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Simulation and Implementation of Hybrid Solar Inverter using Synchronous Buck MPPT Charge Controller and Bidirectional Converter for Domestic Applications

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Abstract: India is the world's third electricity power producer and consumer after US and China, however, the electricity supply in most of the Indian states are generally considered unreliable. Indian Government is taking lot of steps to meet the electricity demand; the renewable energy sector is one of the major focuses by all the state governments. Home inverters with energy storage devices are playing major role in India to overcome the unreliable electricity problems. Lead acid battery is a major energy storage device being used in the Home inverter at the voltage range of 12V to 48V. Efficient usage of energy is very important to have extended battery backup and also it will reduce the greenhouse gas emissions and other pollutants caused by the inefficient use of energy. This paper proposes a Hybridsolar home inverter using Synchronous buck MPPT charge controller and the bidirectional Inverter. The Hybrid Home system consists of a Solar MPPT charge controller, an energy storage device and a bidirectional inverter. The battery can be charged either from the solar energy through MPPT charge controller or from the grid supply through the bidirectional inverter. The bidirectional inverter is operated either in Inverter mode or in the charge mode depending upon the grid and solar availability.

Keywords: Photo voltaic (PV), Maximum power point tracking (MPPT), Sinusiodal pulse width modulation (SPWM), Constant current constant voltage (CCCV).

1. INTRODUCTION

There is a close relation between electricity consumption and economic growth. It was studied that those countries whose income level is higher there consumption of electricity is also higher. When a country condition improves it was seen their level of electricity consumption also increases. As we know India is a developing country and recently India economic growth is been increasing day by day in recent trend. "Residential consumption of electricity in India" a documentation of data methodology by World Bank (2008) stated that currently, lighting accounts for approximately 30 percent of total residential electricity use followed by refrigerators, fans, electric water heaters and TV. As the world energy consumption is growing with a high

Rate and the non-renewable sources reserves are decreasing; the search for alternative energy sources has become an imminent issue in the world. Therefore, there is an increasing interest in standalone generating systems based on renewable energy [1]. Figure 1 shows the block diagram of a proposed solar home inverter. In India the inverters at the rating of 500 VA to 1 KVA are very popular and these inverters are with the energy storage capacity of between 1.2 KWh to 1.8 KWh. Lead acid batteries are the main storage devices being used to meet the required energy support and these batteries are at 12V at the ampere range of 100 to 150 AH.

As shown in Figure 1, the battery will be charged from the two sources – Photo voltaic (PV) and the gird. In this system smart energy management algorithm also built in, higher priority will be given for utilizing the energy generation from the photo voltaic panels; at the mean time the system makes sure that the 100% of energy availability to the loads. The bidirectional inverter will be driven into the charge mode

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of operation as and when the energy generation in the PV is very low and the state of charge in the battery is critically low.

