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Integration of Hybrid Energy Grid Connected Bidirectional Converter for Three Phase Domestic Applications

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ABSTRACT: The efficient use of hybrid energy for three phase domestic applications is presented in this paper. The proposed hybrid system manages the power flow from solar-wind-battery sources and the battery is charged when required from the grid. The proposed converter consists of a half bridge converter to harness the power from solar and battery through bidirectional buck-boost converter and power from wind through the diode rectifier. The high-frequency transformer and voltage multiplier step up the voltage to feed three-phase loads by means of a three-phase inverter. Simulation results for various operating modes are obtained using MATLAB. The improved voltage performance of the various operating modes is validated and results are obtained.

KEYWORDS: Solar photovoltaic, wind source, battery storage, voltage multiplier, three-phase inverter.

I.INTRODUCTION

The demand for energy increases rapidly due to the depletion of fossil fuel reserves. This results in the use of renewable energy resources such as solar photovoltaic and wind sources due to their eco-friendly nature and cost effectiveness. The common inherent drawback of Solar photovoltaic and wind systems are their intermittent nature. To supply stable and continuous power, the battery is used as a backup. This integration of energy resources with the above-mentioned advantage results in hybrid wind-PV systems. By incorporating maximum power point tracking algorithms, the efficiency and reliability can be improved.

A bidirectional multiple input non-isolated dc-dc converter is presented to interface a ultracapacitor and a battery for vehicular applications. The converter is capable of drawing power from multiple energy sources to supply the demand of vehicle loads [1]. At each input port, some components can be shared. However, the flexibility of energy delivery is limited. The parallel or series configuration can be extended at the output to derive multi-port dc-dc converters [2]. The circuit structure is simplified and the power density is improved because the power devices are completely shared in the primary side. The two filter inductors in the bi-directional buck-boost converters and the isolated transformer in the full-bridge topology are integrated and replaced by the coupled inductors. Further, the pulse width modulation (PWM) plus - phase-shift (PPS) control strategy is introduced to achieve voltage regulation within a certain operating range [3].

In [4], the converter is interesting for hybridizing renewable energy sources such as photovoltaic (PV) source, fuel cell (FC) source, and battery. To feed dc loads, a low capacity multi-port converter for a hybrid system is presented. In [5], some power ports share a common ground and these power ports are isolated from the remaining, for matching port voltage levels. By employing pulse width modulation and phase-angle-shift control scheme, Voltage regulations between any two ports can be achieved. B. Mangu [6], proposed a system that aims to satisfy the load demand, manage the power flow from different sources, inject the surplus power into the grid, and charge the battery from the grid as and when required. The proposed converter architecture has reduced number of power conversion stages with less component count and reduced losses compared with existing grid-connected hybrid systems. This improves the efficiency and the reliability of the system. All the state of art on converter topologies presented so far can supply only single phase loads. Whereas in the proposed topology, voltage boosting capability is accomplished by a voltage multiplier. Hence, it can be used for three phase domestic applications. The proposed system has PV source, wind

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source, load, grid, and battery. Hence, a power flow management system is needed to balance the power flow among all these sources.

The main objectives of this system are as follows:

- To generate "clean" and efficient energy using hybrid renewable energy source, in order to decrease both environmental pollution and the energy dependence.
- To Supply un-interruptible power to loads.
- To reduce the number of power conversion stages and to ensure evacuation of surplus power from the two renewable sources to the grid, and charging the battery from the grid as and when required.

II.BLOCK DIAGRAM

The hybrid grid-connected PV-wind-battery based system for household applications is shown in Fig. 1, which can work either in autonomous or grid-connected mode. This system is suitable for domestic three phase applications, where a Low-cost, simple and compact topology capable of autonomous operation is desirable. The core of the proposed system is the voltage multiplier that boosts up the voltage and makes it suitable for three phase applications.

