3 and D_4 able to conduct Input currents i_{L1} and i_{L2}. The steady states and dynamic behavior of the converter is observed in Continuous Current Mode (CCM).

IV.MODES OF OPERATION OF THE CONVERTER

Utilization state of the battery defines three power operation modes of the converter. The assumptions for the operation modes are considered by utilizing saw tooth carrier waveform for S_1 – S_4 and considering d_3, $d_4 <$ min (d_1,d_2) in battery charge or discharge mode. d_1 is assumed to be less than d_2 in order to simplify the operation mode investigation. Further, the steady – state equations are obtained in each operation mode, assuming S_1 – S_4 to be Ideal.

A. First Operation Mode (Existence of sources v_1 and v_2, without battery)

In this operation mode, the sources v_1 and v_2 supplies the load without battery. This is the Basic Operation mode of the converter. From the converter structure, there are two options to conduct Input – power sources currents i_{L1} and i_{L2} without passing through the battery, path1: S_4 – D_3, path2: S_3 – D_4. First path is chosen in this operation mode. Therefore, switch S_3 is turned OFF while turning ON Switch S_4 entirely in the switching period (d_4=1 and d_3=0). Thus, in one switching period, three different switching states of the converter are achieved. The switching states are shown in Fig. 3(a)–(c).



(c)

Fig. 3 First operation mode. (a) Switching state 1: 0 < t < d_1 T. (b) Switching state 2: d_1 T< t < d_2 T. (c) Switching state 3: d_2 T < t < T.

Switching state 1 (0 < t < d_1 T): At $t = 0$, switches S_1 and S_2 are turned ON and inductors L_1 and L_2 are charged with voltages across v_1 and v_2, respectively [see Fig. 3(a)].

Switching state 2 (d_1 T < t < d_2 T): At $t = d_1 T$, switch S_1 is turned OFF, while switch S_2 is still ON (according to the assumption $d_1 < d_2$). Therefore, inductor L_1 is discharged with voltage across $v_1 - v_o$ into the output load and the capacitor through diode D_1, while inductor L_2 is still charged by voltage across v_2 [see Fig. 3(b)].

Switching state 3 (d_2 T < t < T): At $t = d_2 T$, switch S_2 is also turned OFF and inductor L_2 is discharged with voltage across $v_2 - v_o$, as like as inductor L_1 [see Fig. 3(c)].

Based on the balance theory, equations are

$$L_1 : d_1 T(v_1 - r_1 i_{L1}) + (1 - d_1)T(v_1 - r_1 i_{L1} - v_o)$$

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$$= 0 \rightarrow v_o = \frac{v_1 - r_1 i_{L1}}{1-d_1} \quad (1)$$

$$L_2 : d_2T(v_2 - r_2 i_{L2}) + (1-d_2)T(v_2 - r_2 i_{L2} - v_o) = 0 \rightarrow v_o = \frac{v_2 - r_2 i_{L2}}{1-2} \quad (2)$$

$$C: (1-d_1)T i_{L1} + (1-d_2)T i_{L2} = T\frac{v_O}{R_L} \quad (3)$$

$$i_{Batt} = 0 \rightarrow P_{Batt} = 0 \quad (4)$$

In this mode, one of the Input sources is regulated with its corresponding duty ratios, while the other power source is utilized to regulate output voltage with its duty ratio.

B. Second Operation Mode (Existence of sources v_1 and v_2 and battery)

In this operation mode, the sources v_1 and v_2 supplies the load with the battery discharging state. From the converter structure, turning ON switches S_3 and S_4 simultaneously causes i_{L1} and i_{L2} to conduct through the path of S_4, the battery and S_3 which results in discharging of the battery. However, discharging operations of the battery can last until S_1 and/or S_2 are conducting. So, the maximum discharge state of the battery depends on d_1 and d_2 as well as currents i_{L1} and i_{L2}:

$$P^{max}_{bat.dis} = v_B[d_1 i_{L1} + d_2 i_{L2}], \; S_3 = ON, S_4 = ON. \quad (5)$$

