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High Voltage Gain KY Converter with Microinverter for Microsource Application

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Abstract: In this paper, modeling and simulation of photovoltaic system as a microsource with KY converter and microinverter is presented. The output of the PV system is given to a KY converter for boosting the voltage. The KY converter combines one coupled inductor and charge pump capacitor. The high voltage gain is achieved by the coupled inductor. Due to the presence of output inductor at the load side of KY converter, the output current is non-pulsating. Besides this output voltage ripple is considerably reduced. The output from KY converter is fed to a full bridge inverter to generate AC out. Here we use hybrid pulse width modulation technique to drive the inverter, thus reduce switching loss and hence improve the converter efficiency. A model of the proposed system is done with battery source as the input.

Keywords: Coupled inductor, KY converter, Photovoltaic cell, MPPT, Hybrid PWM.

I. INTRODUCTION

To fuel development energy is required. However uncontrolled increase in consumption of energy cause global impact like global warming, deteriorating environment, rise in price of petroleum and other fossil fuel and the like. Studies indicate that rise in energy demand is 8-10% per annum. And this demand is met by using non-renewable sources of energy.

In such a scenario, microsources are gaining more attention. The microsource is classified either a DC source or as a high frequency AC source. These two microsource categories are comprised of diverse renewable energy applications, such as solar cell modules, fuel cell stacks, wind turbines and reciprocating engines. The output of microsource is DC, but the magnitude of output voltage is very low. Here arise the needs of a high voltage boosting converter. The circuit diagram of proposed system is shown in Fig. 1. Different boosting converters are boost converter, SEPIC converter, cuk converter, KY converter and the like. Among these KY converter is the most acceptable one. KY converter is a DC to DC voltage boosting up converter [1]. The output from the microsource is given to KY converter and at the output of KY converter desired voltage will generated by adjusting the duty cycle of KY converter. The DC out from KY converter is given to a full bridge inverter to fuel AC loads. Here we use hybrid PWM switching pulse technique for the full bridge inverter.

KY converter is a step up dc-dc converter. It is invented by the Mr. K. I Hwu and Y. T Yau. Hence, it is called as KY converter. It is a boost converter. It contain two power switches, one power diode one power diode, one energy transferring capacitor and output capacitor and inductor [2]. The voltage conversion ratio of basic KY converter is 1+D, which is higher than that of that of traditional boost converter and buck-boost converter. For further improving the voltage gain, one coupled inductor [3] is incorporated to the basic KY converter [4], [5], [6].

In addition to the high voltage gain, the proposed converter posses very small output voltage ripple and the output current is non-pulsating. Besides, there the output voltage polarity is same as that of input voltage polarity. Again to increase voltage gain voltage multiplier cell is incorporated with the converter circuit [7], [8].

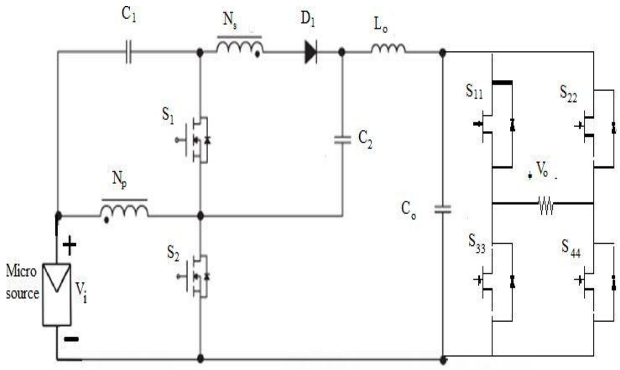

Fig.1. Circuit diagram of proposed system.

II. KY CONVERTER CONFIGURATION

The proposed KY converter has high voltage gain due to the presents of coupled inductor.