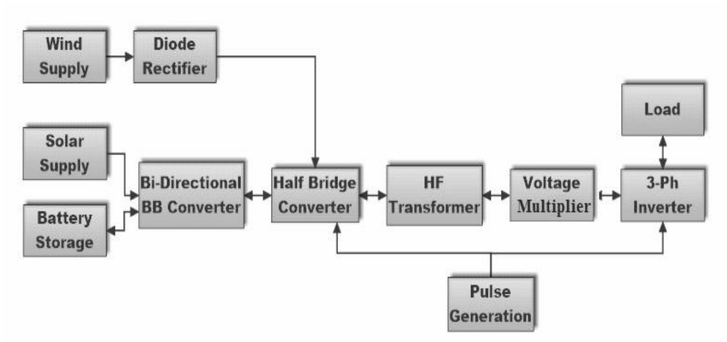

Fig. 1 Grid connected hybrid system with voltage multiplier for three phase applications.

Thus, the proposed configuration and control scheme provide an elegant integration of PV and wind energy source. It has the following advantages:

- Voltage boosting capability is accomplished by a high-frequency step-up transformer and is further enhanced by voltage multiplier.
- The number of turns is reduced in the high-frequency step-up transformer and hence core losses are reduced.
- Different modes of a grid-connected scheme ensure proper operating mode selection and smooth transition between different possible operating modes.

III.PROPOSED CONVERTER CONFIGURATION

The proposed converter consists of a transformer coupled boost half-bridge bidirectional converter and voltage multiplier fused with bidirectional buck-boost converter and a three-phase full bridge inverter. The proposed converter has reduced the number of power conversion stages with less component count and high efficiency compared to the existing grid-connected schemes. The boost half-bridge converter and voltage multiplier have two dc-links on both sides of the high-frequency transformer. Controlling the voltage of one of the dc-links ensures controlling the voltage of the other. 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 three-phase full bridge bidirectional converter is connected to the dc-link of the secondary side. The input of the half-bridge converter is connected to the PV array in series with the battery source, thereby incorporating an inherent boosting stage. The boosting capability is further enhanced by a high-frequency step-up transformer. The transformer ensures galvanic isolation to the load from the sources and the battery. The bidirectional buck-boost converter is used to harness power from PV along with battery charging/discharging control. The uniqueness of this converter is that Multi-point power tracking, battery charge

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control and voltage boosting are accomplished through a single converter.

