PV fed Hybrid Power Converter for rural home applications

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***Abstract*-- This paper proposes a standalone PV fed hybrid power converter for rural home applications. The aim of the proposed system is to simultaneously deliver the power extracted from PV panels to DC and AC home loads using the proposed hybrid converter topology. The system operates in either MPP or Non–MPP mode depending on the total power demanded by the loads. Modified Perturb and Observe (P&O) MPPT algorithm is used to extract maximum power from PV panels. SPWM based modified PWM technique is used for converter operation. In the MPP mode the power distribution to DC load and AC load is in accordance with the duty generated by modified MPPT. In Non MPP mode, power distribution is in accordance with the duty generated by the single loop voltage control for DC load. The simulation studies for the proposed system are carried out in MATLAB/SIMULINK environment.**

Index Terms-- Hybrid power converter, MPPT, Perturb and Observe, MPP mode, Non MPP mode

I. Introduction

Global environmental concerns like Global warming, significant depletion in fossil fuel reserves have led to a rise in demand of alternate forms of energy like solar, wind etc. Remote rural households sometimes face the shortage of electrical energy to run the basic home loads like lighting and fan loads. The factors like lack of interconnection to the national grids, poor maintenance of intermediate transmission lines due to remoteness of localities are some of the causal agents for shortage of electrical energy. The advent of power electronics has enabled the utilization of distributed sources of energy to tackle energy shortage.

Renewable energy based nanogrids [1]-[2] involve integration with different types of locally available energy sources like energy from solar panels, wind energy etc., that are required to source power to various consumer loads that can be of AC or DC type. Power converters are used for integrating the sources with loads to meet the demands [3]. As compared to the installation of individual converters for AC–DC and DC–DC/AC power conversion, to meet the demands of various loads, hybrid power converter topologies [4]-[5] can solitarily handle interfacing and delivery among various types of sources and loads. The key feature of hybrid converter topologies is simultaneous power delivery from sources like grid, battery or PV to DC and AC loads. PV systems provide

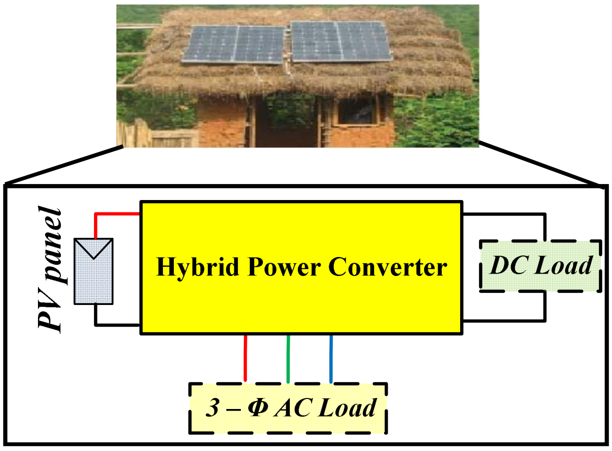

Fig. 1. Rural home with PV fed hybrid converter

clean and optimal solutions to supply power to loads especially in rural areas. In PV fed systems, operating point varies due to variations in irradiance or temperature. PV characteristics have a single peak power point. MPPT algorithms [6]-[9] are required to track the maximum power point continuously. Amongst the proposed MPPT algorithms [6]-[9] P&O is employed owing to it's simplicity. A modification to the conventional P&O algorithm [10]-[11] is employed for more optimal performance.

II. System Architecture and Modelling of Proposed System

A. System Architecture Overview

The Fig. 1. is an illustration of the proposed PV fed hybrid power converter for rural home application. The major components of the proposed system are as follows: i) PV modules ii) Hybrid power converter iii) PWM scheme iv) MPPT. The PV system is modelled using single diode model. The proposed hybrid converter configuration is capable of simultaneous DC and AC power delivery using six switches and provides improved DC gain as compared to conventional DC–DC converter topologies. The converter uses lesser switches as compared to two stage power converters for DC and AC applications, thereby reducing switching losses. A modified PWM technique [9] is used to operate the hybrid power converter. Depending on the load power demand

