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A Renewable Hybrid Wind Solar Energy System Fed Single Phase Multilevel Inverter

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Abstract: With the increasing concern of global warming and depletion of conventional resources we have to look at sustainable energy solutions like renewable energy sources. This paper proposes a renewable hybrid wind solar energy system fed single phase multilevel inverter. The hybrid system is the combination of photo voltaic (PV) array and wind generator. Solar energy is generated by using PV arrays, wind power is generated by using wind generator and both the generated voltages are boosted up by boost converters. These boosted voltages are fed to the single phase multi level inverter. Due to the intermittent nature of both the wind and solar energy sources, a fuel cell can be used as an uninterruptable power source, which is able to feed a certain amount of power to the load under all conditions. Simulation models are constructed for the both single phase inverter, single phase multilevel inverter and it is validated through experimental results using PIC micro controller.

Key words: Photo voltaic, wind generator, Fuel cell, multi level inverter

1. Introduction

The renewable energy resources are omnipresent, freely available, and environmentally friendly. A renewable hybrid energy system consists of two or more energy sources and an optional energy storage system. These hybrid energy systems are becoming popular in remote area power generation applications. This project will combine photovoltaic and wind to make hybrid system. Wind and photovoltaic energies can hold the most potential to meet our energy demands. Alone, wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent nature that makes them unreliable. The combined utilization of these two renewable energy sources, the power transfer efficiency and reliability of the system can be improved significantly.

When a source is unavailable or insufficient in meeting the load demands, the other energy source can compensate the difference. In this system separate DC/DC boost converters are connected to reach maximum demand from both the renewable energy sources.

The systems consists passive input filters to remove the high frequency current harmonics injected into wind turbine generators. These harmonics in the generator decreases its lifespan and increases the power losses. So an alternative multi-input rectifier structure is connected to wind energy system. The both ends of each boost converter are connected to single phase multilevel inverter to get related wave forms to sinusoidal

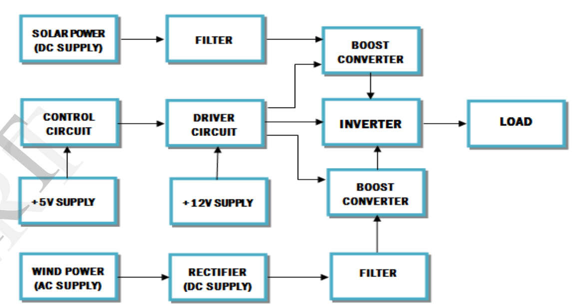


Fig (1): Block diagram of Renewable hybrid wind solar energy system fed single phase inverter.

2. CIRCUIT OPERATION

The circuit diagram of the renewable hybrid energy system fed multilevel inverter is shown in below figure, where one of the inputs is connected to the output of the PV array and the other input connected to the output of a wind generator via bridge rectifier. Configuration of switches allows each converter to operate normally or individually in the event that any source is unavailable.

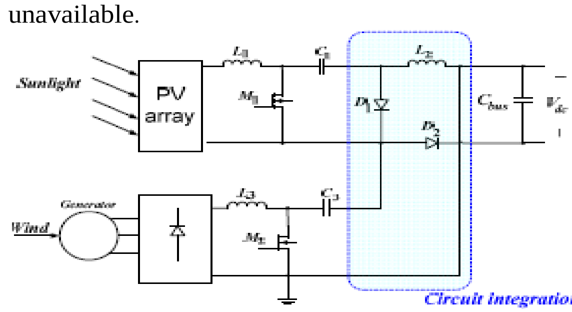


Fig (2): Front end circuit of hybrid wind solar energy system

In the case when only the wind source is available, the input to output voltage relationship is given below

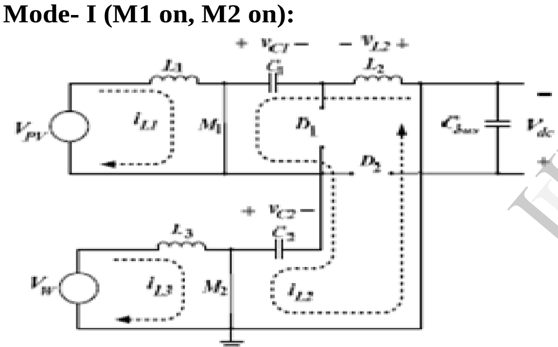
$$\frac{V_{dc}}{V_w} = \frac{d_2}{1-d_2} \quad (1)$$

