Hybrid Renewable Energy System with Single DC-DC Converter for Grid Connected Distributed Generating System

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Abstract – This paper presents a newly modified hybrid PV-PMSG based distributed generation system proposed to reduce the system complexity with a single DC/DC boost converter driven at its peak power point. The proposed work consists of a PV MPPT controlled wind generator and PV which is the two input sources fed to the inverter which tracks the peak power point. The energy from PV is directly connected to the inverter which was given through the DC bus. The proposed work has lesser conversion stages due to less number of converters. These two sources use the current control technique to draw its peak power by modifying inverter current. To obtain peak power from these two sources, two new controllers were introduced. Finally, a DC/DC boost converter was designed the combined operation of both the controllers has been displayed and the simulation results are obtained using MATLAB.

Index Terms – Distributed Generators, DC/DC boost converter, Current control technique, Grid connected hybrid system.

1. INTRODUCTION

Renewable energy sources are becoming popular as they provide major part of energy to energy less consuming buildings [1]. New power electronic interconnection and control techniques are used to make Distributed Generators (DGs) work better and to obtain its efficacy [2, 3]. Seasonal variations make the DG systems uncertain if it has only one interrupted source. If the DG system has more than one renewable source, it may have higher constancy as the resources have balancing nature [4, 5]. Here no reactive power is required, so that permanent magnet synchronous generators (PMSG) are used and gear box arrangement is removed [6]. PMSG has self-excitation property, so that high power factor and efficiency is obtained [7]. Some feasible models of wind and solar systems are depicted in the literary works.

A topography with PV and wind generator outputs boosted to go with the DC bus voltage [8].

Battery connected two sources patched with common DC bus which was linked to the grid followed by an inverter is explained [9]. These two grid connected sources along with battery and DC link voltage is stable with battery voltage [10]. A DC/DC converter with more than one input was proposed with PV-PMSG system coupled to a common DC link [11]. The inverter with the similar arrangement of one or more input was also explained in [12].

From the above mentioned literary works, it is clear that each source had an individual power converter or a battery. Converters are controlled by hidden algorithm to obtain the peak power point. Conversion stages are reduced for increasing the efficiency on the whole. Therefore the conversion stage losses are satisfied by expanding the generators size, so that the cost of the generator is maximised. If full load condition is obtained, DC/DC converter is able to give 95% of its efficiency [13]. Variable source powers won't allow the converter to function at its peak power. The proposed technique reduces 5% efficiency loss by removing this supplementary conversion stage. Hence the proposed generator consists of PV and wind source where the PV array connected directly to the DC bus but not connected through a DC/DC boost converter. Here the rectifier fed DC/DC boost converter's output is patched with the DC bus followed by an inverter. The PV array terminal is linked directly to the DC bus voltage. The current control technique is used to obtain peak power from both the hybrid sources. The current control technique is implemented by introducing two new controllers namely PV MPPT controller and hysteresis controller. The successful function of this proposed topography depends on the level of obtaining its peak power from both the sources and validated with simulation results. Thus the maintenance free function makes this system possible in smart grid scenario.

2. PROPOSED SYSTEM

Wind and PV forms the two sources of the proposed system and PMSG is used to generate mechanical energy which is driven by wind. This is clearly depicted in block diagram shown in Fig. 1. PMSG driven by wind produces an output which is reformed by the rectifier. The rectifier's output is given to DC/DC boost converter.