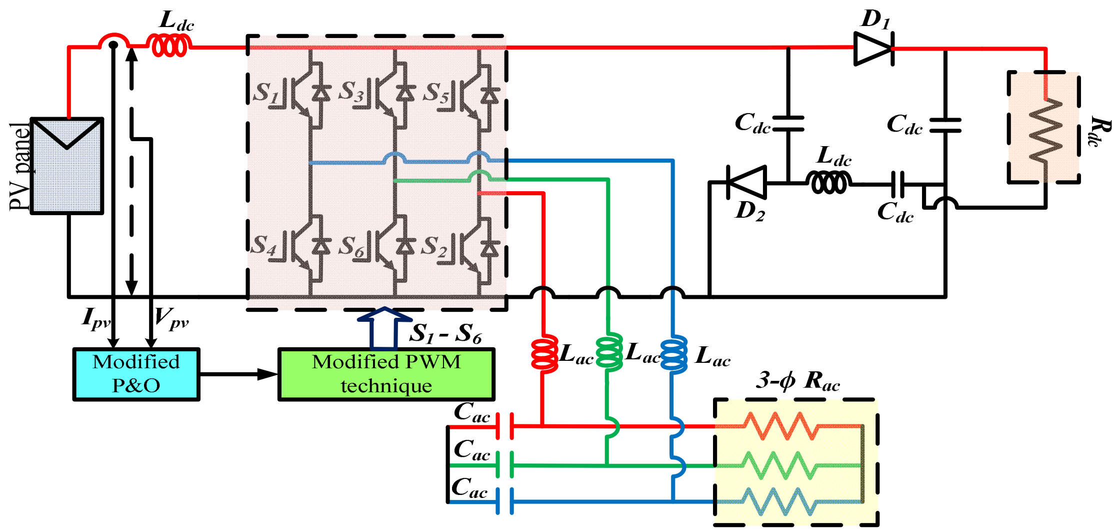

Fig. 2 Control block diagram of the proposed hybrid power converter

the system operates in either Maximum Power Point (MPP) or Non-MPP mode. Modified perturb and observe MPPT algorithm is used to generate a reference voltage for PWM scheme. The system extracts power from two PV panels each capable of delivering a maximum power of 74 W at maximum irradiance of 1000 W/m^2 connected in series configuration.

B. Hybrid Power Converter

The system proposed uses a hybrid power converter as depicted in Fig. 2. The proposed converter topology has the following distinct features: (i) It consists of six switches as compared to seven used in conventional cascaded power converter topologies for DC and AC load applications. (ii) The number of driver circuits are also reduced. (iii) It employs an improved gain DC-DC converter and three phase VSI bridge integrated into a single architecture, interfaced with a PV system, allowing simultaneous power flow for DC and AC loads. (iv) The converter is immune to shoot-through problems since it is an operable state in the converter operation. Effects of misgatings are mitigated and dead-time is not required for the gating pulses. (v) Conventional techniques for DC and AC voltage controls are compatible with the converter. (vi) It can be solitarily used for interfacing and extracting the maximum power from the PV modules i.e. in conventional systems an additional DC–DC converter is used to aid in delivering maximum power to the load at MPP.

C. Control Architecture

The system operates in various modes depending on the magnitudes of power the PV module can supply and the power demanded by DC and AC loads together. The maximum power that can be delivered by PV module (for a given value of irradiance and temperature) is P_{pvmax} and power demanded by the DC and AC loads together is P_{load}. Based on the magnitudes of P_{pvmax} and P_{load} the value of MPP$_{bit}$ is set and the following cases arise: (i) $P_{pvmax} = P_{load}$ (ii) $P_{pvmax} > P_{load}$ (iii) $P_{pvmax} < P_{load}$.

Mode (i): When $P_{pvmax} = P_{load}$, the load demand is equal to the maximum possible power the PV module can supply. In this mode, MPP$_{bit}$ is set to high value (i.e. to 1). The controller reads the value of MPP$_{bit}$ and activates the control loop corresponding to MPP mode as illustrated in Fig 3 and Fig. 4a. The control loop pertaining to the MPP mode consists of Modified P&O algorithm [10]-[11] as shown in Fig 3 and Fig 4b.