On the other hand, if only the PV source is available, then the input to output voltage relationship is given below

$$\frac{V_{dc}}{V_{pv}} = \frac{d_1}{1-d_1} \quad (2)$$

Here bellow illustrates the various switching modes of the converters. If the turn on duration of $M1$ is longer than or equal to $M2$, then the switching states will be state the modes I, II, IV. Similarly, if the turn on duration of $M2$ is longer than or equal to $M1$, then the switching states will be state the modes I, III, IV. In the following, $I_{i,PV}$ is the average input current from the PV source; $I_{i,W}$ is the RMS input current after the rectifier (wind case); and I_{dc} is the average system output current. The mathematical expression that relates the total output voltage and the two input sources in each mode are illustrated below.

Mode- I (M1 on, M2 on):

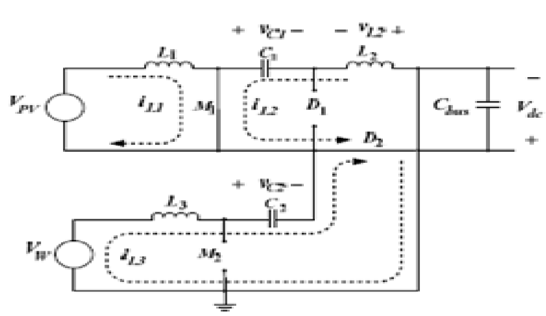


$$i_{L1} = I_{i,pv} + \frac{V_{pv}}{L_1}t \qquad 0<t<d_1T_s$$

$$i_{L2} = I_{dc} + \left(\frac{V_{c1}+V_{c2}}{L_2}\right)t \qquad 0<t<d_1T_s$$

$$i_{L3} = I_{i,w} + \frac{V_w}{L_3}t \qquad 0<t<d_1T_s$$

Mode- II (M1 on, M2 off):

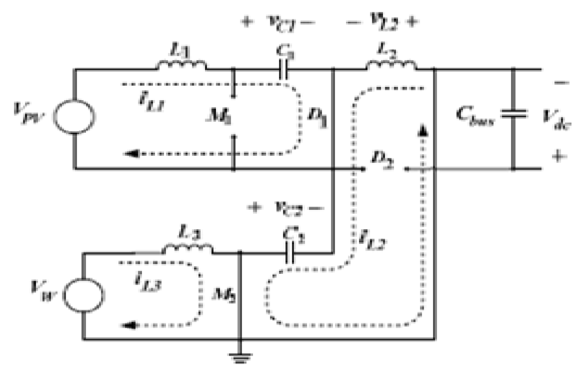


$$i_{L1} = I_{i,pv} + \frac{V_{pv}}{L_1}t \qquad d_2T_s<t<d_1T_s$$

$$i_{L2} = I_{dc} + \frac{V_{c1}}{L_2}t \qquad d_2T_s<t<d_1T_s$$

$$i_{L3} = I_{i,w} + \left(\frac{V_w - V_{c2}}{L_3}\right) \qquad d_2T_s<t<d_1T_s$$

Mode-III (M1 off, M2 on):



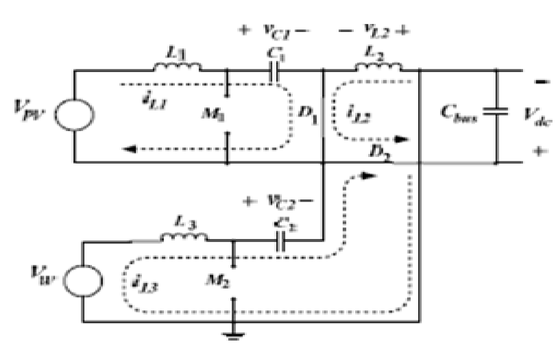
$$i_{L1} = I_{i,pv} + \left(\frac{V_{pv} - V_{c1}}{L_1}\right)t$$