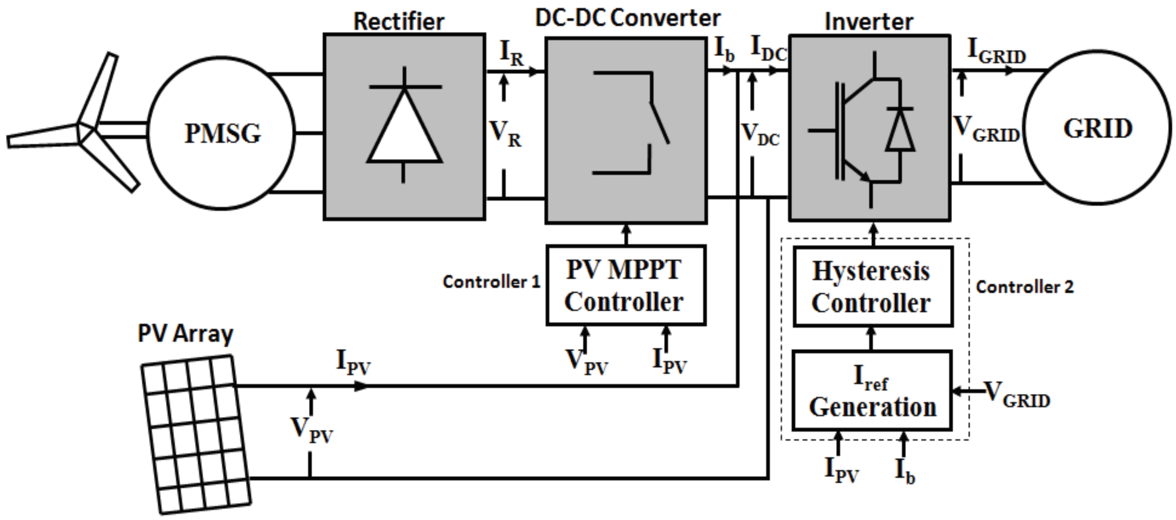

Fig.1 Proposed hybrid DG system with proposed controllers

The varying wind-speed varies the output voltage of the rectifier. The PV array ends are directly coupled to the DC/DC boost converter's output which forms the load line for PV. This load line is then coupled with input ends of the inverter. As the output of DC/DC boost converter forms the load line for PV, the output of the DC-DC converter (VDC) is locked with the PV array output (VPV). Two new controllers namely PV MPPT controller (Controller 1) and hysteresis controller (controller 2) were introduced to obtain high power output from both the sources. Here the PV MPPT controller is used to vary DC-DC converter's output automatically to peak power point of PV array. The hysteresis controller also called as current controller which is associated with the inverter, is used to draw the peak current of the irradiation from the sun. Controller 1 is engaged with basic Perturb & Observe (P&O) algorithm with duty-cycle adjustment [14, 15]. The output of inverter with hysteresis controller is locked with grid voltage and frequency and grid synchronization is met automatically. Reference current signal (I_{ref}) is automatically modified by the hysteresis controller for drawing the peak current from the two available sources and is followed by the grid current (I_{GRID}). The selection of this reference current of inverter with hysteresis controller to derive peak current is used to obtain peak power from both the sources.

3. PROPOSED SYSTEM MODEL

The system performance is examined by developing the proposed DG system model. The DC output voltage of rectifier (V_R) and current (I_R) on the basis of stator phase voltage V_S (rms) and stator current I_S (rms) are represented as [16, 17]. Since the output voltage of rectifier V_R is a fluctuating DC, the wind-speed also fluctuate with V_S. DC/DC boost converter is fed by this fluctuating DC. The output voltage of the DC-DC boost converter is represented as

$$V_b = V_{DC} = V_R\,[1/[\,1 - \delta]] \qquad (1)$$

where δ is duty-cycle adjustment of the DC-DC boost converter. The current at DC bus is

$$I_{DC} = I_b + I_{pv} \qquad (2)$$

and the current from PV array (I_{PV}) is represented by [3]