The scheme continuously monitors the instantaneous voltage and current outputs from the PV module and hence instantaneous power (P_i) is calculated. Variations in irradiance or temperature result in change in the output voltage from the module. Output voltage perturbations lead to changes in power output. With reference to the P-V characteristics of the module, perturbation in voltage (ΔV) in a given direction is considered and difference (ΔP) of instantaneous power (P_i) and previous value of power before perturbation, is calculated. If ΔP is greater than zero, positive perturbations in voltage (ΔV) increases reference voltage generated, to attain MPP, else the magnitude of reference voltage generated is decreased. If ΔP is lesser than zero, positive perturbations in voltage (ΔV) decreases reference voltage generated, to attain MPP, else the magnitude of reference voltage generated is increased. The PV voltage at MPP (V_{mpp}) is taken as reference signal for comparison with instantaneous PV voltage (V_{pv}) to generate an error signal. The error signal is passed to PI controller to generate duty ratio (D_{shoot}) for PWM scheme.

The converter uses six switches for AC and DC power delivery, thus constraining the range of values taken by duty ratio (D_{shoot}) and modulation index (M). The constraint is given by [5]:

$$D_{shoot} + M \leq 1$$

For ease of control the switching strategy operates at the maximum constraint condition i.e.

$$M = 1 - D_{shoot} \quad (1)$$

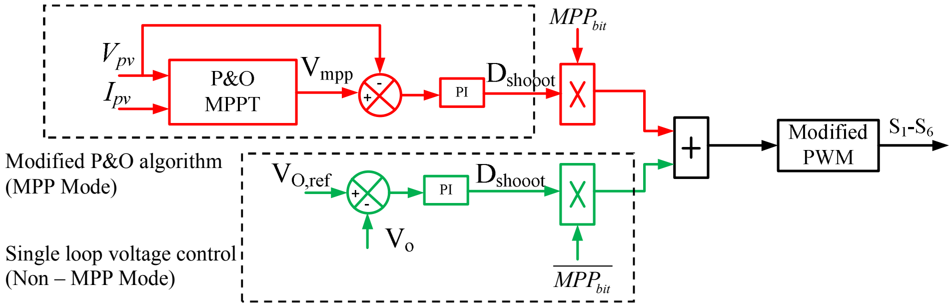

Fig. 3. Control block diagram of the proposed hybrid power converter

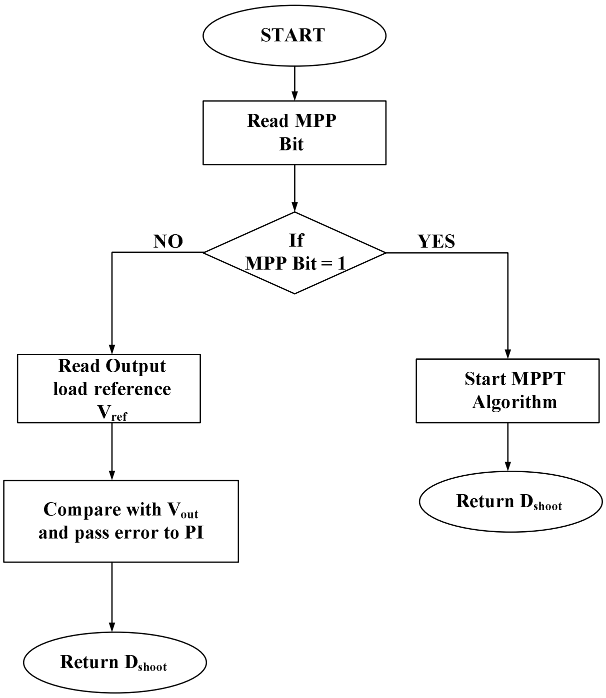

Fig 4a. Control scheme flowchart

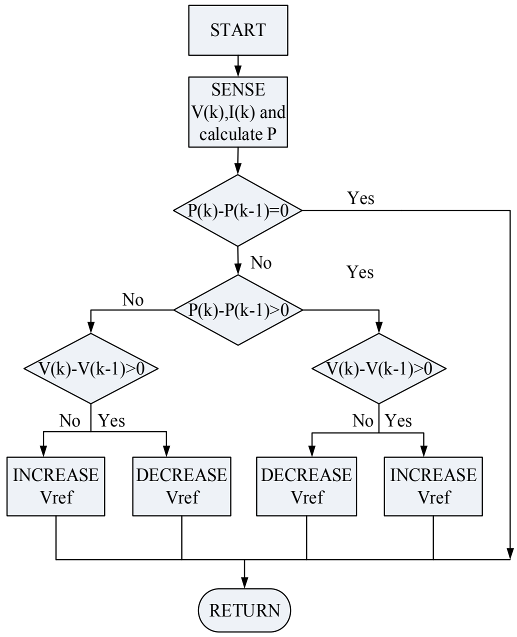

Fig 4b. MPPT algorithm flowchart

During MPP mode, power extracted from the PV panels is shared between DC and AC loads based on D_{shoot} generated by modified MPPT algorithm. Given that I_{mpp} is current delivered by PV system at MPP, current sharing depends on DC and AC loads connected.

$$I_{mpp} = I_{dc} + I_{ac} \quad (2)$$

$$P_{dc} = V_{dcout} * I_{dc} \quad (3)$$

Here, P_{dc} refers to power delivered to DC load, I_{dc} refers to DC load connected. P_{dc} depends upon I_{dc} which is governed by the load attached and V_{dcout} which is a function of D_{shoot}.

$$P_{ac} = V_{acout} * I_{ac} \quad (4)$$

Here, P_{ac} refers to per phase power delivered to AC load, I_{ac} refers to AC load connected. P_{ac} depends upon I_{ac} which is governed by the load attached and V_{dcout} which is a function of M, which is also governed by (1).

Mode (ii): When $P_{pvmax} > P_{load}$, the load demand is less than the maximum possible power the PV module can supply.

