ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 3, Issue 3, March 2017

Transformer Coupled Bidirectional DC-DC Converter for Grid-Connected PV-Wind-Battery

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Abstract: **— The control strategy for power flow management of a grid-connected hybrid PV-wind-battery based system with an efficient multi-input transformer coupled bidirectional dc-dc converter is presented. The proposed system aims to satisfy the load demand, manage the power flow from different sources, inject surplus power into the grid and charge the battery from grid as and when required. A transformer coupled boost half-bridge converter is used to harness power from wind, while bidirectional buck-boost converter is used to harness power from PV along with battery charging/discharging control. A single-phase full-bridge bidirectional converter is used for feeding ac loads and interaction with grid. The proposed converter architecture has reduced number of power conversion stages with less component count, and reduced losses compared to existing grid-connected hybrid systems. This improves the efficiency and reliability of the system. Simulation results are obtained using MATLAB/Simulink show the performance of the proposed control strategy for power flow management under various modes of operation.**

***Index Terms:*— Hybrid system, solar photovoltaic, wind energy, transformer coupled boost dual-half-bridge bidirectional converter, bidirectional buck-boost converter, maximum power point tracking, full bridge bidirectional converter, battery charge control.**

I. INTRODUCTION

These converters are not effectively utilized, due to the intermittent nature of the renewable sources. In addition, there are multiple power conversion stages which reduce the efficiency of the system. Dynamic performance of a stand-alone hybrid PV-wind system with battery storage is analyzed.

In integrated converters for PV and wind energy systems are presented. PV-wind hybrid system, proposed has a simple power topology but it is suitable for stand-alone applications. Hybrid PV-wind based generation of electricity and its interface with the power grid are the important research areas. The proposed a multi-input hybrid PV-wind power generation system which has a buck-boost fused multi-input dc-dc converter and a full-bridge dc-ac inverter. This system is mainly focused on improving the dc-link voltage regulation. In the six-arm converter topology Proposed. The outputs of a PV array and wind generators are fed to a boost converter to match the dc-bus voltage. The steady-state performance of a grid connected hybrid PV and wind system with battery storage is analyzed. In a hybrid PV-wind system along with a battery is presented, in which both sources are connected to a common dc-bus through individual power converters.

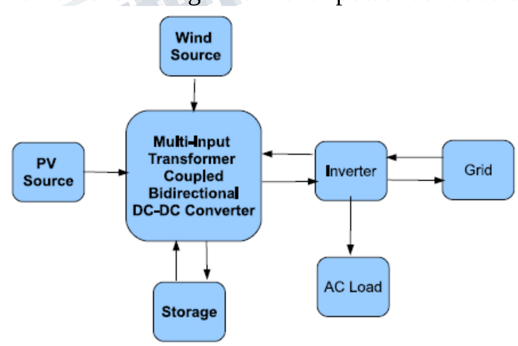

Fig.1. Grid-connected hybrid PV-wind-battery

In the above fig.1, this can work either in stand-alone or grid connected mode. This system is suitable for household applications, where a low-cost, simple and compact topology capable of autonomous operation is desirable. A control scheme for effective power flow management to provide uninterrupted power supply to the loads, while injecting excess power into the grid is proposed. Thus, the proposed configuration and control scheme provide an elegant integration of PV and wind energy source.

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II. PROPOSED CONVERTER CONFIGURATION

The proposed converter consists of a transformer coupled boost dual-half-bridge bidirectional converter fused with bidirectional buck-boost converter and a single-phase full-bridge inverter. The topology is simple and needs only six power switches. The schematic diagram of the converter in Fig. 2.The boost dual-half-bridge converter has two dc-links on both sides of the high frequency transformer. Moreover, additional converters can be integrated with any one of the two dc-links. A bidirectional buck-boost dc-dc converter is integrated with the primary side dc-link and single-phase full bridge bidirectional converter is connected to the dc-link of the secondary side.