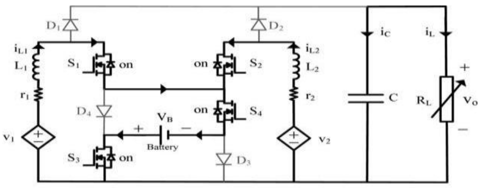
The discharging power of the battery below $P^{max}_{bat.dis}$ can be made by changing the state of only one of switches S_3 and S_4 before switches S_1 and S_2 are turned OFF. d_3 is controlled to regulate the discharging power of the battery. When S_4 is turned ON, it results in passage of currents of power sources through the battery; hence, battery discharge mode is started, and its turn OFF state starts D_4 to conduct and stops discharging mode of battery. The switching states are shown in Fig. 4(a)–(d).

Switching state 1 ($0 < t < d_4 T$): At $t = 0$, switches S_1, S_2, and S_4 are turned ON, so inductors L_1 and L_2 are charged with voltages across $v_1 + v_B$ and $v_2 + v_B$, respectively [see Fig. 4(a)].

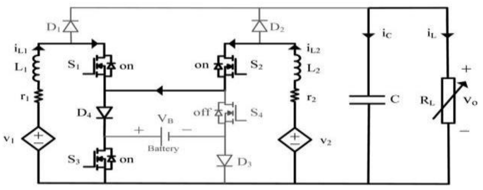
Switching state 2 ($d_4 T < t < d_1 T$): At $t = d_4 T$, switch S_4 is turned OFF, while switches S_1 and S_2 are still ON. Therefore, inductors L_1 and L_2 are charged with voltages across v_1 and v_2 , respectively [see Fig. 4(b)].

Switching state 3 ($d_1 T < t < d_2 T$): At $t = d_1 T$, switch S_1 is turned OFF, so inductor L_1 is discharged with voltage across v_1- v_o , while inductor L_2 is still charged with voltages across v_2 [see Fig. 4(c)].

Switching state 4 ($d_2 T < t < T$): At $t = d_2 T$, switch S_2 is also turned OFF and inductors L_1 and L_2 are discharged .



(a)



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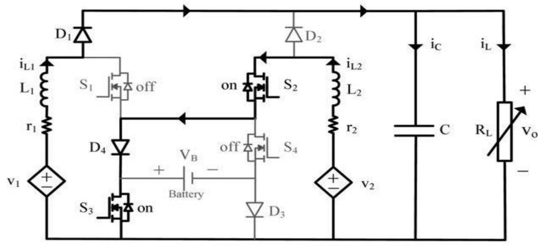

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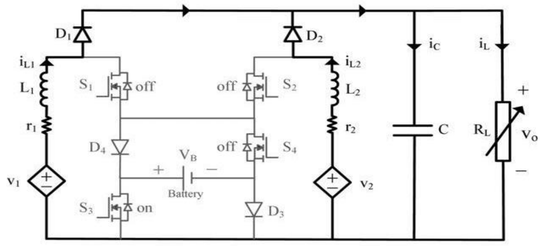

(d)

Fig. 4 Second operation mode. (a) Switching state 1: 0 < t < d4 *T*. (b) Switching state 2: d_4 *T*< *t* < d_1 *T*. (c) Switching state 3: d_1 *T* < *t* < d_2 *T*. (d) Switching state 4: d_2 *T* < *t* < *T*.

with voltage across $v_1 - v_o$ and $v_2 - v_o$,respectively [see Fig. 4(d)]. Based on the balance theory equations are

$$L_1 : d_4T(v_1 - r_1 i_{L1} + v_B) + (d_1 - d_4)T(v_1 - r_1 i_{L1}) + (1-d_1)T(v_1 - r_1 i_{L1} - v_o) = 0$$

$$= 0 \rightarrow v_o = \frac{v_1 - r_1 i_{L1} + d_4 v_B}{1-d_1} \quad (6)$$

$$L_2 : d_4T(v_2 - r_2 i_{L2} + v_B) + (d_2 - d_4)T(v_2 - i_{L2}) + (1-d_2)T(v_2 - r_2 i_{L2} - v_o) = 0$$

$$L_2 = 0 \rightarrow v_o = \frac{v_1 - r_1 i_{L2} + d_4 v_B}{1-d_2} \quad (7)$$

$$C: (1-d_1)T i_{L1} + (1-d_2)T i_{L2} = T\frac{v_O}{R_L} \quad (8)$$

$$Battery \begin{cases} i_{Batt} = d_4(i_{L1} + i_{L2}) \\ P_{Batt} = -v_B[d_4(i_{L1} + i_{L2})] \end{cases} \quad (9)$$

In this mode, d_1 and d_2 regulates powers of the input sources, while d_4 is utilized to regulate output voltage through battery discharging.