In this case, MPP_{bit} is set to low value (i.e. to 0). The controller reads the value of MPP_{bit} (as in Fig 4a) and activates the control loop corresponding to Non-MPP mode as illustrated in Fig. 3.

The control loop pertaining to the Non - MPP mode consists of single loop voltage control [10] as shown in Fig. 3 and Fig. 4b. The power thus generated by the PV module is shared based on load requirement with reference to values of D_{shoot} and M. The value of D_{shoot} is generated by single loop voltage control as illustrated in Fig. 3.

The reference voltage ($V_{o,ref}$) signal is set based on the output voltage requirement of the DC load. The output load voltage signal (V_o) is compared with the reference and the error signal generated is given to PI controller to obtain the duty signal D_{shoot}. The modulation signal M is generated using (1). In this control scheme, preference is given to the voltage control of DC load. Hence the value of D_{shoot} is utilized to internally generate the value of M. The advantage of this method of generation of M is the diversion of excess power to the AC load during situations of increase in temperature or irradiance to PV module (without changing the operating point) without affecting the power delivered to the DC load. This is based on the underlying assumption that the AC load has a higher tolerance. The value of M could also be generated using control schemes dedicated to AC load voltage control.

Mode (iii): When $P_{pvmax} < P_{load,}$ the load demand is higher than maximum possible power the PV module can supply. In this case, few of the loads can be progressively isolated from the supply to match the load demand to the maximum power generated. In several systems, battery energy storage systems are additionally used to cater to the excess power demand [12]-[14].

D. PWM Scheme

The proposed hybrid power converter uses a modified PWM technique [15] based on conventional SPWM (Sine PWM). As in Fig 5, input signals to the PWM scheme are M_a, M_b, M_c, V_{shoot}, V_{tri}, D_{shoot}, where V_{shoot} is the DC signal that yields D_{shoot} upon comparison with V_{tri} (triangular wave signal of frequency F_s, equal to that of the switching frequency) and M_a, M_b, M_c are sine wave reference signals. The modes involved are: (i) Shoot Through (Shoot) (ii) No Power (NP) (iii) Power Delivery (PD).

Shoot mode involves turn on of both the switches of any one of the 3 legs of the hybrid converter i.e. consider leg A, S_1 and S_4 are turned on. Inductor L_{dc} gets charged in this mode. The DC and AC loads receive power from the energy stored in the capacitors on the respective sides.

NP mode involves the supply of power to the DC load from the source as well as energy stored in the inductor L_{dc}. The AC load receives power from the energy stored in the capacitors on the AC side.