$d_1T_s<t<d_2T_s$

$$i_{L2} = I_{dc} + \frac{V_{c2}}{L_2}t \qquad d_1T_s<t<d_2T_s$$

$$i_{L3} = I_{i,w} + \frac{V_w}{L_3}t \qquad d_1T_s<t<d_2T_s$$

Mode-IV (M1 off, M2 off):



$$i_{L1} = I_{i,pv} + \left(\frac{V_{pv} - V_{c1}}{L_1}\right)t \qquad d_2T_s<t<T_s$$

$$i_{L2} = I_{dc} - \frac{V_{dc}}{L_2}t$$

$d_2T_s<t<T_s$

$$i_{L3} = I_{i,w} + \left(\frac{V_w - V_{c2} - V_{dc}}{L_3} \right) t \qquad d_2T_s<t<T_s$$

The voltage and inductor current waveforms that illustrate the switching modes of above modes in below waveforms explained for condition the turn on duration of *M*2 is longer than or equal to *M*1.

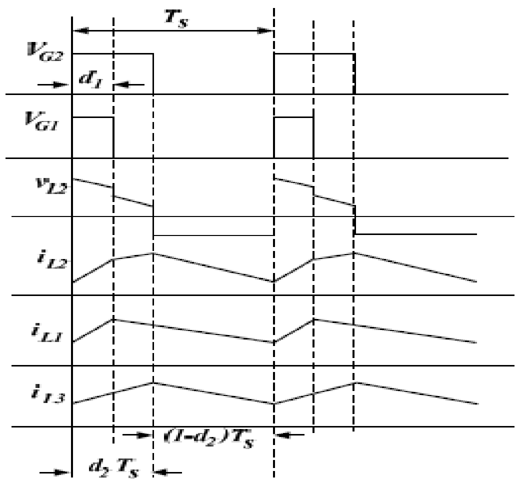


Fig (3): waveforms of inductor currents for switching modes M2 is longer than or equal to *M*1.

To find an expression for the output DC bus voltage V_{dc}, the volt-balance of the output inductor *L2*, is examined according to above figure with $d_2 > d_1$. Since the net change in the voltage of *L2* is zero, applying volt-balance to *L2* results in eq (3). The expression that relates the average output DC voltage (V_{dc}) to the capacitor voltages (v_{c1} and v_{c2}) is then obtained as shown in eq (4), where v_{c1} and v_{c2} can then be obtained by applying volt-balance to *L1* and *L3*. The final expression that relates the average output voltage and the two input sources (V_W and V_{PV}) is then given by eq (5). It is observed that V_{dc} is simply controlled by *M1* and *M2* individually or simultaneously.

$$(V_{c1}+V_{c2})d_1T_s + (V_{c2})(d_2-d_1)T_s + (1-d_2)(-V_{dc})T_s = 0 \quad (3)$$

$$V_{dc} = \left(\frac{d_1}{1-d_2}\right)V_{c1} + \left(\frac{d_2}{1-d_2}\right)V_{c2} \quad (4)$$

$$V_{dc} = \left(\frac{d_1}{1-d_2}\right)V_{pv} + \left(\frac{d_2}{1-d_2}\right)V_w \quad (5)$$

To describe a wind turbine power characteristic, below equation describes the mechanical power that is generated by the wind.

$$P_m = 0.5 \rho A C_p(\lambda, \beta) V_\omega^{\ 3}$$

Where

ρ = air density
A = rotor swept area
$C_p(\lambda,\beta)$ = power coefficient function
λ = tip speed ratio
β = pitch angle
V_ω = wind speed

The power coefficient (C_p) is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The TSR (λ) refers to a ratio of the turbine angular speed over the wind speed. The mathematical representation of the TSR is given below. The pitch angle (β) refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis.

$$\lambda = \frac{R\omega_b}{V_\omega}$$

Where,

R = turbine radius
ω_b = angular rotational speed

Figure 7 and 8 are illustrations of a power coefficient curve and power curve for a typical fixed pitch (β =0) horizontal axis wind turbine. It can be seen from figure 7 and 8 that the power curves for each wind speed has a shape similar to that of the power coefficient curve. Because the TSR is a ratio between the turbine rotational speed and the wind speed, it follows that each wind speed would have a different corresponding optimal rotational speed that gives the optimal TSR. For each turbine there is an optimal TSR value that corresponds to a maximum value of the power coefficient ($C_{p,\max}$) and therefore the maximum power. Therefore by controlling rotational speed, maximum power can be obtained for different wind speeds.