The power flow from wind source is controlled through a unidirectional boost half-bridge converter. For obtaining MPP effectively, smooth variation in source current is required which can be obtained using an inductor. In the proposed topology, an inductor is placed in series with the wind source which ensures continuous current and thus this inductor current can be used for maintaining MPP current. When switch T3 is ON, the current flowing through the source inductor increases. The capacitor C1 discharges through the transformer primary and switch T3. In secondary side capacitor C3 charges through transformer secondary and anti-parallel diode of switch T5. When switch T3 is turned OFF and T4 is turned ON, initially the inductor current flows through anti parallel diode of switch T4 and through the capacitor bank. During this interval, the current flowing through diode decreases and that is flowing through transformer primary increases. When current flowing through the inductor becomes equal to that flowing through transformer primary, the diode turns OFF. Since, T4 is gated ON during this time, the capacitor C2 now discharges through switch T4 and transformer primary. During the ON time of T4, anti-parallel diode of switch T6 conducts to charge the capacitor C4. During the ON time of T3, the primary voltage VP = −VC1. The secondary voltage VS = nVp = −nVC1 = −VC3, or VC3 = nVC1 and voltage across primary inductor Lw is Vw. When T3 is turned OFF and T4 turned ON, the primary voltage VP = VC2. Secondary voltage VS = $nV_P = nV_{C2}$ = VC4 and voltage across primary inductor L_w is $V_w - (V_{C1} + V_{C2})$.It can be proved that $(V_{C1} + V_{C2}) = \frac{V\omega}{1-D\omega}$. The capacitor voltages are considered constant in steady state and they settle at VC3 = nVC1, VC4 = nVC2. Hence the output voltage is given by

$$VDC = VC3 + VC4 = n\frac{V\omega}{1-D\omega} \qquad (1)$$

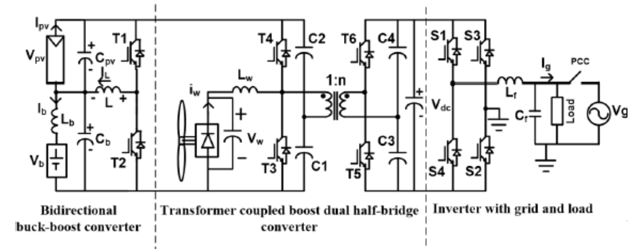

Fig.(2). Proposed converter configuration

In the above fig.2, a bidirectional buck-boost converter is used for MPP tracking of PV array and battery charging/discharging control. Further, this bidirectional buck-boost converter charges/discharges the capacitor bank C1-C2 of transformer coupled half-bridge boost converter based on the load demand. The half-bridge boost converter extracts energy from the wind source to the capacitor bank C1-C2. During battery charging mode, when switch T1 is ON, the energy is stored in the inductor L. When switch T1 is turned OFF and T2 is turned ON, energy stored in L is transferred to the battery. If the battery discharging current is more than the PV current, inductor current becomes negative. Here, the stored energy in the inductor increases when T2 is turned on and decreases when T1 is turned on. It can be proved that $Vb = \frac{D}{1-D}Vpv$. The output voltage of the transformer coupled boost half-bridge converter is given by,

$$Vdc = n(Vc1 + Vc2) = n(Vb + Vpv) = nVw(1 - Dw) \qquad (2)$$

This voltage is n times of primary side dc-link voltage. The primary side dc-link voltage can be controlled by half-bridge boost converter or by bidirectional buck-boost converter. The relationship between the average value of inductor, PV and battery current over a switching cycle is given by $I = Ib + Ipv$. Therefore, the MPP operation is assured by controlling I_L, while maintaining proper battery charge level. IL is used as inner loop control parameter for faster dynamic response while for outer loop, capacitor voltage across PV source is used for ensuring MPP voltage. An incremental conductance method is used for MPPT.

III. PROPOSED CONTROL SCHEME FOR POWER FLOW MANAGEMENT

A grid-connected hybrid PV-wind-battery based system consisting of four power sources (grid, PV, wind source and battery) and three power sinks (grid, battery and load), requires a control scheme for

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ISSN (Online) 2395-2717
International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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power flow management to balance the power flow among these sources. In this case, the power balance is achieved by charging the battery until it reaches its maximum charging current limit I_{bmax}. In the grid-connected system both the sources always operate at their MPP. In the absence of both the sources, the power is drawn from the grid to charge the battery as and when required. The equation for the power balance of the system is given by:

$$Vpv\, Ipv + VwIw = VbIb + VgIg \quad (3)$$

The peak value of the output voltage for a single-phase full-bridge inverter is,

$$v = ma\, Vdc \quad (4)$$

and the dc-link voltage is,

$$Vdc = n(Vpv + Vb) \quad (5)$$

Hence, by substituting for V_{dc} in (4), gives,

$$Vg = \frac{1}{\sqrt{2}} ma\, n(Vpv + Vb) \quad (6)$$

In the boost half-bridge converter,

$$V = (1 - D\omega)(Vpv + Vb) \quad (7)$$

Now substituting Vw and Vg in (3),

$$VpvIpv + (Vpv + Vb)(1 - D\omega)I\omega = VbIb + \frac{1}{\sqrt{2}} ma\, n(Vpv + Vb)Ig \quad (8)$$