PD mode involves the supply of power to the AC load and the DC load from the supply and the energy stored in the inductor L_{dc}. In this mode the switches are given gating pulses in a fashion like that of a 3–phase VSI. The value of V_{shoot} is obtained from the value of D_{shoot}, generated by the control scheme. Magnitude of M_a, M_b, M_c are decided using (1) and the value of D_{shoot}. For independent control of AC load voltage, separate control schemes can be used to generate M_a, M_b, M_c signals.

III. SIMULATION RESULTS

The performance of PV fed hybrid power converter for rural home application is evaluated in MATLAB /SIMULINK environment and illustrated in Fig. 6-8. In this section, simulation results for two modes of operation viz. (i) MPP and (ii) Non-MPP modes of the proposed system are presented.

Case 1: MPP Mode:

In this case the irradiance is varied from 700 to 850 W/m^2 as shown in Fig. 6a. During change in irradiation (700 to 850 W/m^2) maximum power is extracted from the PV module i.e. maximum power point of PV current (I_{mpp}), voltage (V_{mpp}) and power (P_{mpp}) using modified P&O algorithm as shown in Fig. 6b-d. Each panel delivers 74W at MPP for irradiance of 1000 W/m^2. At irradiances of 700 W/m^2 and 850 W/m^2 the two panels together deliver 102W and 125 W respectively. It is observed from Fig. 6b that, the average PV voltage is constant at 33V and the average

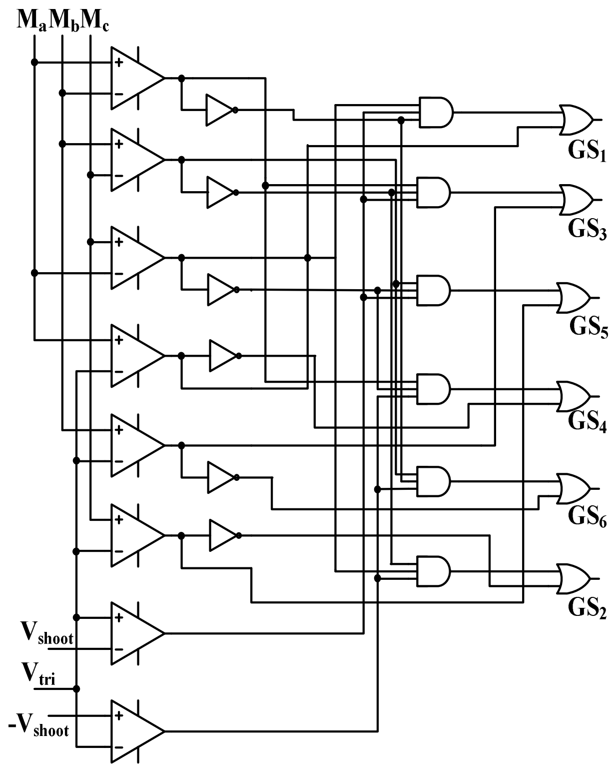

Fig. 5. Implementation of PWM scheme.

PV current increases from 3 to 3.75 A as shown in the Fig. 6b. It is evident that the power delivered by PV module increases from 102 W to 125 W as shown in the Fig. 6c, using the modified P&O algorithm. In this regard the average output voltage of the hybrid converter to DC load increases from 98 V to 110 V and the current increases from 0.8 A to 0.9 A (Fig. 6d-e). This variation in the DC output voltage and current does not affect the performance of lights and fan loads used in rural homes. Similarly, the Fig. 6g-h depict the three - phase output voltage and current delivered by hybrid converter to AC load. The power delivered to AC loads can be used for lighting loads like LEDs. The voltage delivered to AC load can also be stepped up using a transformer.

Case II: Non-MPP Mode:

In this mode irradiance is kept constant at 750 W/m^2 as shown in Fig. 7a, to analyze the performance of the hybrid converter. In this case, the output reference voltage ($V_{o,ref}$) is considered as 48 V. Fig. 7b-c show the PV voltage and current maintained constant at 15.3V, 3.54A respectively. At 750 W/m^2 irradiation the maximum power that can be delivered to system by the PV panel is 111 W. The DC side output voltage is set as 48V, hence the power demanded by the DC and AC load is such that 54.2 W is drawn from the PV panels as shown in Fig. 7d. Thus, the system operates in Non MPP mode. The output voltage to DC load is maintained at 48V, as shown in Fig. 7e, by single loop voltage control. The current to DC load of hybrid converter is also constant at 0.8A as shown in Fig. 7f. Similarly, the Fig. 7g-h illustrate the three-phase voltage and currents delivered to AC load respectively.