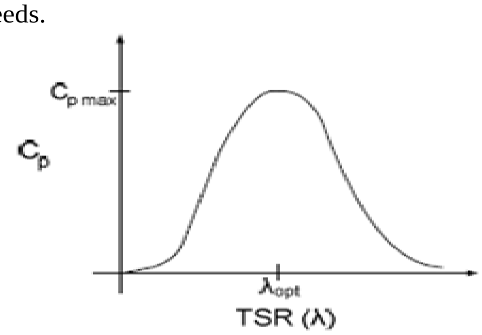


Fig (4): Power Coefficient Curve for a typical wind turbine

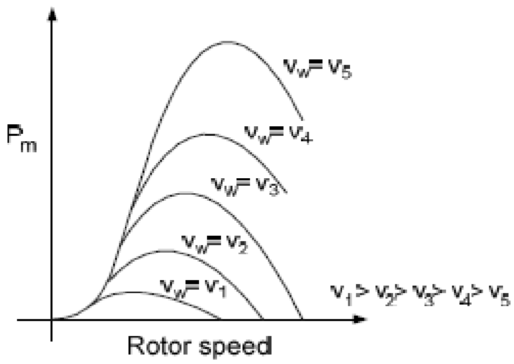


Fig (5): Power Curves for a typical wind turbine

A solar cell is comprised of a P-N junction semiconductor that produces currents via the photovoltaic effect. PV arrays are constructed by placing numerous solar cells connected in series and in parallel. The equivalent circuit is shown by below figure. The current-voltage characteristic of a solar cell as follows

$$I = I_{ph} - I_D$$

$$I = I_{ph} - I_0\left[\exp\left(\frac{q(V + R_s I)}{Ak_B T}\right) - 1\right] - \frac{(V + R_s I)}{R_{sh}}$$

Where

I_{ph} = photo current

I_D = diode current

I_0 = saturation current

A = ideality factor

q = electronic charge 1.6x10-9

k_B = Boltzmann's gas constant (1.38x10-23)

T = cell temperature

R_s = series resistance

R_{sh} = shunt resistance

I = cell current

V = cell voltage

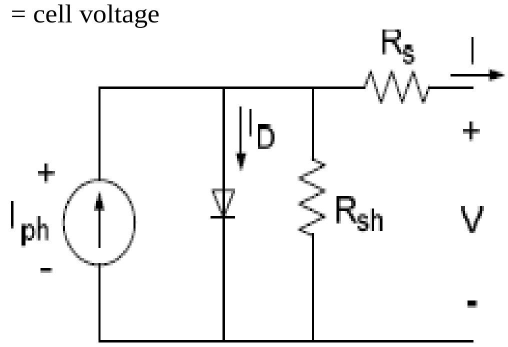


Fig (6): PV cell equivalent circuit

Typically, the shunt resistance (R_{sh}) is very large and the series resistance (R_s) is very small. Therefore, it is common to neglect these resistances in order to simplify the solar cell model.