C. Third Operation Mode (Existence of sources v_1 and v_2 with battery charging)

In this operation mode, the sources v_1 and v_2 supplies the load while the battery is in charging state. From the converter structure, switches S_3 and S_4 are turned OFF, by turning ON S_1 and S_2, currents i_{L1} and i_{L2} are conducted through the path of D_4, the battery, and D_3. Hence the condition of battery charging is provided. However, the charging mode of the battery prevails until S_1 and/or S_2 are conducting. So, the maximum charging of the battery depends on d_1 and d_2 as well as i_{L1} and i_{L2}.

$$P^{max}_{bat.ch} = -v_B[d_1 i_{L1} + d_2 i_{L2}], \; S_3 = OFF, S_4 = OFF. \quad (10)$$

Regulating charging power of the battery below $P^{max}_{bat.ch}$ can be made by change of state of switches S_3 and S_4 before

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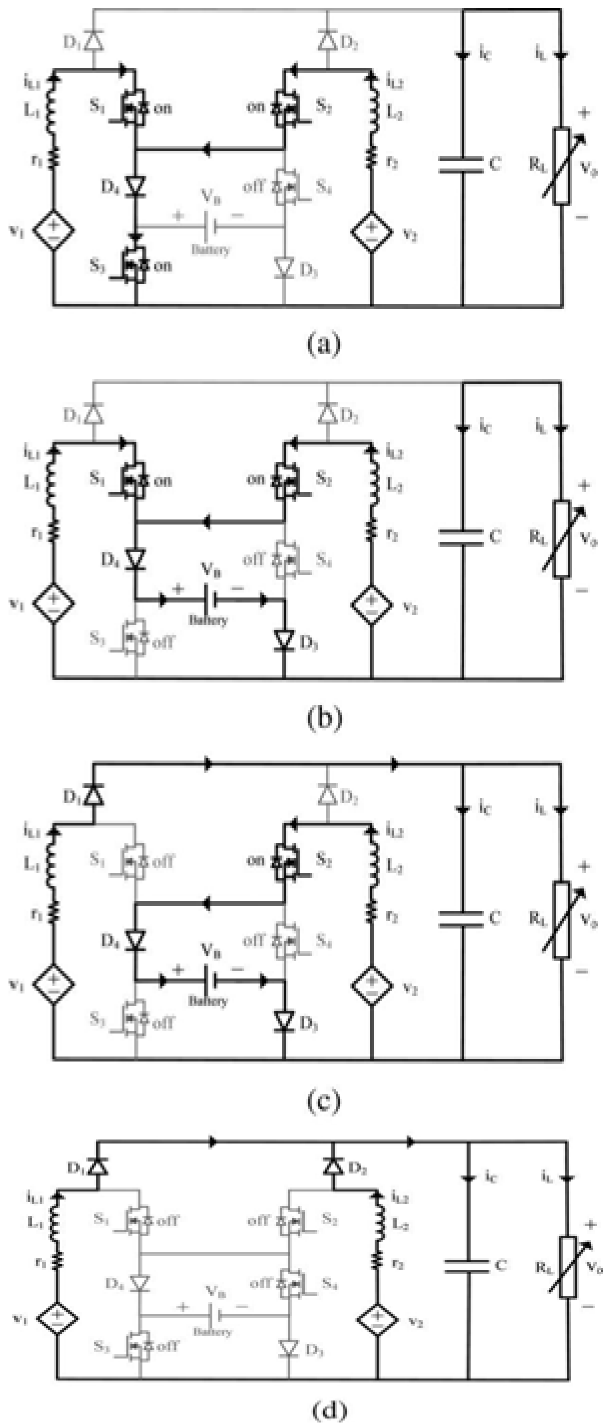

Fig. 5 Third operation mode. (a) Switching state 1: $0 < t < d_3 T$ (b) Switching state 2: $d_3 T < t < d_1 T$. (c) Switching state 3: $d_1 T < t < d_2 T$. (d) Switching state 4: $d_2 T < t < T$.

turning OFF switches S_1 and S_2 (Assuming that d_3, d_4<min(d_1, d_2)).In order to regulate, the charging state of the battery, S_3 is controlled. The battery charging is not accomplished when S_3 is turned ON. In one switching period, Four different switching states obtained are shown in Fig. 5(a)–(d).