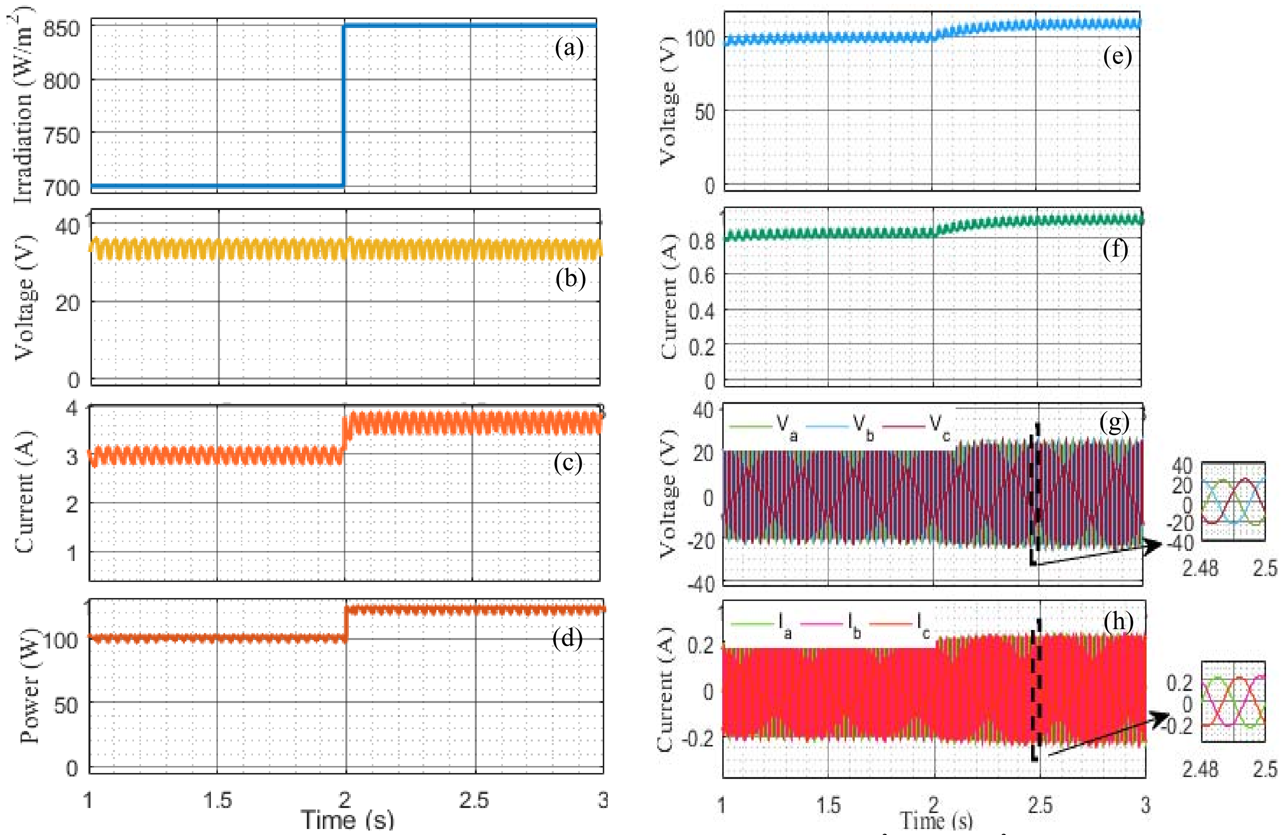

Fig. 6. Performance of hybrid power converter in MPP mode during change in irradiation from 700 W/m^2 to 850 W/ m^2. (a) Irradiation. (b) PV panel voltage. (c) PV panel current. (d) PV power, (e) DC output voltage (f) DC output current. (g) 3 phase AC output voltage, (h) 3 phase AC output current.