After simplification,

$$Ib = Ipv\frac{1 - Dpv}{Dpv} + I\omega\frac{1 - D\omega}{D\omega} - Ig\frac{ma\, n}{\sqrt{2}Dpv} \quad (9)$$

IV. RESULTS VERIFICATION BY SIMULINK

Detailed simulation studies are carried out on MATLAB/Simulink platform and the results obtained for various operating conditions are presented in this section. Values of parameters used in the model for simulation are listed in Table I.

TABLE I Simulation Parameter

Parameter	Value
Solar PV power	525W (I_{mpp}=14.8A) (V_{mpp}=35.4V)
Wind power	300W (I_{mpp}=8A) (V_{mpp}=37.5V)
Switching frequency	15kHZ
Transformer turns ratio	5.5
Inductor-half bridge boost converter, $L\omega$	500μH
Inductor-bidirectional converter L	3000 μH
Primary side capacitors C1-C2	500 μF
Secondary side capacitors C3-C4	500 μF
Secondary side capacitor entire dc-link	2000 μF
Battery capacity & voltage	400Ah, 36V

The steady state response of the system during the MPPT mode of operation is shown in Fig. 4. The values for source-1 (PV source) is set at 35.4 V (V_{mpp}) and 14.8 A (I_{mpp}), and for source-2 (wind source) is set at 37.5 V (V_{mpp}) and 8 A (I_{mppp}). It can be seen that V_{pv} and Ipv of source-1, and V_w and I_w of source-2 attain set values required for MPP operation. The battery is charged with the constant magnitude of current and remaining power is fed to the grid.

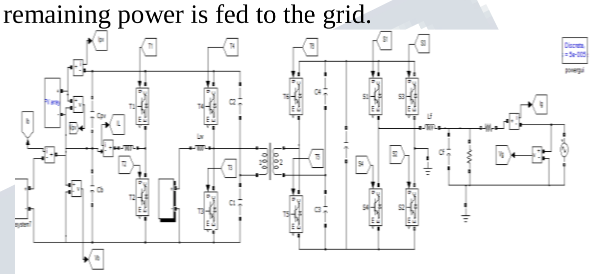
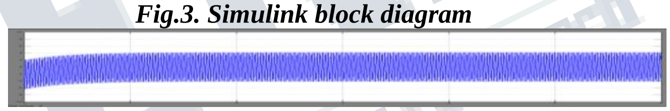
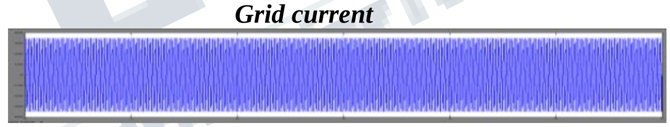