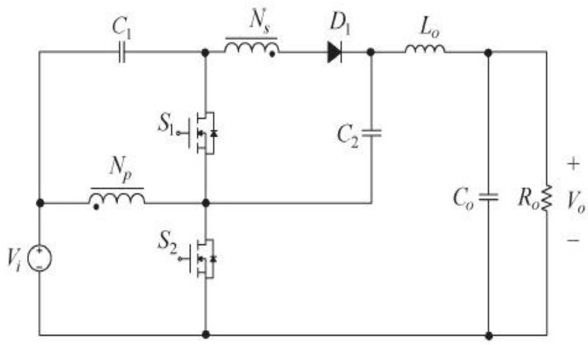

Fig.2. KY converter with coupled inductor.

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Fig. 2 shows the circuit diagram of KY converter with coupled inductor for voltage boosting.

The circuit consist of two MOSFET S_1 and S_2, one coupled inductor of primary winding with N_p turns and the secondary winding with N_s turns, two capacitor C_1 and C_2, output inductor Lo, output capacitor C_o and load Ro, capacitor C_o and load R_o. The input to the converter is 12 V DC from PV array. And gate signal for the MOSFET have duty cycle in the order of (1 – D) and D for S_1 and S_2.

III. OPERATING PRINCIPLE

There are two operating modes in the proposed KY converter with coupled inductor.

Mode 1: During mode 1, switch S_1 is OFF and S_2 is ON shown in Fig. 3(a). As S_1 OFF and S_2 ON input voltage V_i imposed on primary winding N_p of coupled inductor. This cause magnetizing inductor L_m, which is connected in parallel with the primary winding of coupled inductor to magnetize. Also voltage across N_s to be induced due to the voltage in the primary of coupled inductor.

$$V_{Ns} = V_{Np} * N_s/N_p$$

Where, N_s/N_p is the turns ratio of coupled inductor is the turns ratio of coupled inductor.

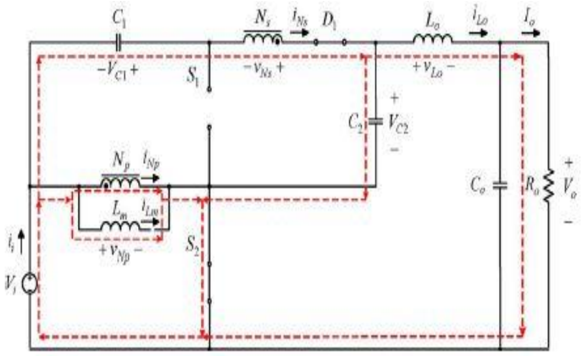

Fig. 3(a). Current flow in mode 1.

As a result diode D_1 is forward biased. Also the charge pump capacitor C_2 is charged.

Mode 2: In this mode switch S_1 is ON and S_2 is kept OFF. Mode 2 circuit diagram is shown in Fig. 3(b). Therefore, the primary of coupled inductor gets the voltage of capacitor C_1.

$$V_{Np} = -V_{c1} * N_s/N_p$$

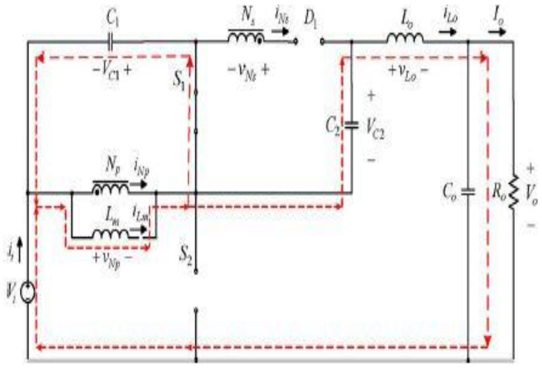

Fig. 3(b). Current flow in mode 2.

Hence, the magnetizing inductor L_m demagnetized. Due to voltage in the primary of coupled inductor, voltage is imposed in the secondary. Because of the negative voltage at the secondary coupled inductor diode D_1 is reverse biased.

Fig. 4 shows the corresponding waveform at interval of mode 1 and mode 2 operations. V_{g1} and V_{g2} is the gate signal for the power switch S_1 and S_2. i_{Np} and i_{Ns} indicate the coupled inductor primary and secondary current. V_{Lo} and i_{Lo} is the output inductor voltage and current respectively.