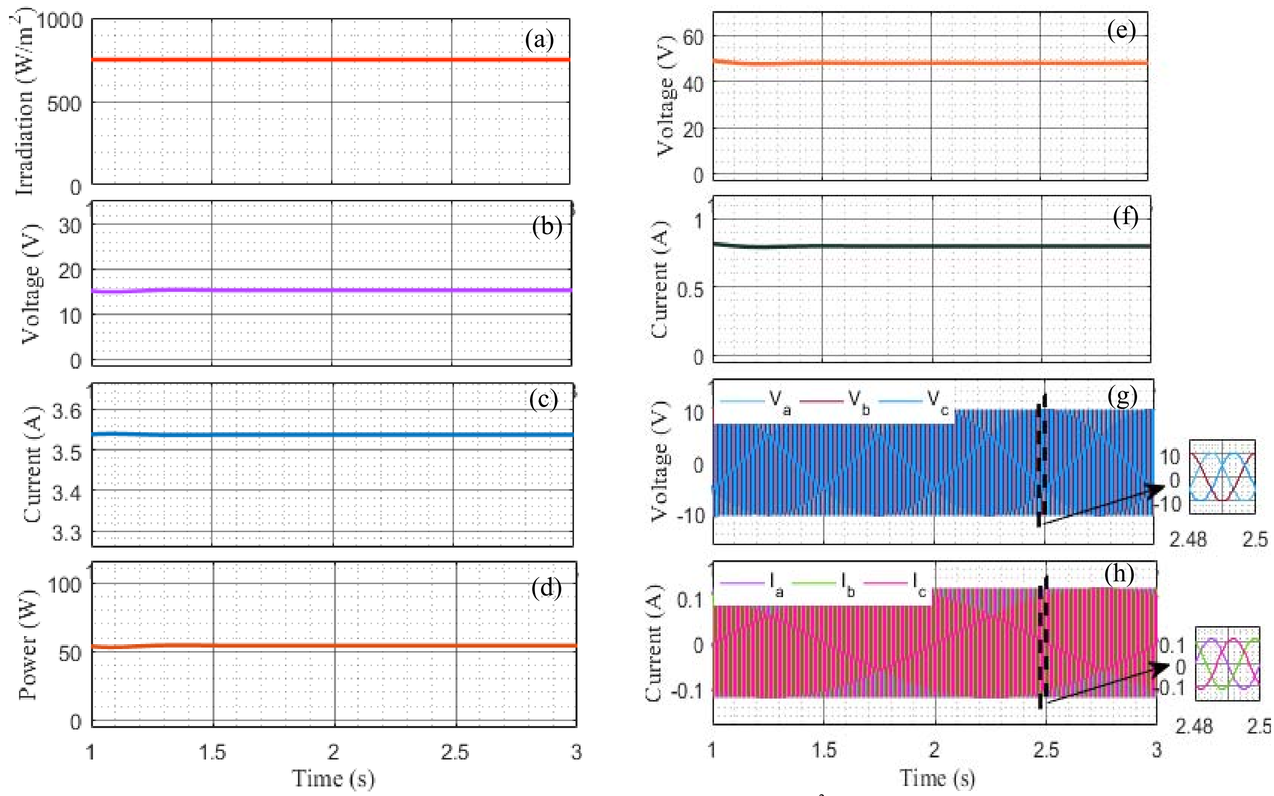

Fig. 7. Performance of hybrid power converter in non-MPP mode at constant irradiation (750 W/m^2). (a) Irradiation. (b) PV panel voltage. (c) PV panel current. (d) PV power, (e) DC output voltage (f) DC output current. (g) 3 phase AC output voltage, (h) 3 phase AC output current.