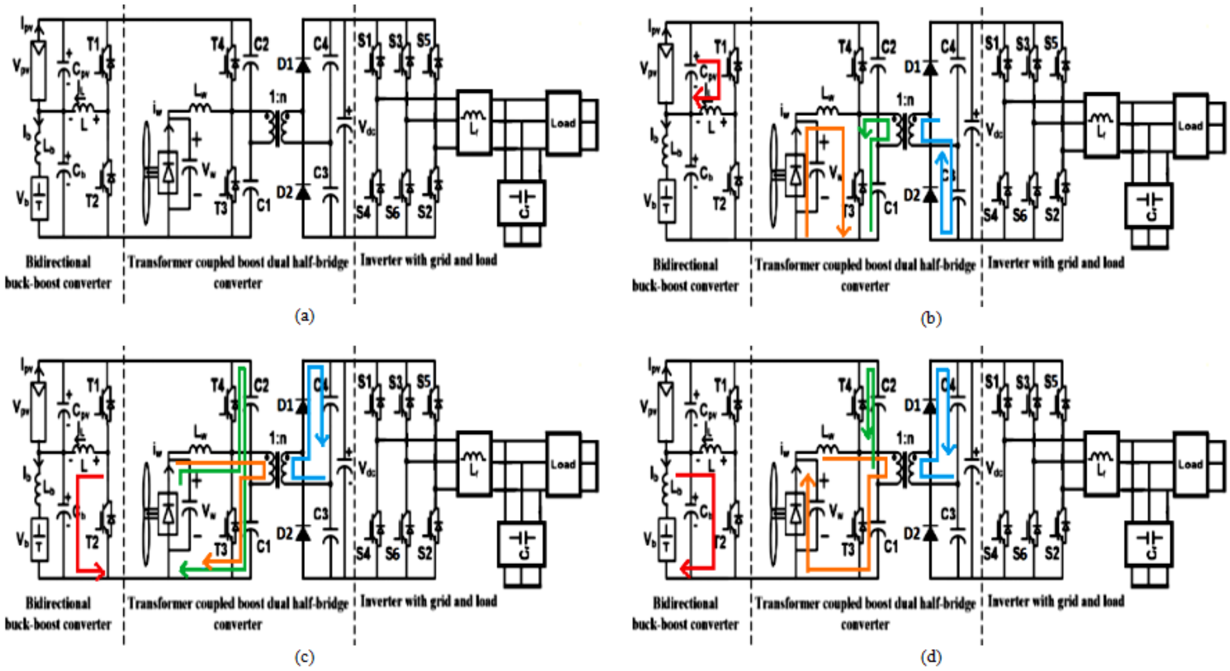

Fig. 2 operating modes of proposed hybrid grid connected transformer coupled bidirectional dc-dc converter for three phase domestic applications. (a) Proposed converter configuration. (b) Operation when switch T3 switch is turned ON. (c) Operation when T4 switch ON, charging the capacitor bank. (d) Operation when switch T4 ON, capacitor C2 discharging.

Transformer coupled boost half-bridge converter is used for harnessing power from the wind, voltage multiplier is used for boosting the voltage and a three-phase full bridge bidirectional converter is used for feeding AC loads and interaction with the grid. In order to ensure continuous current, an inductor is placed in series with the wind source and thus this inductor current can be used for maintaining MPP current. When switch T3 is ON, the source inductor current increases. The capacitor C1 discharges through the transformer primary and switch T3 as shown in Fig. 2(b). In secondary side capacitor, C3 charges through transformer secondary and anti-parallel diode D5. When switch T4 is turned ON and T3 is turned OFF, initially the inductor current flows through antiparallel diode of switch T4 and through the capacitor bank. The path of current is shown in Fig. 2(c). During this interval, the diode current decreases and the current flowing through transformer primary increases. When the current flowing through the inductor becomes equal to the current flowing through transformer primary, the diode turns OFF. Since T4 is gated ON during this time, the capacitor C2 now discharges through T4 and primary of the transformer. During the ON time of T4, anti-parallel diode D6 conducts to charge the capacitor C4. The path of current is shown in Fig. 2(d). During the ON time of T3, the primary voltage Vp = −VC1. The secondary voltage Vs = −nVC1 = nVp = −VC3, or VC3 = nVC1 and voltage across primary inductor Lw is Vw. When T4 is turned ON and T3 turned OFF, the primary voltage Vp = VC2. Secondary voltage Vs = nVC2 = nVP = VC4 and voltage across primary inductor Lw is Vw −(VC1 +VC2). It can be proved that (VC2 + VC1) = Vw / (1−Dw). The capacitor voltages are constant in steady state and they settle at VC4 = nVC2, VC3 = nVC1. Hence the dc link voltage is given by Vdc = Vc3 + Vc4 = nVw / (1-Dw).

Therefore, the output voltage of the secondary side dc-link is a function of the duty cycle of the primary side converter and turns ratio of transformer. In the proposed configuration as shown in Fig. 2(a), a bidirectional buck-boost converter is used for MPP tracking of the photovoltaic array and battery charging/discharging control. Further, this bi-directional converter charges/discharges the capacitor bank C1-C2 of transformer coupled boost converter based on the load demand.

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The half-bridge boost converter extracts the energy from the wind source to the capacitor bank C1-C2. During battery charging mode, the energy is stored in the inductor L, when switch T1 is ON. When switch T1 is turned OFF and T2 is turned ON, the 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 = DVpv/(1−D). 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 the bidirectional buck-boost converter. The relationship between the average value of the inductor, PV, and battery current over a switching cycle is given by IL = Ib + Ipv. It is evident that, Ib and Ipv can be controlled by controlling IL. Therefore, the MPP operation is assured by controlling IL, 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.

IV.SIMULATION RESULTS AND DISCUSSION

Simulation results are obtained for various operating conditions using MATLAB platform. Simulation parameters used in the model are listed in Table I. The simulation circuit diagram of proposed hybrid grid connected transformer coupled bidirectional dc-dc converter for three phase domestic applications is shown in Fig. 3.