$$I_{PV} = I_{SC} - I_d \qquad (3)$$

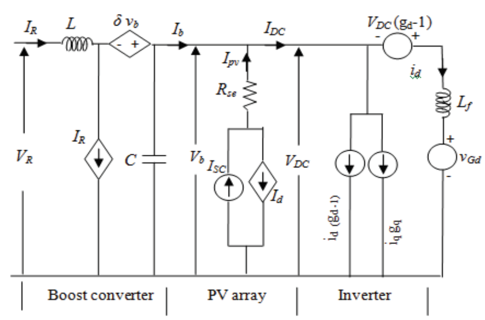

Fig. 2 d-axis equivalent of the system

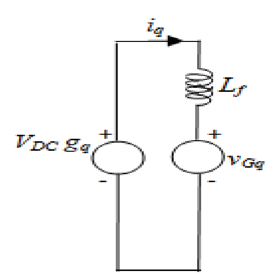

Fig. 3 q-axis equivalent of the system

Assuming zero power loss in DC-DC converter,

$$V_R I_R = V_b I_b \qquad (4)$$

The equivalent circuits of *d* axis and *q* axis of the proposed system are depicted in Fig. 2 and Fig. 3 respectively. To obtain peak current I_{DC} at any time, δ and I_{ref} are modified in the proposed technique. Using these equations the DG system with new proposal can be analyzed on any platform. Here MATLAB is chosen to analyze the proposed technique to obtain its peak power.

4. CONTROLLER OPERATION

The controller operation depends up on the generation of power from the sources. For different conditions of sources available, reference current I_{ref} results to obtain peak power from both the sources.

A. Generation of power from both PMSG and PV:

In this case, power generating energy from wind and PV sources together and PV array's voltage disturbance (since $V_{DC} = V_{PV}$) is caused by the duty ratio modification of the converter. This makes V_{DC} to be fixed with the peak power point voltage (V_m) of PV array. So that wind-speed alters the rectifier voltage and automatically duty cycle adjustment is done. Hence peak current (I_m) is delivered by the PV array at this point (V_{PV} = VDC = V_m). The PV MPPT controller modify the duty ratio of DC/DC boost converter output voltage and fixed to peak voltage V_m to function PV array at its highest operating point. The modification in duty ratio of PV MPPT controller is given by

$$\delta_{new} = \delta_{old} + sgn(\Delta P) sgn(\Delta V_{PV}) \Delta\delta \qquad (5)$$

where $\Delta\delta$ is the disruption in duty-ratio, *sgn* is signum function, ΔP is the PV array's power variance and ΔV_{PV} is the PV array's voltage variance before and after disruption. The increment or decrement in duty ratio depends on the values of ΔP and ΔV_{PV}. Hysteresis Controller has the objective to modify the resultant current of inverter given to the utility. Hysteresis current controller's reference current (I_{ref}) is fixed on the basis of peak power obtained from both the sources. Due to PV MPPT controller, PV array's peak power is fixed for $V_{PV.}$ I_{ref} is modified by draining current from the converter (I_b) and PV array (I_{PV}). If there is increment in current drained from the converter, the resultant reference current I_{ref} also incremented. For each terms of given irradiance and wind-speed, the reference current at steady state is

$$I_{ref} = 2(V_{PV} I_{PV} + V_R I_R) / V_{GRID} \qquad (6)$$

B. PMSG alone generating power:

There will not be any feedback at night time when the current transducer is fixed to the PV array. If this is the condition, the PV MPPT controller won't function and voltage control mode is utilized. The voltage output of transducer (V_{DC}) is taken as return signal and DC link voltage is retained on the basis of DC voltage of utility grid. The hysteresis controller will keep adjusting the (I_{ref}) at I_{PV} = 0 in (6), to obtain the peak power from the PMSG alone.

$$I_{ref\,(new)} = I_{ref\,(old)} + sgn[\Delta(I_b)]K \qquad (7)$$

C. PV alone generating power:

C/DC boost converter has not given any input since PMSG has not generated any power. Therefore pulse is not generated by PV MPPT controller. Hence the hysteresis controller modifies I_{ref} at I_b = 0 in (6), to feed the peak power from PV source alone.

$$I_{ref\,(new)} = I_{ref\,(old)} + sgn[\Delta(I_{PV})]K \qquad (8)$$

D. Composite operation of controllers:

From these three cases, it is clear that hysteresis controller operates always to give the peak power either from the two available sources or from any one of the sources to the grid by modifying I_{ref} and PV MPPT controller is idle when power is generated by PV alone. The functions of two controllers are summarized in Table. I according to the available sources.