Switching state 1 ($0 < t < d_3 T$): At $t = 0$, switches S_1 , S_2 , and S_3 are turned ON, so inductors L_1 and L_2 are charged with voltages across v_1 and v_2 , respectively [see Fig. 5(a)].

Switching state 2 ($d_3 T < t < d_1 T$): At $t = d_3 T$, switch S_3 is turned OFF while switches S_1 and S_2 are still ON (according to the assumption). Therefore, inductors L_1 and L_2 are charged with voltages across $v_1 - v_B$ and $v_2 - v_B$, respectively [see Fig. 5(b)].

Switching state 3 ($d_1 T < t < d_2 T$): At $t = d_1 T$, switch S_1 is turned OFF, so inductor L_1 is discharged with voltage across v_1 - v_o , while inductor L_2 is still charged with voltage across v_2- v_B [see Fig. 5(c)].

Switching state 4 ($d_2 T < t < T$): At $t = d_2 T$, switch S_2 is also turned OFF and inductor L_2 as like as L_1 is discharged with voltage across $v_2 - v_o$ [see Fig. 5(d)].

Based on the balance theory, equations are

$$L_1 : d_3T(v_1 - r_1 i_{L1}) + (d_1 - d_3)T(v_1 - r_1 i_{L1} - v_B) + (1 - d_1)T(v_1 - r_1 i_{L1} - v_o) = 0$$

$$L_1 = 0 \rightarrow v_o = \frac{v_1 - r_1 i L_1 (d_1 - d_3) v_B}{1 - d_1} \quad (11)$$

$$L_2 : d_2T(v_2 - r_2 i_{L2}) + (d_2 - d_3)T(v_2 - r_2 i_{L2} - v_B) + (1 - d_2)T(v_2 - r_2 i_{L2} - v_o) = 0$$

$$= 0 \rightarrow v_o = \frac{v_2 - r_2 i L_2 (d_2 - d_3) v_B}{1 - d_2} \quad (12)$$

$$C: (1 - d_1)T i_{L1} + (1 - d_2)T i_{L2} = T\frac{v_O}{R_L} \quad (13)$$

$$Battery \begin{cases} i_{Batt} = -(d_1 - d_3)i_{L1} - (d_2 - d_3)i_{L2} \\ P_{Batt} = -v_B[(-d_3)(iL_1 + iL_2) + d_1 i_{L1} + d_2 i_{L2} \end{cases} \quad (14)$$

In this mode, d_1 and d_2 regulates powers of the Input sources, while d_3 is utilized to regulate output voltage through battery charging by the extra-generated power.

V. DETERMNATION OF OPERATION MODE

The proper operation mode should be determined based on availability of P_{PV}^{max} , P_{wind}^{max} , the output voltage value, and the battery charging necessity. In order to keep the battery voltage in allowable minimum and maximum voltages given by,

$$v_{Batt.Min} < v_{Batt} < v_{Batt.Max} \quad (15)$$

If the battery voltage is lesser than $v_{Batt.Min}$, then the state of battery charging is required. The amount of the battery charging power depends on the capacity of the battery C_B, which is usually chosen to be less than $0.2C_BV_B$. On the other hand, battery discharging states, occurs when battery voltage is higher than $v_{Batt.Min}$. The proper operation mode can be determined as follows:

A. First Operation Mode

Basic operation mode which takes place in the conditions that the summation of the PV and Wind powers can completely supply the load, without battery existence. Here d_1 is used to regulate PV source and d_2 is utilized to regulate output voltage.