Mode 1 - Steady State Operation In MPPT Mode: The steady-state response of the system during the MPPT mode of operation is shown in Fig. 4. The values for PV source is set at 35.4 V and 14.8 A, and for the wind, the source is set at 37.5 V and 8 A. It can be seen that Vw and Iw of Wind source and Vpv and Ipv of PV source attain set values required for MPP operation. During this operation battery is charged with the constant magnitude of current and remaining power is fed to the grid.

Table 1. Simulation parameters

Parameter	Value
Solar PV power	525 W ($I_{m\text{-}pp}$ = 14.8 A) ($V_{m\text{-}pp}$ = 35.4 V)
Wind power	300 W ($I_{m\text{-}pp}$ = 8 A) ($V_{m\text{-}pp}$ = 37.5 V)
Switching frequency	15 kHz
Transformer turns ratio	1:6
Inductor-half bridge boost converter, Lw	500 µH
Inductor-bidirectional converter, L	3000 µH
Primary side capacitors, C1-C2	560µF
secondary side capacitor, C3-C4	560µF
Secondary side capacitor for the entire dc-link	2000 µF
Battery capacity & voltage	400 Ah, 36 V

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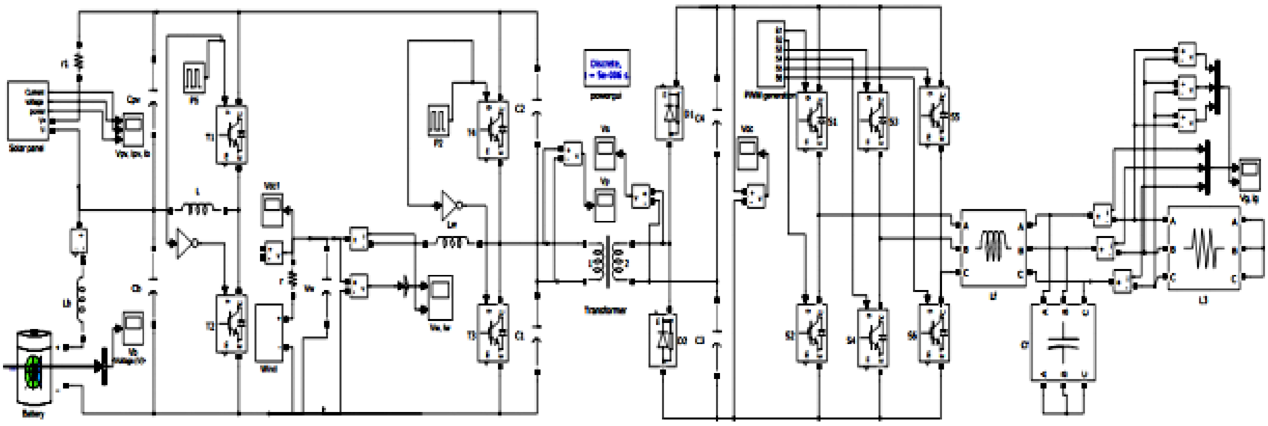
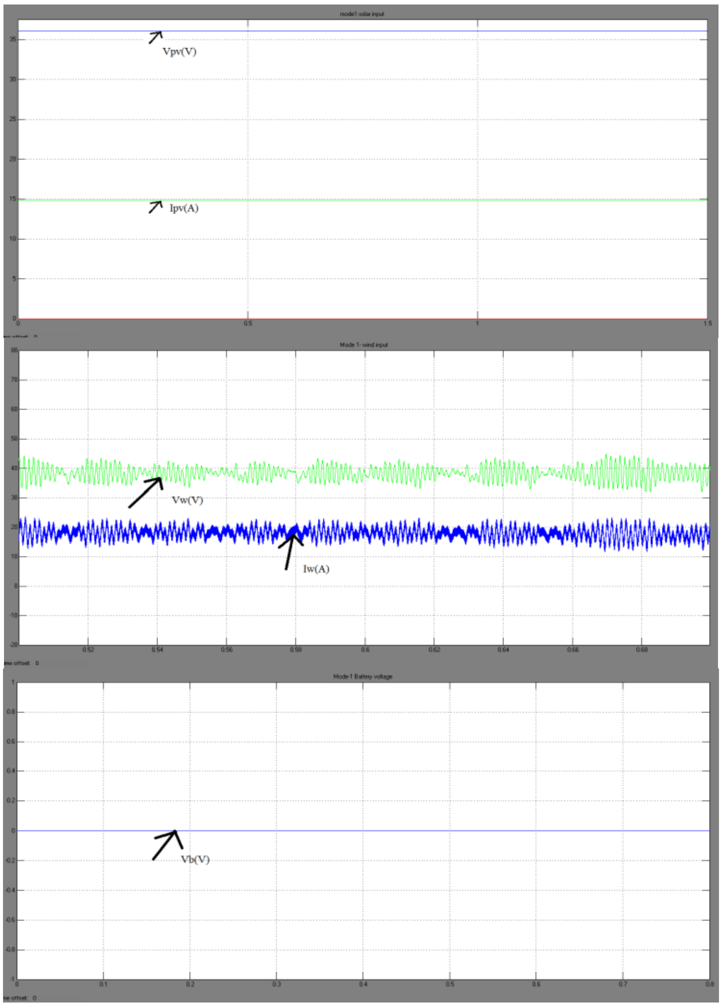