TABLE I

CONTROLLER FUNCTIONS BASED ON POWER AVAILBLE

Sources	Controller 1	Controller 2
PV and PMSG	Produces duty ratio	Current command is developed
PV alone	No duty ratio	Current command is developed
PMSG alone	Duty ratio is produced	Current command is developed

5. CONTROLLER IMPLEMENTATION

A. Controller for DC/DC boost Converter:

The DC/DC boost converter controller is implemented using a very low cost 16 bit microcontroller (PIC 16F876A) from MICROCHIP. PV array polarities which are combined to voltage and current transducer are used for producing feedback signals to the controller. Signal conditioning circuit (SCC) is used to process these signals from transducers and attached to the microcontroller. Internal Analog to Digital Conversion (ADC) module is used to digitize these signals. The function of PV MPPT controller is featured in this microcontroller. The desired pulses from PWM for DC/DC boost converter is produced by the pulse width modulation (PWM) module which is inbuilt in the microcontroller.

B. Hysteresis Current Controller:

The diagrammatic representation of hysteresis controller is depicted clearly in Fig. 4. Hysteresis-current-controller is constructed by the op-amps of high frequency level. Current transducer detects the I_{PV} and I_b and gets computerized microcontroller. To achieve a DC value respective to the highest value of I_{ref}, a Digital to Analog Conversion (DAC) IC is used to process the digital value. This DC value is induced to the multiplier IC with the reference sine wave obtained from the voltage at grid and fed as the reference current signal to the hysteresis current-controller. I_{ref} is tuned automatically to achieve the peak power from PV array (or PMSG), if PV array (or PMSG) alone produces power, I_b (or I_{PV}) will havea least value. When both the sources are used to produce power, I_{ref} will be tuned based on (6) and tuned to increment the DC link current I_{DC} for the respective terms of irradiation and wind-speed.

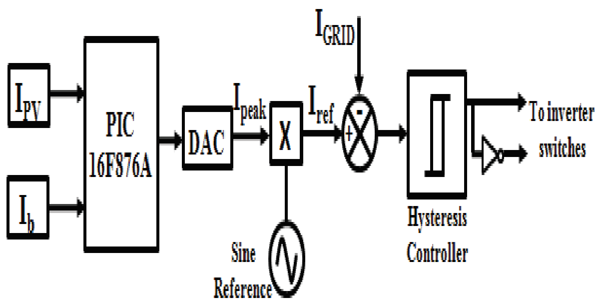

Fig. 4 Production of current reference in hysteresis controller

The output of inverter will be symmetrically equal with grid frequency and voltage, since it has taken reference sine-wave.

6. SIMULATION RESULTS

In order to validate the performance of the proposed converter and the gird connected system, this paper is designed with a wind and PV generator system with voltage and current controller along with the gird connected control system that maintains the dc link voltage based on the PQ transform, the grid voltage and current are synchronized through the inverter which stabilizes the link dc voltage. The hysteresis controller produces firing pulses and given to the switches. For validating the performance of the proposed system, the rated power for PMSG is chosen as 0.7 p.u., 12 pole, Speed = 1 p.u., which is star connected and there are 6 panels pf PV array which is combined in series. Each panel has open circuit voltage (V_{oc})= 0.20 p.u., Short circuit current (I_{SC}) = 0.45 p.u., peak power 0.08 p.u., and the base values are chosen according to the desired output which has the base power of 1 kVA; base voltage of 100 V and base current of 10 A and base Speed of 450 rpm. The simulink is designed in MATLAB to produce an expected output with values chosen above. The above designed system is simulated to get desired waveforms and a transformer is used to step-up the voltage to be in phase with the grid, if PMSG and PV array voltages were chosen to be lower than the voltage at grid. A minor increment in speed of DC motor for steady irradiation of 600 W/m^2 is applicable. The DC link voltage is maintained or fixed to make PV array function at its peak operating point so that output of rectifier is incremented from 25 V to 45 V and there is decrement in duty ratio. The alteration in rectifier output and duty ratio is evidently depicted in Fig. 5.