B. Second Operation Mode

This mode takes place in the conditions that the output voltage cannot be regulated because summation of Wind and PV cannot completely supply the load and $v_{Batt.Min} < v_{Batt}$ the battery discharging is accomplished.

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Here, d_1 and d_2 regulates powers of the input sources, while d_4 is utilized to regulate output voltage through battery discharging.

C. *Third Operation Mode*

This mode takes place in the conditions that summation of the Wind and PV powers can regulate the output voltage as like as first operation mode, while the battery is needed to be charged. In this mode d_1 and d_2 regulates power of the input sources, while d_3 is utilized to regulate output voltage through battery charging by the extra – generated power.

VI. SIMULATION RESULTS

In order to verify the performance of the proposed converter, simulations have been done in all three operation modes by MATLAB / SIMULINK software. The simulation parameters are $r_1 = r_2 = 0.1\,\Omega$, $L_1 = L_2 = 4mH$, C = 200MF, f_s = 20KHZ and P_{ll} with a peak power of 3.5 KW and average power of 2.3KW is supplied at the dc link. The dc link voltage of the converter is designed to be regulated on V_o = 325V and I/P power sources with $P_{PV}^{max} = 2.5\ KW$ and $P_{wind}^{max} = 2.5\ KW$, $P_{bat.dis}^{max} = \pm 1\ KW$. In this paper, P & O algorithm has been used to track P_{PV}^{max}. The powers of input sources ,Corresponding source currents and load characteristics for the second mode are given below in the simulation diagrams.