Fig .3 Simulation circuit diagram of proposed hybrid grid connected transformer coupled bidirectional dc-dc converter for three phase domestic applications.



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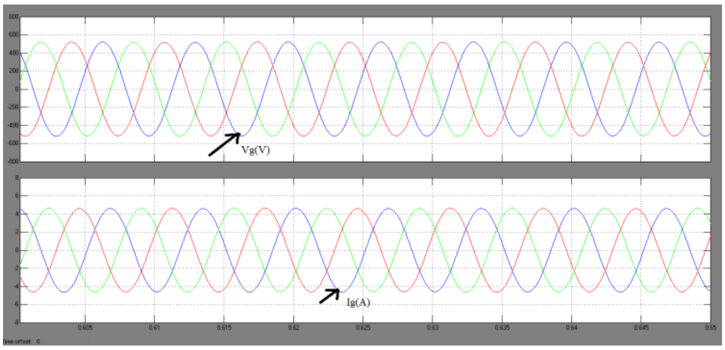
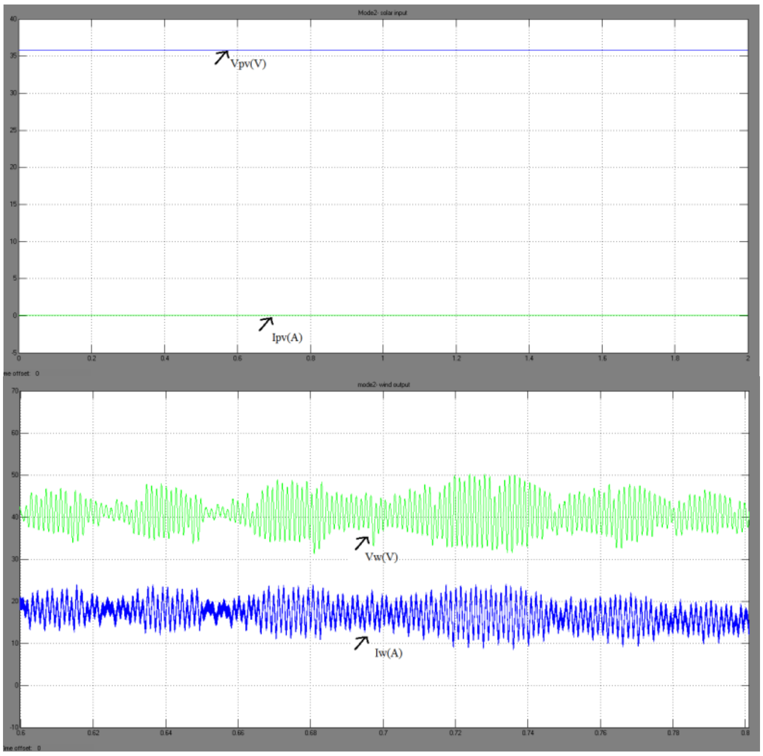


Fig.4. Steady state operation in MPPT mode.