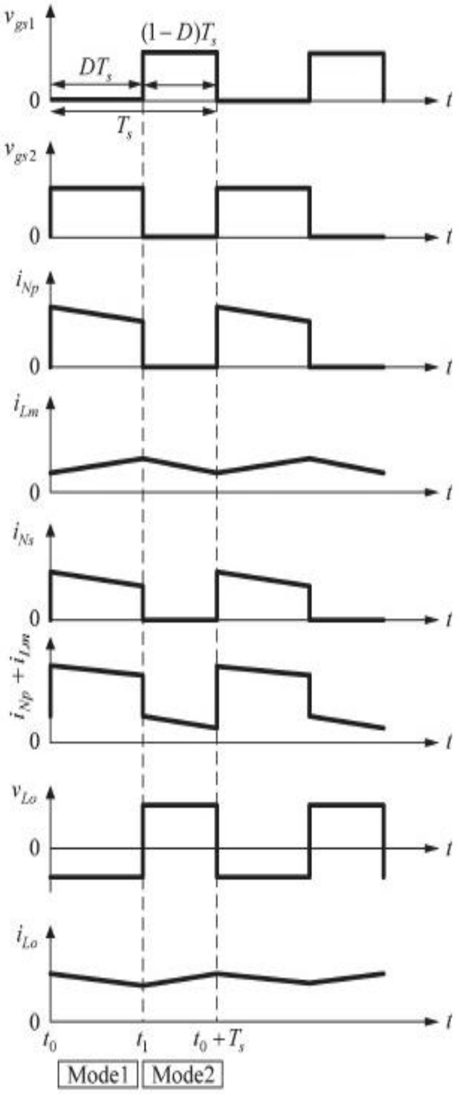

Fig. 4. Waveform of KY converter.

By voltage second balance principle to L_o and L_m over one switching cycle. We get the output voltage equation,

$$V_o = V_i*(2\text{-}D/1\text{-}D + N_s/N_p)$$

Where,

V_o - Output voltage

V_i - Input voltage

D - Duty cycle of power switch

N_s/N_p- Turns ratio of coupled inductor

Design consideration of the components used in the KY converter is discussed below. The energy transferring capacitor C_1 is designed in such a way that the peak-to peak value of capacitor voltage is minimized. Hence the value of C_1 can be written as:

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$$C_1 \geq \frac{i_{C1}\Delta t}{\Delta v_{C1}} \quad (1)$$

The charge pump capacitor C_2 value is obtained in order to minimize the variation in capacitor voltage and is given by:

$$C_2 \geq \frac{i_{C2}\Delta t}{\Delta v_{C2}} \quad (2)$$

Magnetizing inductor L_m is designed o operate in the positive region. And it can be obtained as:

$$L_m \geq \frac{V_i D T_s}{\Delta i_{Lm}} \quad (3)$$

Assuming the value of duty cycle as 50% and frequency as 100 kHz we get the values of all the components use in the converter.

IV. MODELLING OF PV CELL

To generate electricity from solar energy photovoltaic panel is used. When solar light hit the surface of photovoltaic panel, it generates direct current electricity. The photovoltaic panel consists of number of solar cells connected in series and parallel fashion. To analysis the photovoltaic generator, the physical modeling is not efficient. Here arises the mathematical modeling approach, because the voltage-current equation of solar cell is nonlinear and the solar cell parameters are varying with temperature and solar irradiation [12].

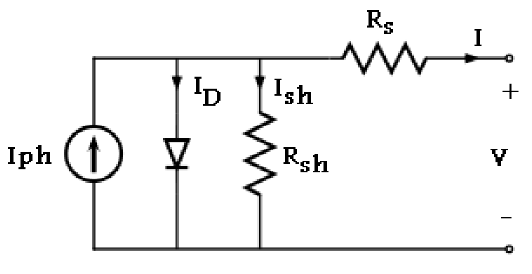

Fig. 5. Equivalent circuit of PV cell.