The resultant ideal voltage-current characteristic of a photovoltaic cell is given as follow and illustrated by below fig (6).

$$I = I_{ph} - I_0\left[\exp\left(\frac{qV}{k_B T}\right) - 1\right]$$

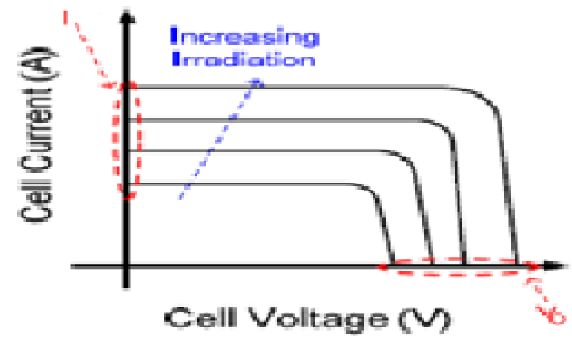


Fig (7): waveform of 1-ph seven level inverter circuit

The typical output power characteristics of a PV array under various degrees of irradiation is illustrated and it can be observed in below figure that there is a particular optimal voltage for each irradiation level that corresponds to maximum output power. Therefore by adjusting the output current (or voltage) of the PV array, maximum power from the array can be drawn.

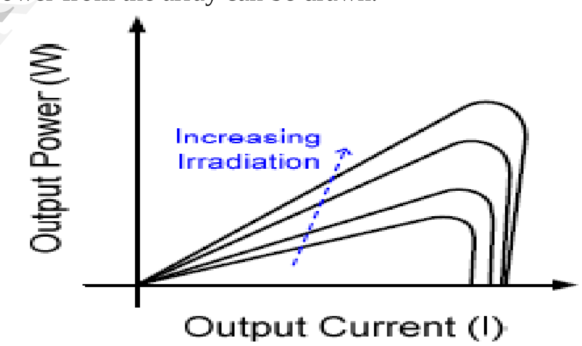


Fig (8): PV cell power characteristics

3. 1-PH MULTILEVEL INVERTER

The power electronics device which converts DC power to AC power at required output voltage and frequency level is known as inverter. The voltage source inverters produce an output voltage or a current with levels either 0 or +ve or -ve V dc. They are known as two-level inverters. Multilevel inverter is to synthesize a near sinusoidal voltage from several levels of dc voltages. They typically synthesize the stair case voltage waveform which has reduced harmonic content.

$$L = 2n + 1$$

Where,
L = Level of inverter
n = number of cascaded inverters

For example here number of cascaded inverters is three (n=3) is substituted in equation we get L=7 means the level of the inverter is seven.

In this paper simulation model of single phase Seven-level inverter has been developed using MOSFETs. Gating signals for these MOSFETs have been generated by pulse generators. In order to maintain the different voltage levels at appropriate intervals, the conduction time intervals of MOSFETs have been maintained by controlling the pulse width of gating.