Mode 2 - Response In The Absence Of PV Source: The response of the system in the absence of PV source is shown in Fig. 5. Till time 2 s, both the sources are generating the power by operating at their corresponding MPPT and charging the battery at the constant magnitude of the current, and the remaining power is being fed to the grid. At 2 s, PV source is disconnected from the system. The charging current of the battery remains constant, while the injected power to the grid reduces. At instant 4 s, PV source is brought back into the system. There is no change in the charging rate of the battery. The additional power is fed to the grid.



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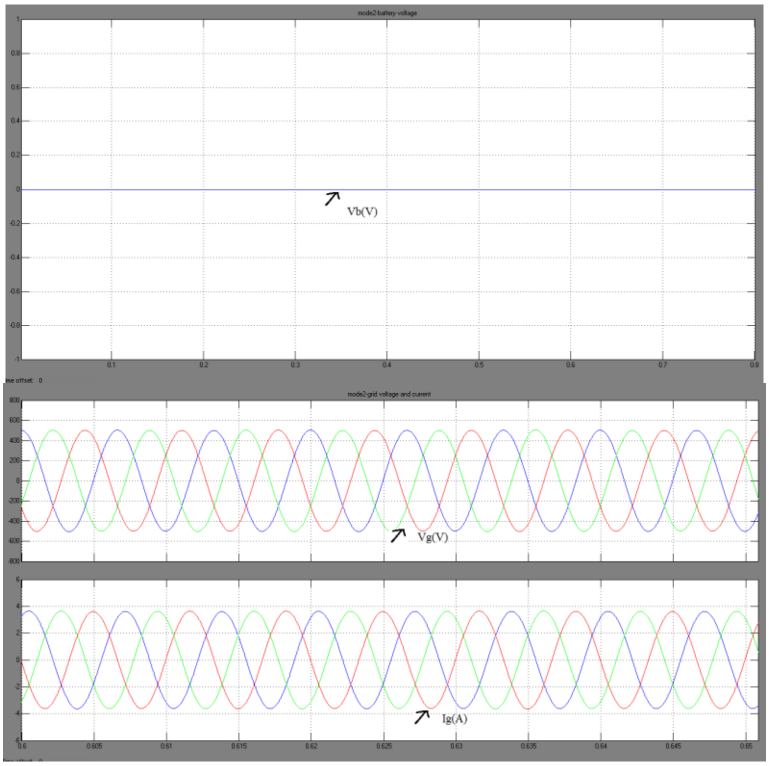
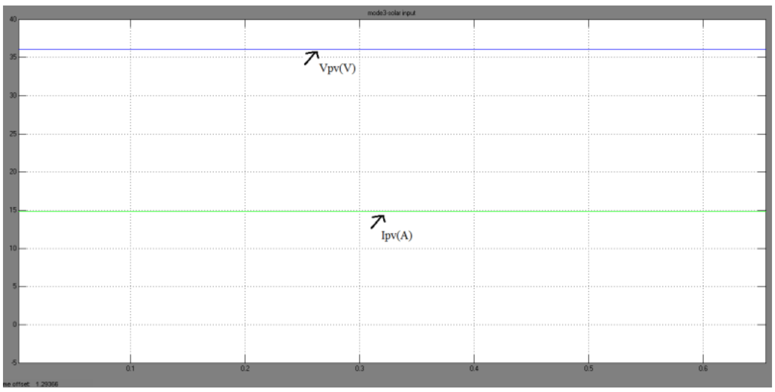


Fig.5. Response of the system in the absence of PV source while wind source continues to operate at MPPT

Mode 3 - Response In The Absence Of Wind Source: The response of the system in the absence of wind source is shown in Fig. 6. Till time 2 s, both the sources are generating and the wind source is disconnected from the system. The charging current of the battery remains constant, while the injected power to the grid reduces. At instant 4 s, wind source is brought back into the system. There is no change in the charging rate of the battery. The additional power is fed to the grid.