The equivalent circuit of PV cell is shown in Fig. 5. The modeling of photovoltaic array is depends on the basic equation of the solar cell. The module photo current, reverse saturation current, saturation current and the current output of PV module is given in equation (4), (5), (6) and (7) respectively.

$$I_{ph} = [I_{scr} + k_i(T - 298)]\frac{\lambda}{1000} \quad (4)$$

$$I_{rs} = \frac{I_{scr}}{\exp\left(\frac{q V_{oc}}{N_s k A T}\right) - 1} \quad (5)$$

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\frac{q E_{go}\left[\frac{1}{T_r} - \frac{1}{T}\right]}{Bk} \quad (6)$$

$$I_{pv} = N_p I_{ph} - N_p I_o\left[exp\left[\frac{q(V_{PV} + I_{PV} R_s)}{N_s A kT}\right] - 1\right] \quad (7)$$

Where,
T_{ref} - Reference temperature
= 298 K
T - Module operating temperature in Kelvin
A - An ideality factor
= 1.6
A=B
K - Boltzman constant
= 1.3805 × 10-23 J/K
q - Electron charge
= 1.6 × 10-19 C
Rs - Series resistance of a PV module
λ is the PV module illumination (W/m2) = 1000W/m2
Ego - Band gap for silicon = 1.1 eV
Ns - Number of cells in series
Np - Number of cells in parallel
Here we put, Vpv = Voc, Np = 1 and Ns = 36

MATLAB model of I_{pv} is generated based on the above equations. Then incorporating this model with equivalent circuit of PV cell, we get a model for PV array. In the modeling the varying parameter are temperature and irradiation level. Fig. 6 shows the MATLAB/SIMULINK model of photovoltaic cell.

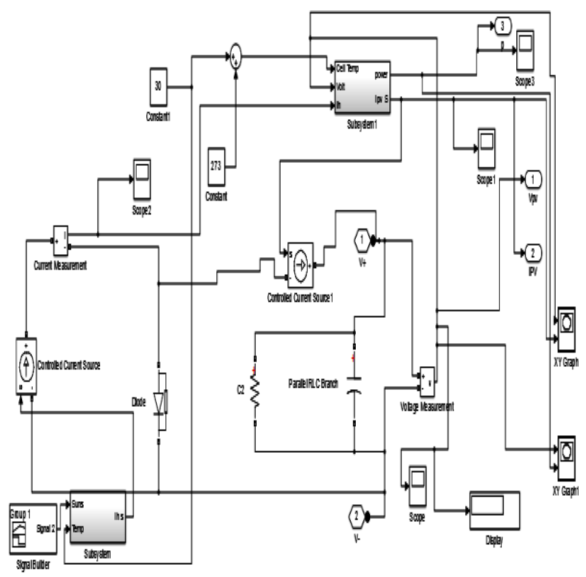

Fig. 6. Simulink model of PV array.

V. MICROINVERTER

The word inverter in the context of power-electronics denotes a class of power conversion (or power conditioning) circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. By definition inverter is a device which convert dc power into ac power of desired voltage and frequency. In the proposed system a full bridge inverter with hybrid PWM (HPWM) technique is used.

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In hybrid pulse width modulation technique is generated by comparing a carrier signal with a control signal. HPWM ensure without significant switching loss penalty, from which a high-quality output waveform, can be obtained. With this method, only two of the four power switches are commutated at high frequency. Although total switching loss is reduced, the switching losses of the four switches are unequal, especially at higher frequency or heavy load. The switching signal using hybrid PWM technique is indicated in Fig. 7.