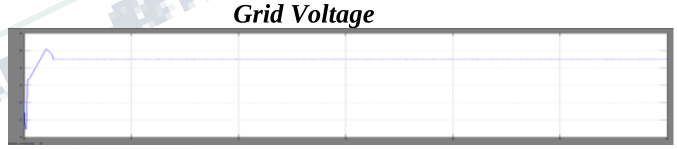
Fig.3. Simulink block diagram



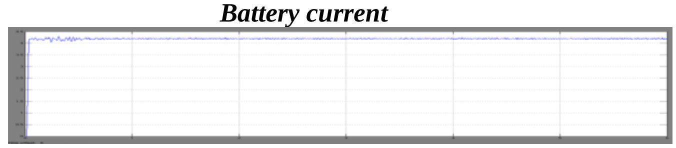
Grid current



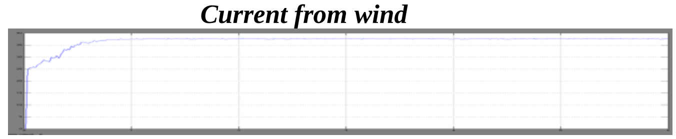
Grid Voltage



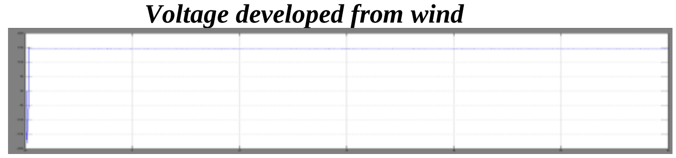
Battery current



Current from wind



Voltage developed from wind



Current generated from PV

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International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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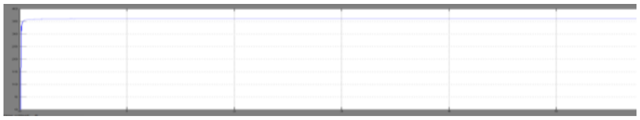
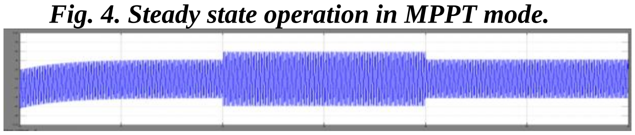
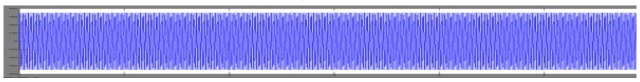
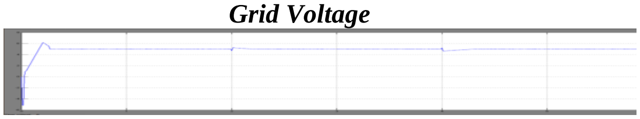
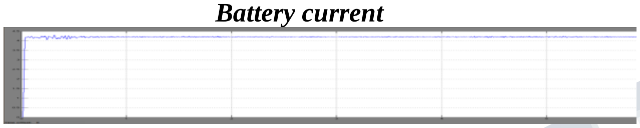

Voltage generated from PV

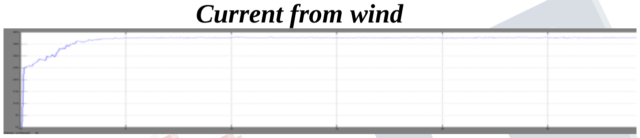
Fig. 4. Steady state operation in MPPT mode.


Grid current


Grid Voltage


Battery current

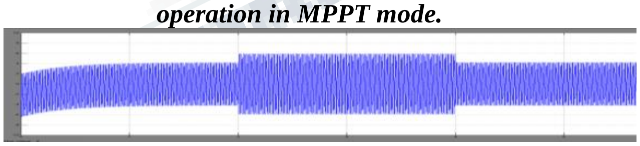

Current from wind

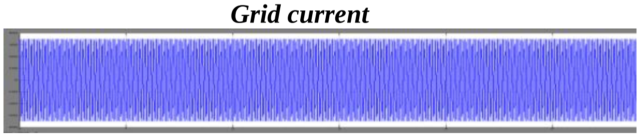

Voltage developed from wind

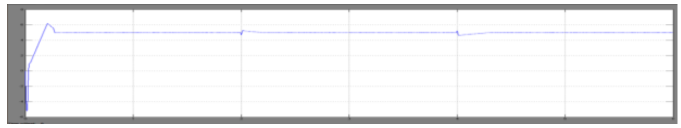

Current generated from PV

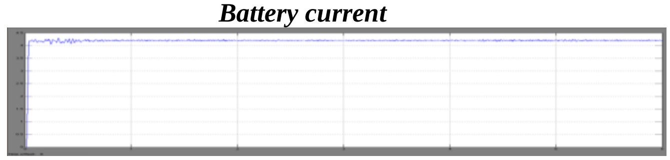

Voltage generated from PV

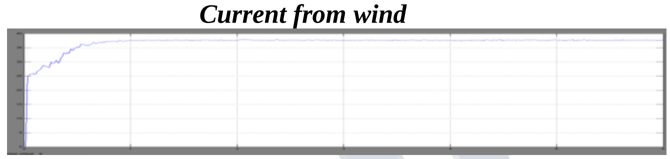
Fig.5. Response of the system for changes in insolation level of source-1(PV source) during operation in MPPT mode.