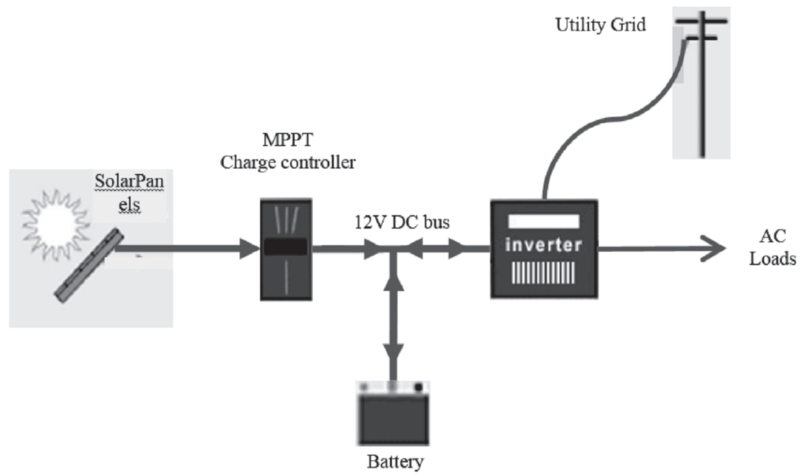

Figure 1: Block diagram of Hybrid Solar Home inverter

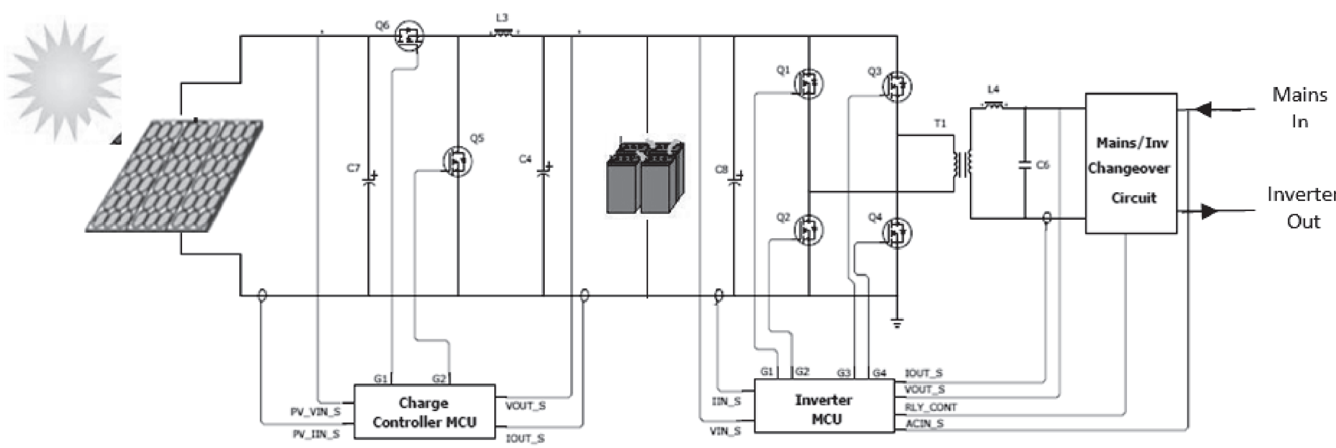

Figure 2: Proposed Hybrid Solar Home Inverter using Synchronous Buck MPPT charge controller and Bidirectional Inverter

Otherwise the PV charges the battery; bidirectional inverter will be in standby mode and Grid supports the AC loads. If there is excess power generation in the PV and the state of charge of battery is more than 80%, then the entire Load will be powered from the PV energy. Automatic inverter/mains switch over circuit available in the inverter drives the loads either on the mains or on the inverter depending upon the inverter mode of operation.

2. FEATURES & ELECTRICAL SPECIFICATION

A. Special Features:

- MPPT charge controller based on Efficient Synchronous Buck topology
- Built in Perturb & Observe (P & O) MPPT & Constant Current Constant Voltage (CCCV) charge control algorithm
- Battery storage capacity up to 1.8KWh
- Priority to solar for charging
- Bidirectional off grid inverter based on Full bridge topology

- Optional Battery less operation
- Battery charging through Solar and Grid options
- Built in Efficient Energy management algorithm
- Supporting the load during excess PV availability

B. Electrical specification:

Table 1
The Electrical specification of proposed system

Parameter	*Value*
Rated Input Power	600W
No. of PV modules	2#
Open circuit Voltage (V_{OC}) max	100V
MPPT Voltage range	25 – 76V
Grid Input	230VAC, 50HZ
Battery	12V, Pb
Rated AC output Power	500W
MPPT Charge controller topology	Synchronous Buck
Inverter Topology	Full bridge

3. SYSTEM CONFIGURATION

Figure 1 shows the main components of the system and the proposed system is a standalone system with battery backup and the optional grid input provides an added benefit to the households as a second source of energy available during bad weather conditions.