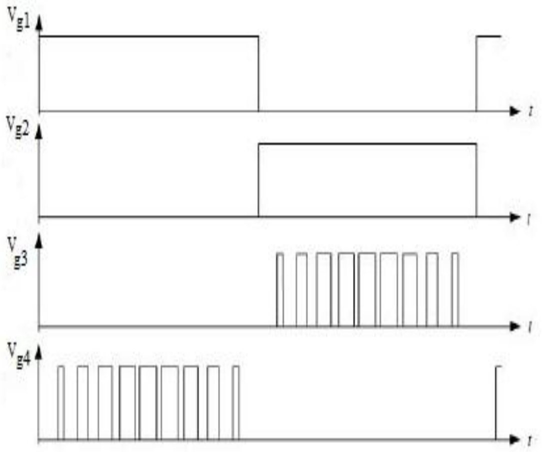

Fig.7. Hybrid PWM pulses for inverter.

VI. SIMULATION RESULT

The simulation of the proposed KY converter combining coupled inductor with PV array and HPWM inverter is done using MATLAB SIMULINK model and is shown in Fig. 8. Table I shows specifications of components of the proposed KY converter.

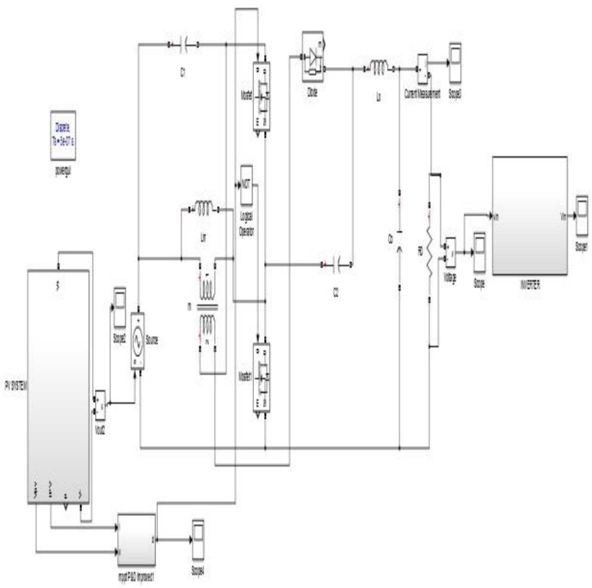

Fig.8. Simulink model of KY converter with microinverter.

Fig. 9 shows the input voltage given to the converter from the PV module. Fig. 10 indicates the output voltage of the KY converter.

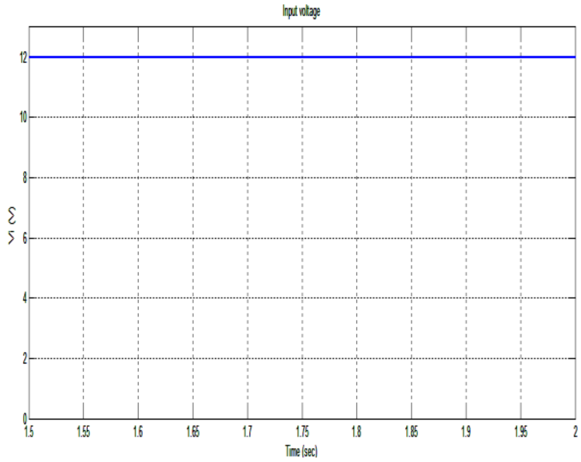

Fig.9. Input PV voltage waveform.

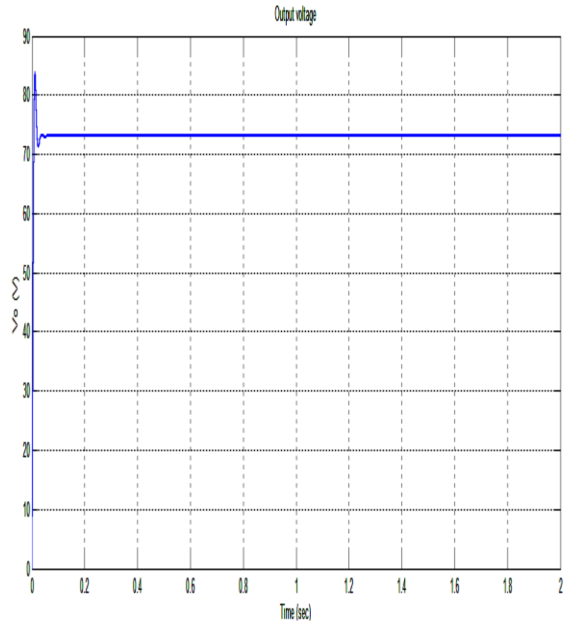

Fig.10. Output voltage waveform of KY converter.