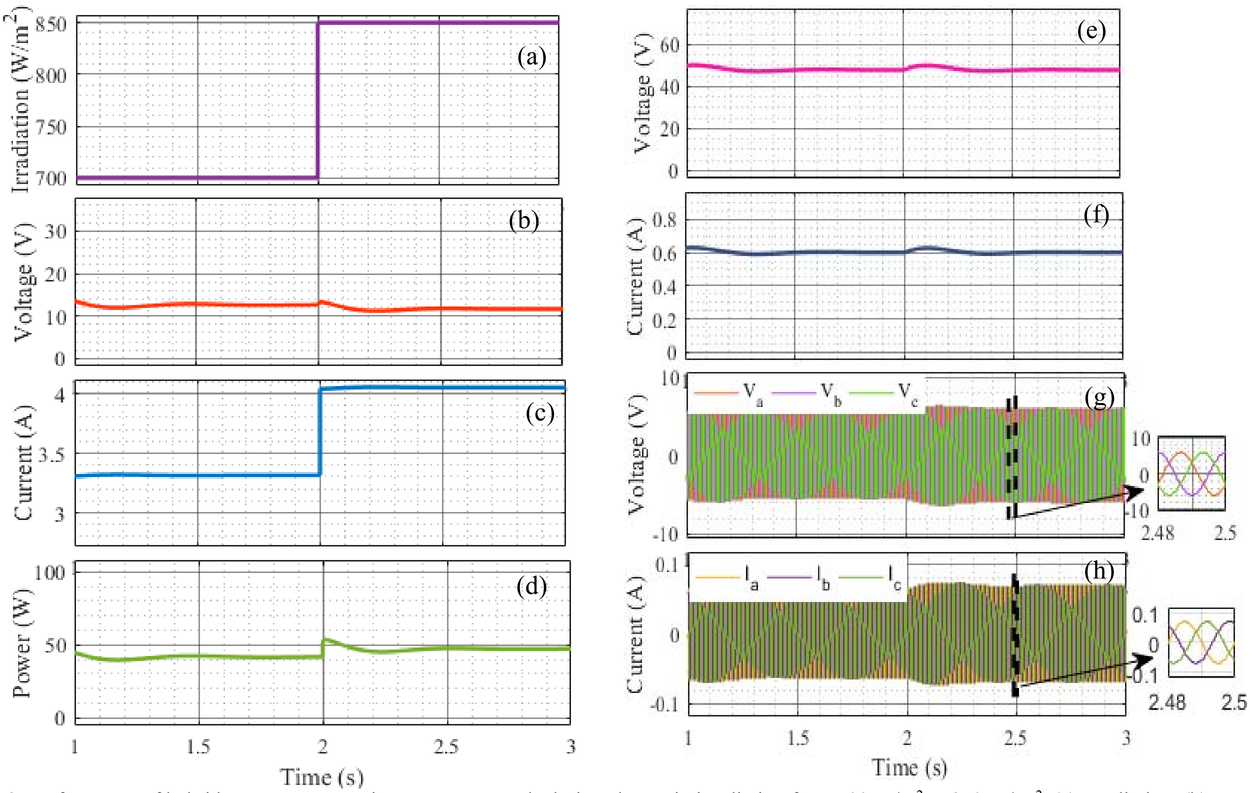

Fig. 8. Performance of hybrid power converter in Non - MPP mode during change in irradiation from 700 W/m^2 to 850 W/ m^2. (a) Irradiation. (b) PV panel voltage. (c) PV panel current. (d) PV power, (e) DC output voltage (f) DC output current. (g) 3 phase AC output voltage, (h) 3 phase AC output current.

Fig. 8a-h represent the system operation in Non-MPP mode when there is change in irradiance. An increase in irradiance from 700 W/m^2 to 850 W/m^2 (Fig. 8a) results in an increase in the power generated by the PV panels from 40W to 45W (Fig. 8d). The single loop voltage control ensures that the voltage at the load end is maintained at the given reference value, in this case 48V (Fig. 8e). Also, the loads connected are also constant, hence, the power delivered to the DC load is constant (Fig. 8e-f). The excess power generated is diverted to the AC loads. The voltage increases from 10V (pk–pk per phase) to 12V (pk–pk per phase) (Fig. 8g) and the corresponding power delivered increases from 2.5 to 4 W per phase.

V. Conclusion

PV fed hybrid power converter for rural home applications is proposed in this paper. The PV module consists of two panels connected in series to deliver power to DC and three phase AC rural home loads simultaneously. It uses lesser number of switches and drivers, thereby reducing the cost and the overall losses. The system operation in MPP and Non MPP modes is based on load requirements. From the simulation results it is observed that: (i). In MPP mode, during variation in the irradiation maximum power is extracted from the PV panels using modified P&O algorithm, (ii) In Non-MPP mode, for the constant irradiation the desired output voltage is achieved satisfactorily.

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