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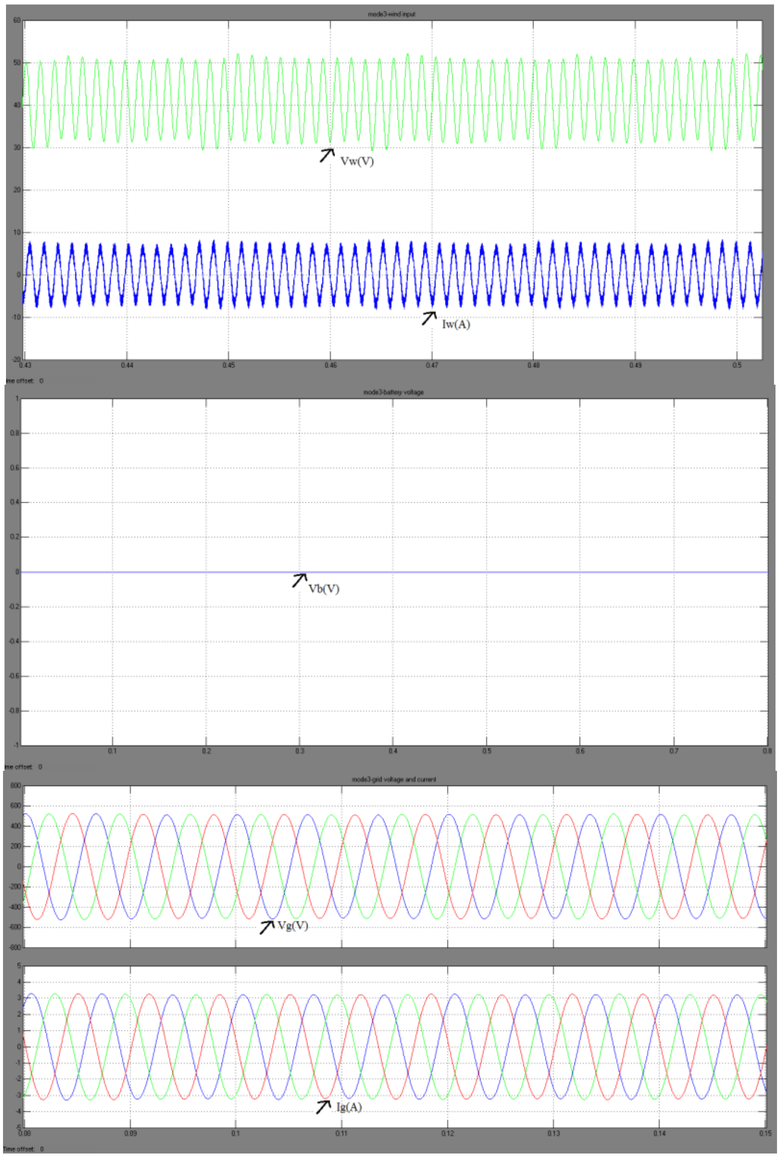

Fig.6. Response of the system in the absence of wind source while PV source continues to operate at MPPT.

VI.CONCLUSION

The efficient use of hybrid energy for three phase domestic applications, which can work either in autonomous or grid-connected mode is proposed. The proposed hybrid system manages the power flow from wind-solar-battery sources and the battery is charged when required from the grid. The proposed converter consists of a half bridge converter to harness the power from solar and battery through bidirectional buck-boost converter and power from wind through the diode rectifier. The core of the proposed system is the voltage multiplier that boosts up the voltage and makes it suitable for three phase applications. Simulation results for various operating modes are obtained using MATLAB. The the power by operating at their corresponding MPPT and charging the battery at the constant magnitude of the current, and the remaining power is being fed to the grid. The improved voltage performance of the various operating modes is validated and results are obtained.

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