Grid current


Grid Voltage


Battery current

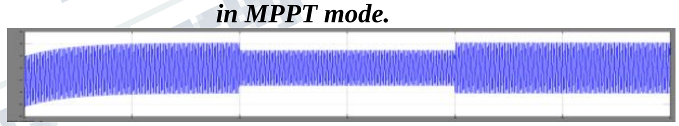

Current from wind

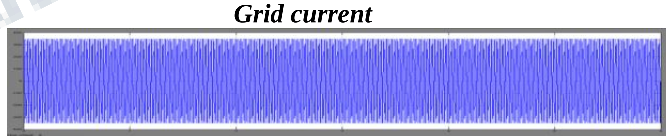

Voltage developed from wind

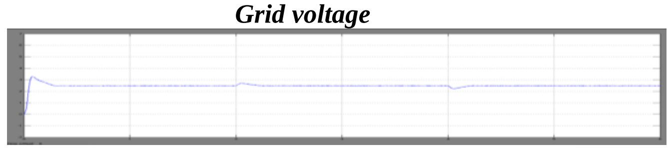

Current generated from PV

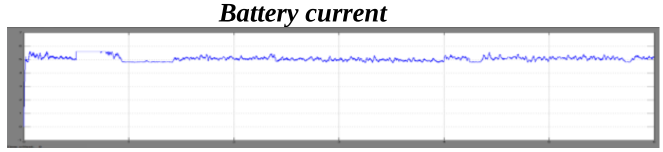

Voltage generated from PV

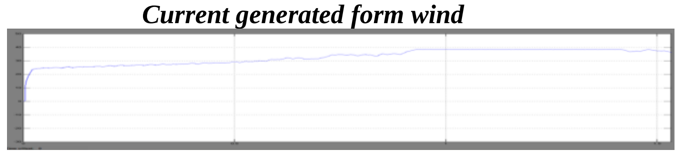
Fig.6. Response of the system for changes in wind speed level of source-2 (wind source) during operation in MPPT mode.


Grid current


Grid voltage


Battery current

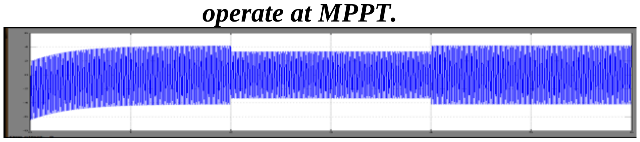

Current generated form wind


Voltage generated form wind

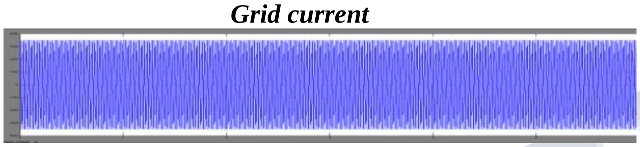
PV current

PV voltage

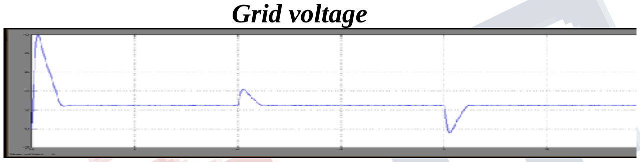
Fig.7. Response of the system in the absence of source-1 (PV source) while source-2 continues to operate at MPPT.