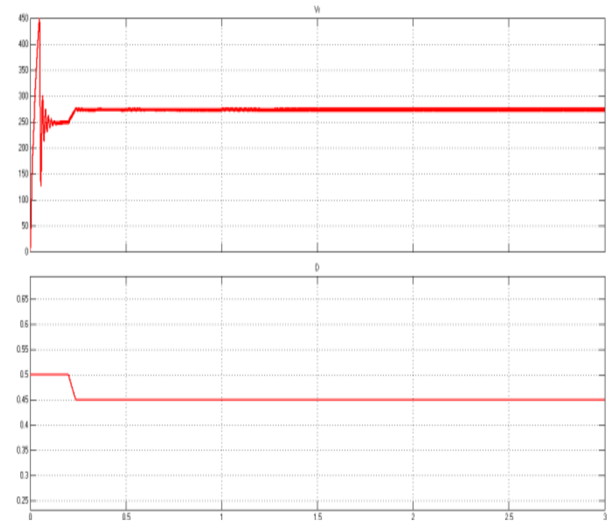

Fig. 5 Rectifier output and duty ratio alteration

The reference current value have incremented (from 12 A to 20 A) for this step-change, which induces the power transported to the utility to increment. The DC voltage which is achieved from both the sources is given to the inverter for obtaining AC voltage. Fig. 6 clearly depicts the output voltage of inverter before filtering. Then the converted AC voltage is filtered for harmonics reduction which is shown in fig. 7 and then it is synchronized into the grid. The respective voltage and the current waveforms at grid side are figured in Fig. 8.