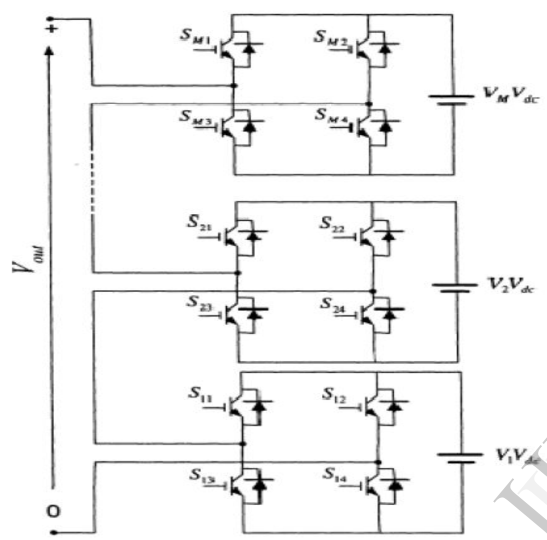


Fig (9): 1-ph seven-level inverter circuit

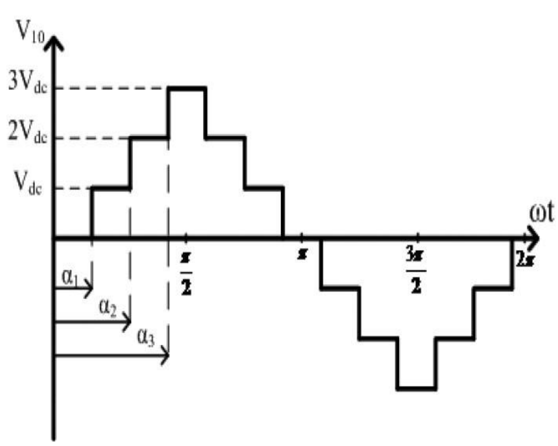


Fig (10): waveform of 1-ph seven-level inverter circuit

4.SIMULATION MODEL

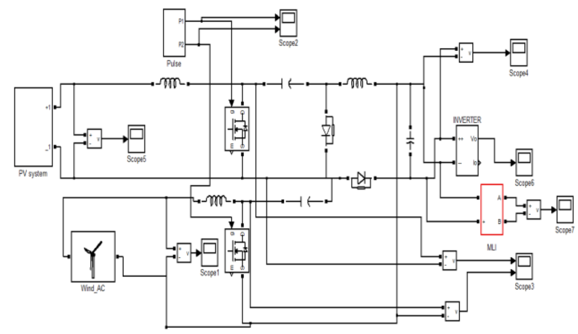
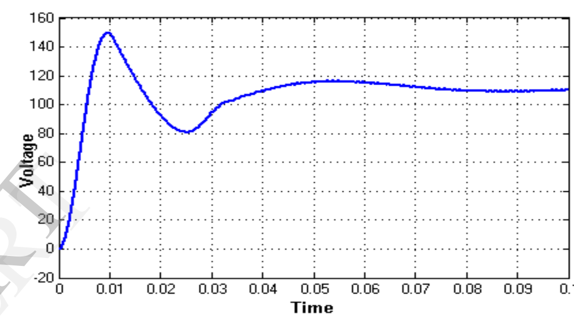
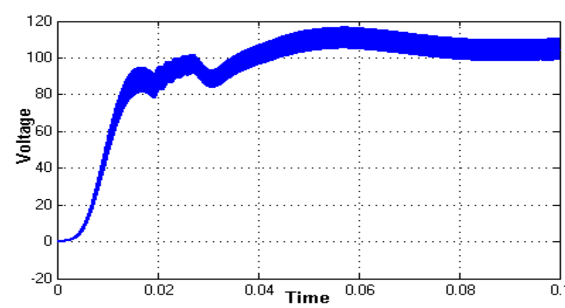


Fig (11): Simulation model for hybrid wind solar energy system

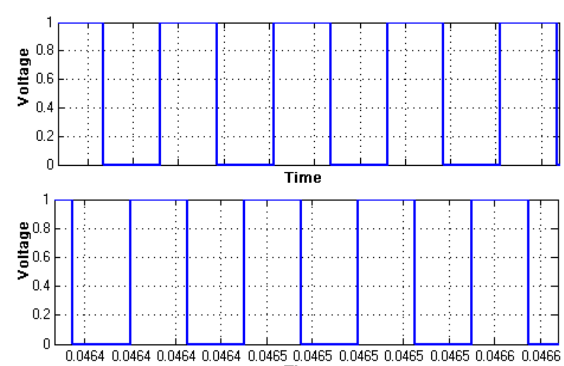
Simulation results:



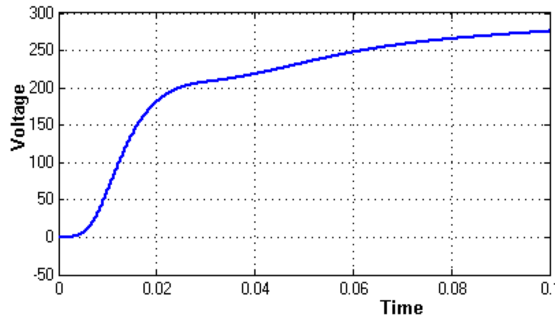
(a)



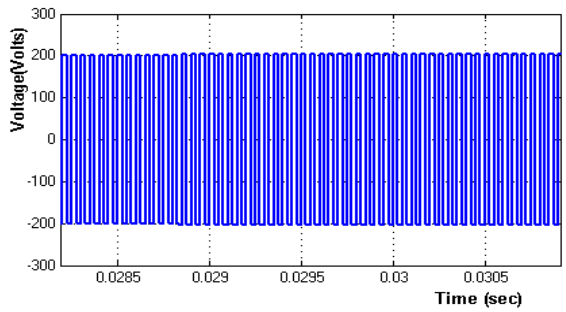
(b)