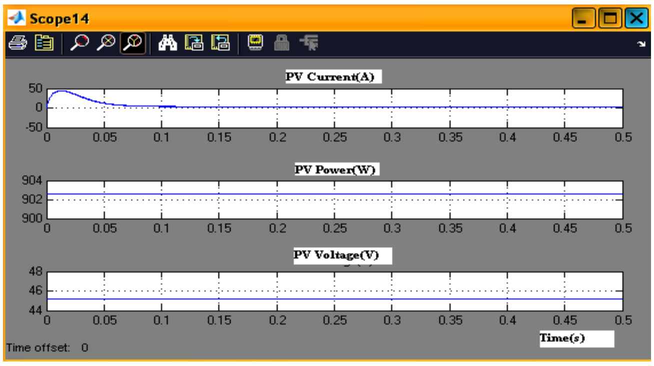

Fig.6 Power, Current and Voltage of Input Source1

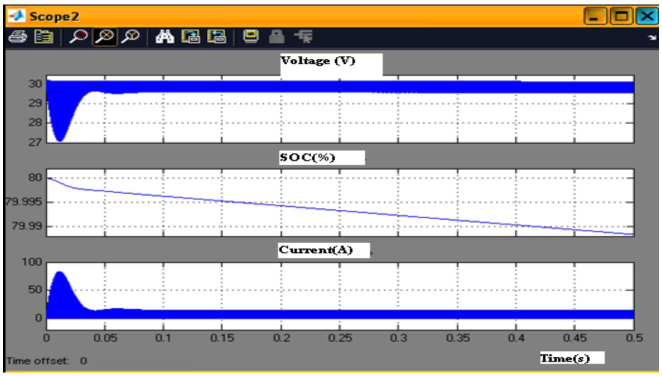

Fig.7 Battery discharging mode

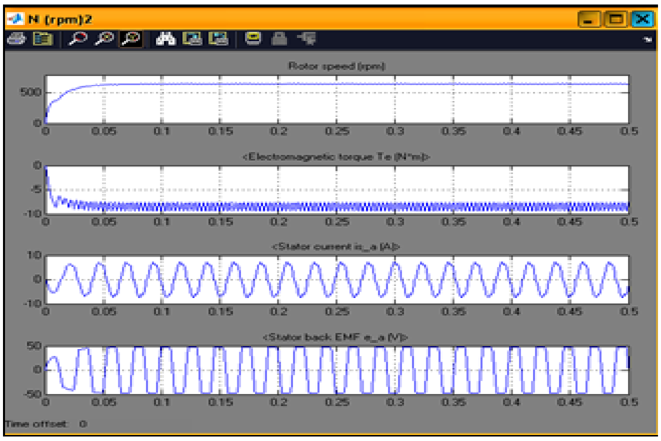

Fig.8 Wind Speed Torque Characteristics

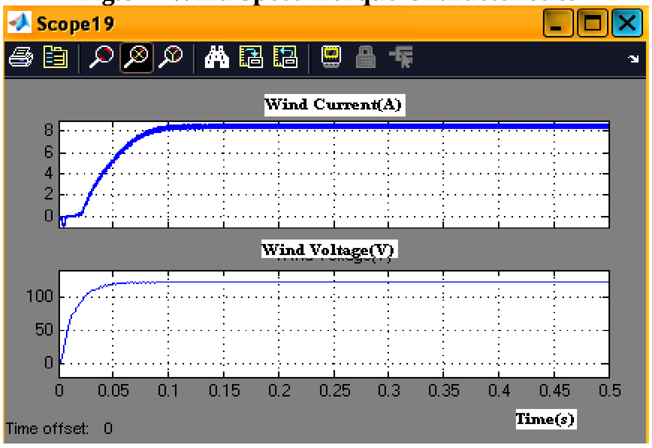

Fig.9 Wind Current & Voltage

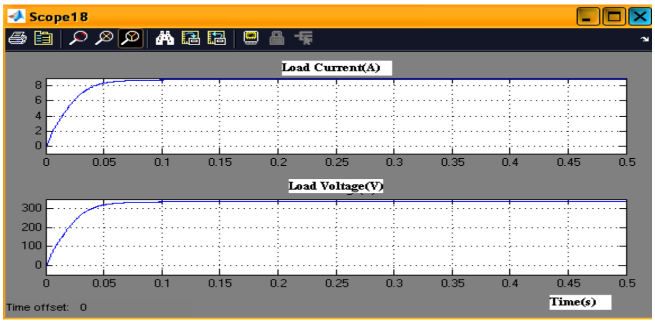

Fig.10 Load Voltage & Current

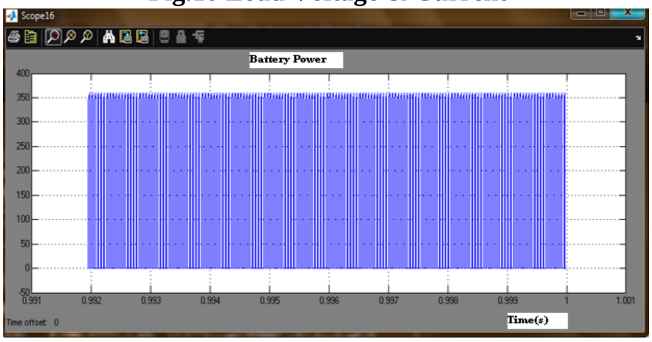

Fig.11 Battery Power

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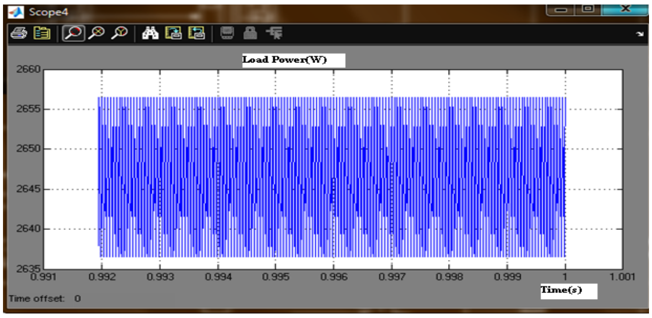

Fig.12 Load Power

VII. CONCLUSION AND FUTURESCOPE

This paper describes renewable energy hybrid Wind-PV with battery energy storage system. A complete description of the hybrid system has been presented along with its detailed simulation results which ascertain its feasibility. The simulation results showed satisfactory performance of the hybrid system. The proposed system is a good alternative for the multiple- source hybrid power systems and has may advantages such as bidirectional power flow at the storage port ,simple structure, low power components, centralized control, no need of transformer, low weight and high level of boosting. On addition, the structure utilizes from power switches with four different duty ratios. It is also applicable for hybrid power system. The future work will be to design the proposed hybrid system and implement in hardware. Also, the system has to be extended to higher ratings and solve for the synchronization issues.

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