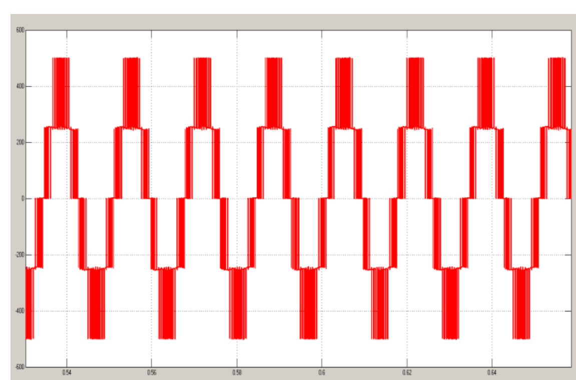

Fig. 6 Unfiltered inverter output voltage

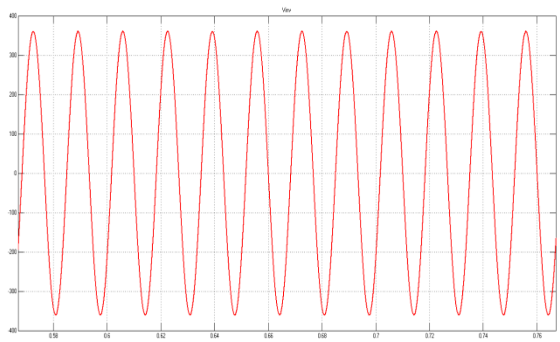

Fig. 7 Filtered inverter output voltage

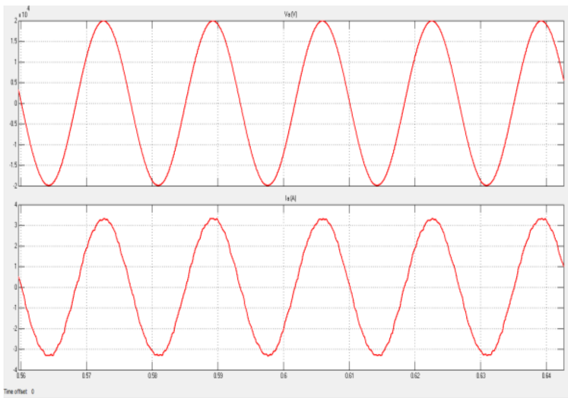

Fig. 8 grid voltage and current waveforms

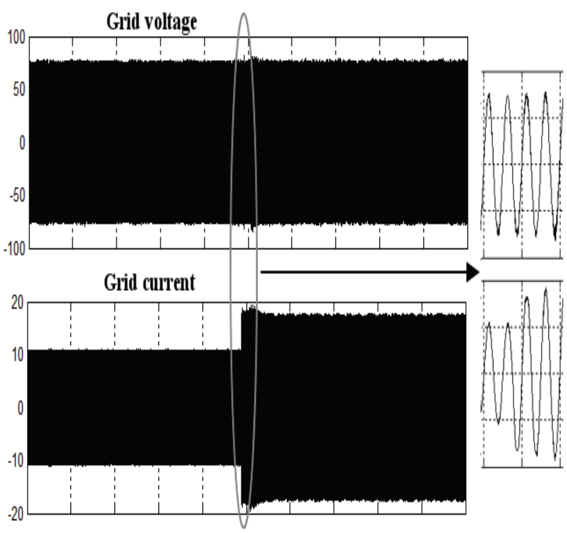

Fig. 9 Changes in grid voltage and current

The current modification at grid side for small increment is revealed in Fig. 8. Fig. 9 obviously reveals that both the PV MPPT controller and hysteresis controller acts quickly for a small increment in wind-speed. The simulated peak power obtained for various conditions are compared for further tracking of highest power from the two available sources.

Power quality conditioner was used to measure the total harmonic distortion (THD) of the voltage and the current at utility side and the results are depicted in Fig. 10.

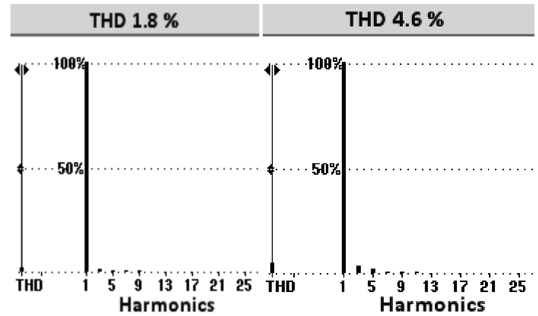

Fig. 10 THD of voltage and current at utility

Therefore to interconnect distributed resources with utility, the voltage and current THD should be below the level recommended by IEEE and this was proved by the proposed system results.

7. IMPLEMENTATION OF PROPOSED SYSTEM

This Hardware is designed with a microcontroller followed by an opto-isolator which acts as a isolation between the power circuit and the control circuit. PIC 16F877A microcontroller used for generating PWM signals for the MOSFET triggering. This microcontroller has the programmable PWM generators which could be used to generate the PWM pulse directly. A MOSFET driver is connected with an IR2110 driver which is used to generate the exact driving voltage level. The reference voltage is taken from the control point, by adding a suitable voltage reference; the MOSFET driver generates the voltage signal out of the supply. A separate +12 V power supply is required to operate the driver. The PIC microcontroller works with a +5V supply which is connected to the pins 31,32 and 11,12 , an 20 MHz clock frequency is connected to the microcontroller in the pins 13,14 . The voltage output of the converter is glanced through the microcontroller to adjust the PWM for maintaining the voltage set. The hardware circuit is designed up to single converter output which proves that energy from two sources is taken as inputs and maximum obtainable output from the sources by the implementation MPPT controller is shown in fig. 11.