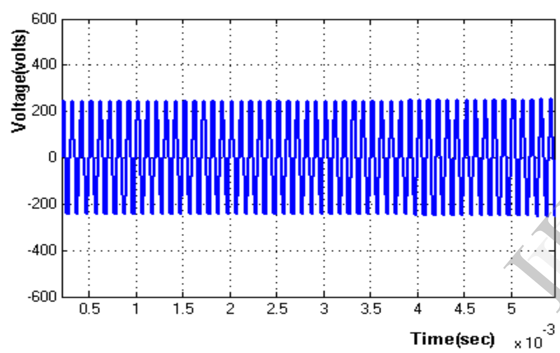
(c)



(d)



(e)



(f)

Fig (12): simulation results for (a) Solar generated voltage (b) Wind generated voltage (c) Pulses for M1&M2 (d) Inverter incoming dc voltage waveforms (e) Inverter output ac voltage (f) Output ac voltage of multi-level inverter

5.HARDWARE IMPLEMENTATION

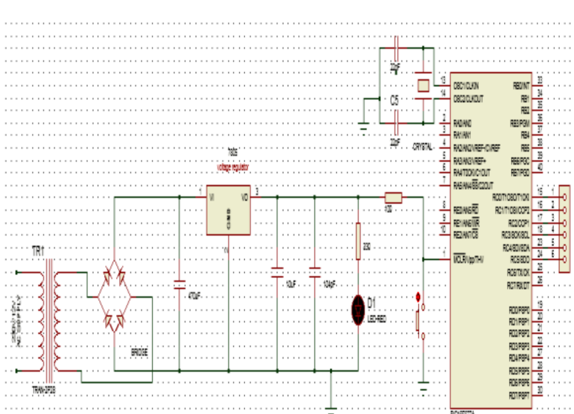


Fig (13): Control circuit diagram used in Hardware

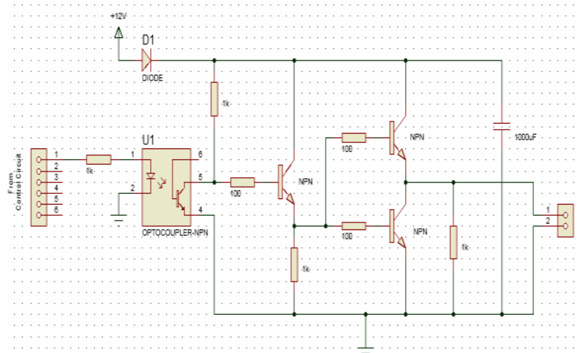


Fig (14): Driver circuit diagram used in Hardware

Fig (15): Experimental setup of Renewable hybrid wind solar energy system fed single phase inverter.

Hardware results:

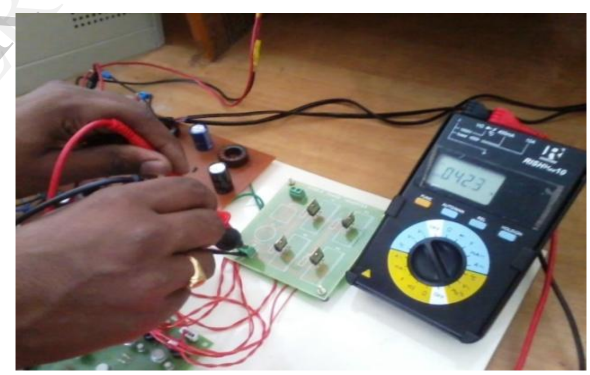


Fig (16): Output voltage of inverter

CONCLUSION

In this paper a renewable hybrid wind solar energy system fed single phase multilevel inverter presented. The features of this circuit are: Additional input filters are not necessary to filter out high frequency harmonics. Both renewable sources can be stepped up/down. Individual and simultaneous operation is supported. Simulation results have been presented. Simulation models are constructed for the both single phase inverter and single phase multilevel inverter, hardware is implemented for single phase inverter.

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BIOGRAPHY

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