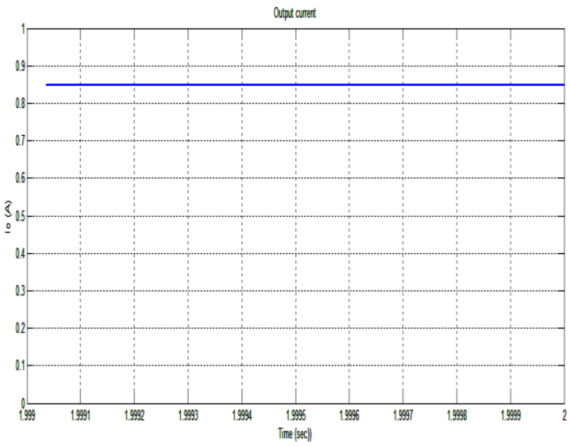

Fig.10. Output current waveform.

From Fig. 10 it is clear that the input 12 V DC is step up to 72 V DC. The high voltage gain is achieved due to the presents of the coupled inductor. Gate signal for the switch S_1 and $S_{2\ \mathrm{at}}$ 50% duty cycle is generated. Switch voltage of S_1 and S_2 are shown in Fig. 11.

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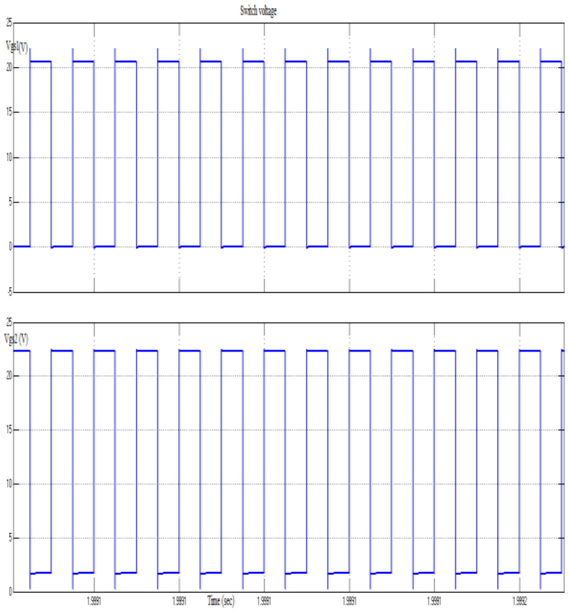

Fig.11. Switch voltage waveform of S_1 and S_2.

The operation of converter is done at high frequency at around 100 kHz. The advantage of high frequency operation is that the components size will reduced to a great extend. The gate pulses are complimentary to each other. Hence, at a time only one switch is on. So, switching loss is very low. The gate pulses for experimental set up is generated using microcontroller. Here we use ATMEGA 16 as the controller. It has four ports and each port has eight pins. Hence it has the capability to generate number of gate pulses from the same controller.

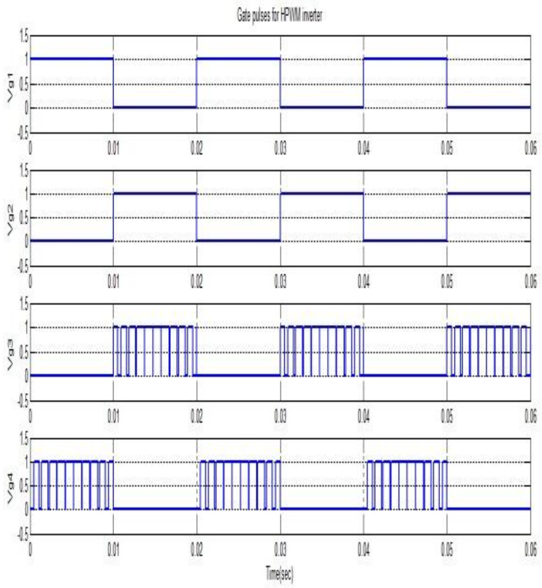

Fig.12. Hybrid PWM pulses for inverter.