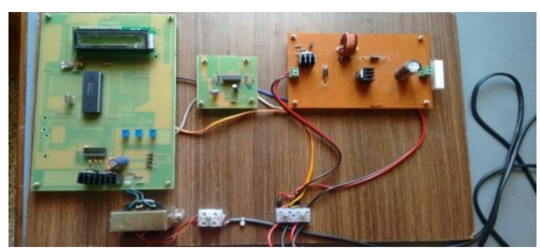

Fig. 11 Proposed system hardware circuit

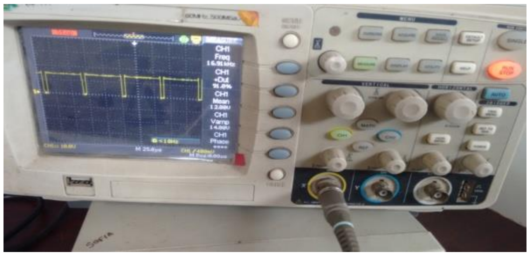

Fig. 12 Inductor output voltage with single input source

The hardware implemented was tested with appropriate values with limitations due to safety issues. The following output waveforms are able to obtain with digital oscilloscope and shown below. Fig. 12 shows the output of inductor voltage at converter with the availability of one source alone. Now the system with single input source is tested with further conditions and able to control the output voltage and shown in fig. 13. Fig. 14 shows the output voltage of converter with lot of variations in the input source. But we are able to get the maximum output voltage by the implementation of MPPT controller.

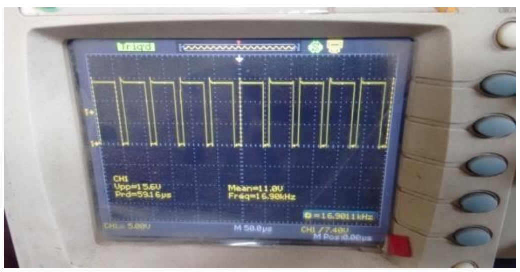

Fig. 13 Controlled output voltage

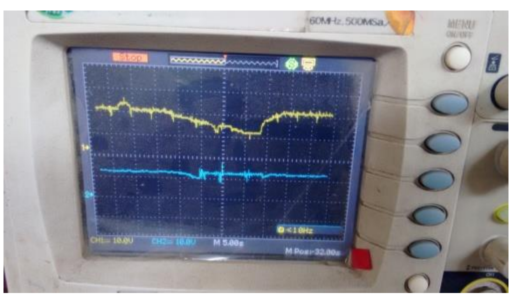

Fig. 14 Input variations with stability

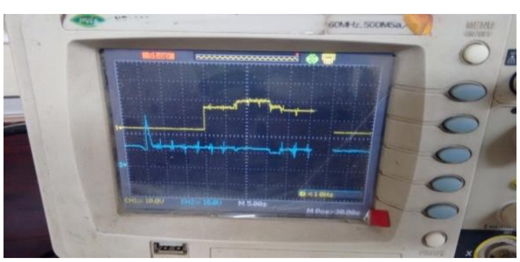

Fig. 15 Rectifier output voltage and duty cycle variation

When there is change in speed of wind (source 1), there is sudden change in rectifier's output voltage and duty cycle which shows the quick response of the converter designed and this shown clearly in fig. 15. The proposed system is tested with 3 modes (i) single input source alone, (ii) two input sources of normal operation and (iii) second input source greater than first one, which is a voltage control mode.

TABLE II

EXPERIMENTAL RESULTS

Input 1(V)	Input 2(V)	Output (V)
8.5	0	13.3
0	10	13.4
14	8	13.8
13.2	12	13.6
15	12	13.8
11	13	13
10	12.8	12.8

This tabular column proves that the single DC-DC converter reduces the conversion stages when compared to system with dual converters and able to obtain the maximum power point of 13.4 V independent of two input sources. The proposed system can be tested for various input values and can be experimentally proved.

8. CONCLUSIONS

A stable hybrid DG system with wind and solar sources, with only one DC/DC boost converter traced by an inverter with controllers, has been effectively designed. The simulink model developed in MATLAB has been verified for its performance. The system is examined for other irradiation conditions and speeds imply that this can be used for zero net energy buildings. The implementation of two controllers namely PV MPPT controller and hysteresis current-controller is utilized in better manner to achieve the highest power from the two available sources. Further the assurance of stability and less maintenance makes this proposed system utilised in distribution progress. Here the power produced is given to the grid at unity power factor and it is well suited for smart grid scenario. The proposed scheme easily finds application for erection at domestic consumer sites in a smart grid scenario.

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