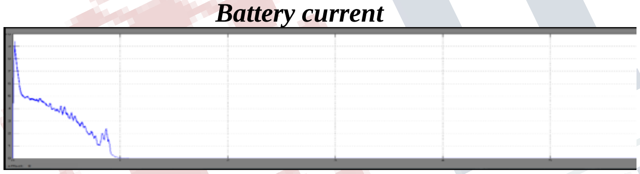
Grid current



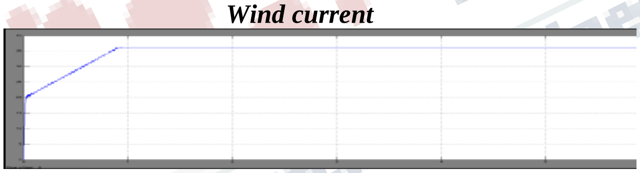
Grid voltage



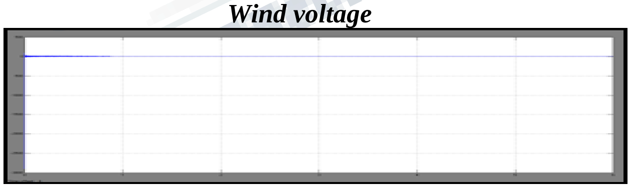
Battery current



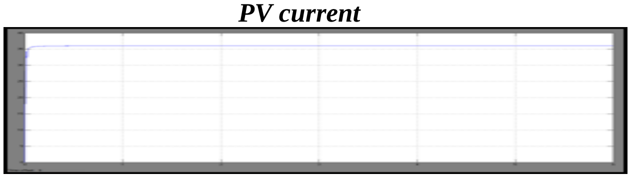
Wind current



Wind voltage

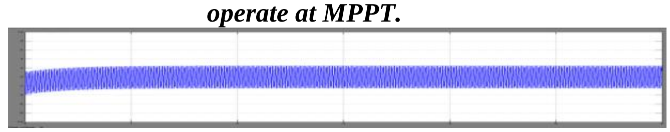


PV current

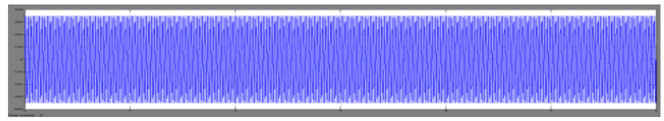


PV voltage

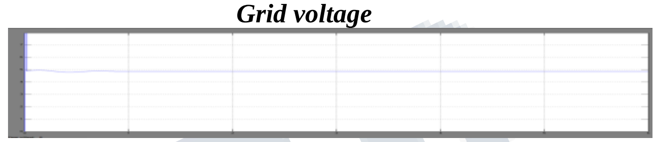
Fig.8. Response of the system in the absence of source-2 (wind source) while source-1 continues to operate at MPPT.



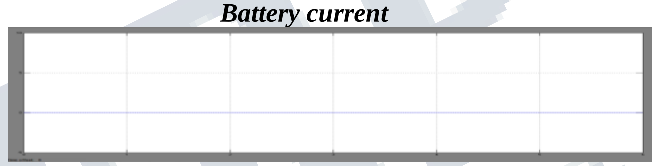
Grid current



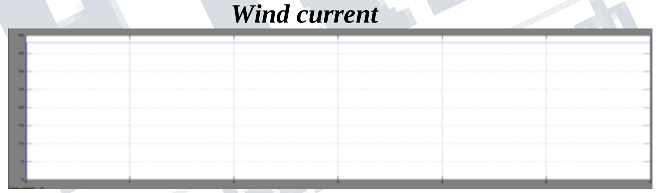
Grid voltage



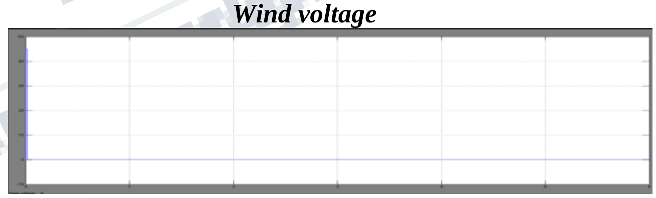
Battery current



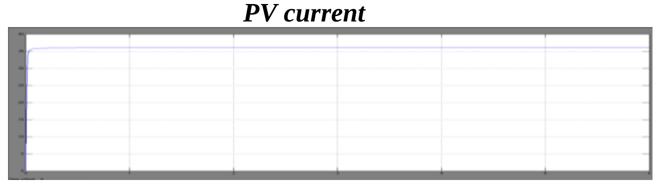
Wind current



Wind voltage



PV current



PV voltage

Fig.9. Response of the system in the absence of both the sources and charging the battery from grid.

V. CONCLUSION

A novel multi-input transformer coupled bidirectional dc-dc converter followed by a conventional full-bridge inverter. A versatile control strategy which achieves better utilization of PV, wind power, battery capacities without effecting life of battery and power flow management in a grid-connected hybrid PV-wind-battery based system feeding ac loads is presented. Detailed simulation studies are carried out to ascertain the viability of the scheme. the capability of the system to operate either in grid feeding or stand-alone mode. The proposed configuration is capable of supplying un-interruptible power to ac loads, and ensures evacuation of surplus PV and wind power into the grid.

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