The output of KY converter is DC, which is given to the input of full bridge inverter. The gate pulses for full bridge inverter is generated using HPWM technique as in Fig. 12. The AC output waveform of inverter is shown in Fig. 13.

In the simulink model of the proposed converter PI controller feedback is used. The output voltage is compared with the reference voltage.

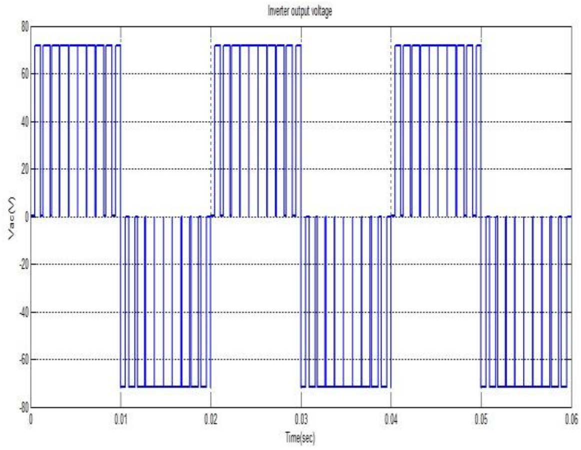

Fig.13. Output voltage waveform of HPWM inverter.

In the proposed converter step voltage is used as the reference voltage. The error voltage result from the difference of the actual voltage and desired voltage and the MPPT (Maximum Power Point Tracking) controller out is given to the PI controller to generate corresponding gate signal for the power switches. MPPT is used to operate the converter at the MPP (Maximum Power Point) of the solar panel even under varying temperature and irradiation level. We use perturb and observe algorithm (P and O) for MPPT because it is the most common method for tracking the MPP of a solar power system. Besides this, (P and O) require less computation in the controller. The major drawbacks of perturb and observe method is that the tracking speed is much low and create oscillation. Oscillation mean the output will fluctuate around the MPP.

Table I. Components specifications of KY converter

Components	Specifications
Magnetizing inductor, Lm	148.7 µH
Energy transferring capacitor, C_1	470 µF
Charge pump capacitor, C_2	94 µF
Coupled inductor,	N_p:N_s = 1:3
Output inductor, Lo	188 µH
Output capacitor, Co	440 µF
Output resistor, Ro	89 Ω

VII. EXPERIMENTAL RESULTS

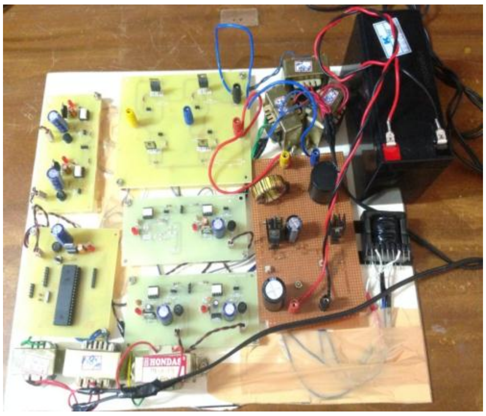

Fig.14. Hardware of proposed system.

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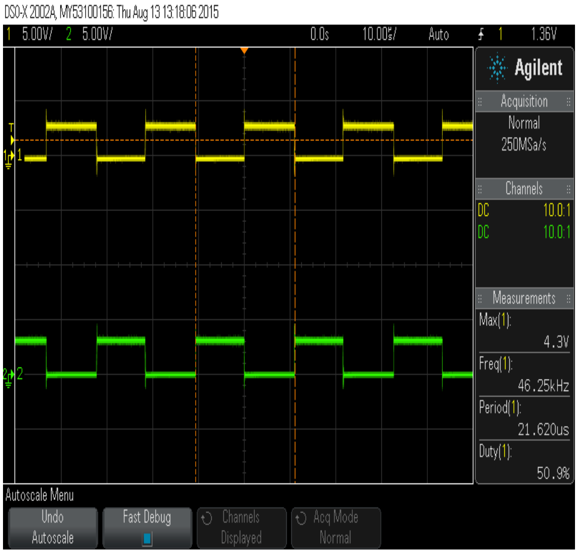

Fig. 15.Gate pulses for KY converter.

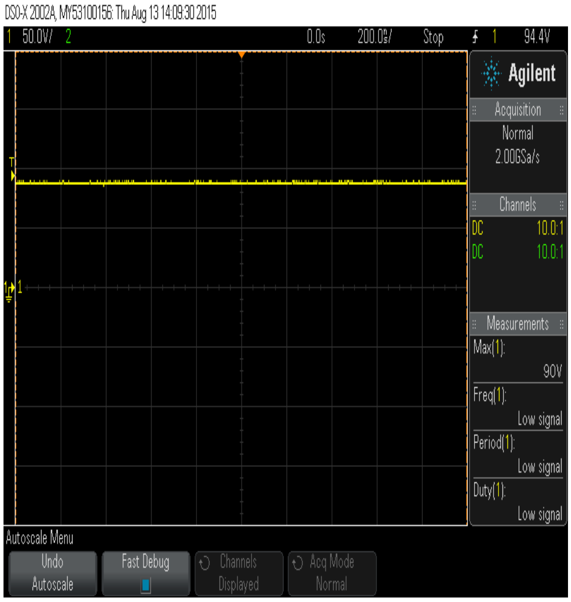

Fig.16. Output voltage waveform of KY converter.

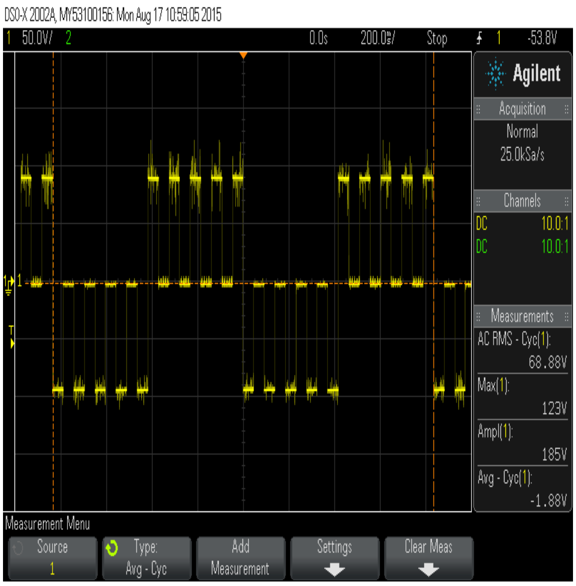

Fig.17. Output voltage waveform of HPWM inverter.

The proposed prototype of the system is designed with the assumption that the microsource energy system shall be replaced by a 12 V DC supply. Fig. 14 shows the photograph of hardware model. The switching pulses for KY converter and inverter are generated using ATMEGA 16 microcontrollers. Fig. 15 shows the switching pulses for KY converter. Fig. 16 indicates the KY converter output voltage and Fig. 17 shows the inverter output voltage waveform.

VIII. CONCLUSION

A high voltage boosting KY converter combining coupled inductor fed with solar panel has been presented herein. Photovoltaic panel is modelled using MATLAB software and the model provides greater flexibility to the varying parameter of temperature and irradiation level. The high voltage gain of KY converter is achieved with the help of coupled inductor. The output inductor of the load side of the converter cause non pulsating output current. Furthermore, the converter structure is quite simple and required less components. Moreover the converter is best suitable to boost the output voltage from the PV cell and fuel cell. The main disadvantage of the converter is the core loss of the coupled inductor. To feed the AC loads a hybrid PWM full bridge inverter is used, which reduce the switching losses. The hardware of the proposed system is implemented and the result seems to be similar with simulation results.

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