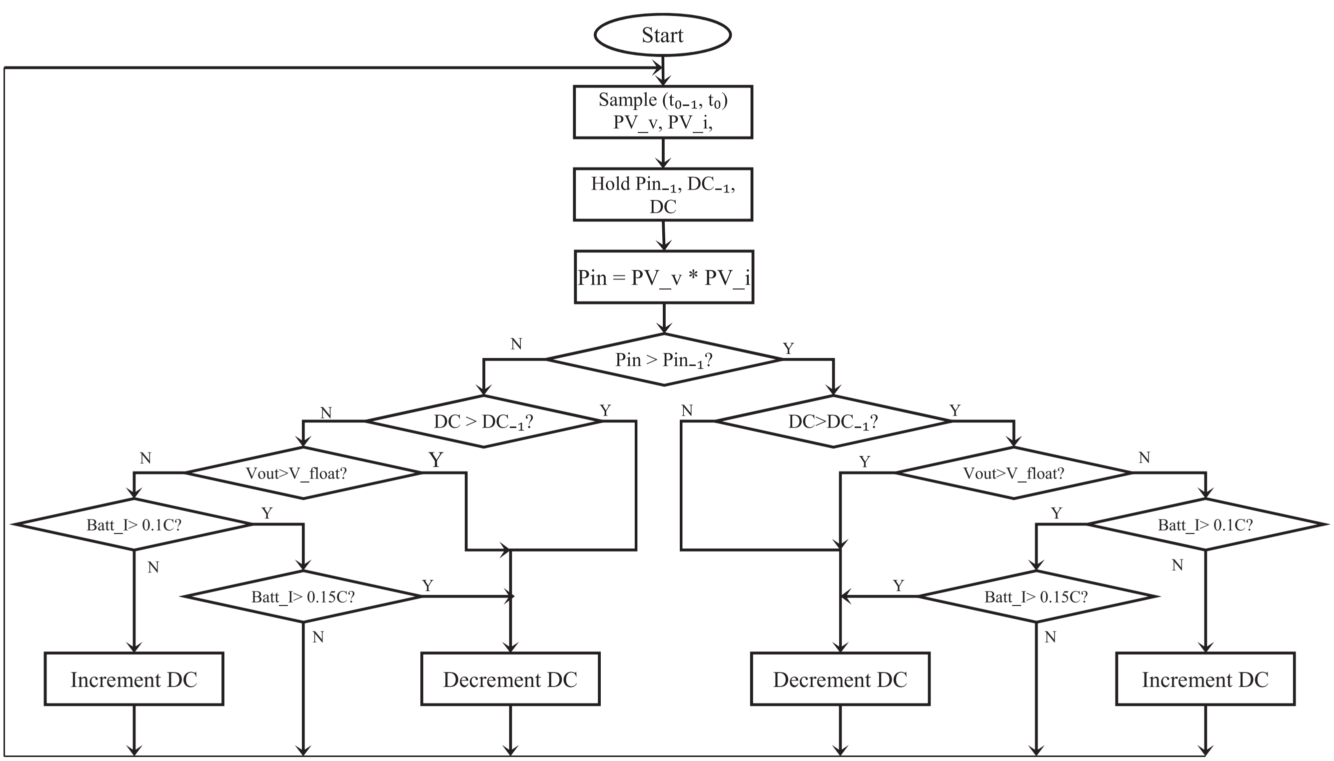

Figure 3: Flowchart of MPPT charge controller

Solar panels charge the battery during day time as well as support the loads connected at the output of bidirectional inverter. The MPPT charge controller is a buck DC – DC converter with built in MPPT and charge control algorithm for the Lead acid batteries. The bi directional inverter operates either as an inverter to convert the DC voltage to 230VAC or as a Charge controller to charge the battery from the grid input as and when needed. Figure 2 shows the power circuit configuration of the system.

A. MPPT Charge Controller

A solar panel can be assumed to be a DC Source whose internal impedance varies over the amount of light striking its surface or the cell temperature. Basic energy transfer theory dictates that for maximum power, the source impedance and the load impedance should be equal. In the case PV panels, the source impedance varies with environmental conditions. Hence, to get the maximum power generated out of the panels, the MPPT controller is used to match the load impedance with the PV panel impedance on various environmental conditions.

The Buck topology has been used in the proposed system for maximum power point tracking. The freewheeling diode in the buck converter is replaced with a MOSFET in synchronous buck topology to reduce the losses due to Vf of the freewheeling diode.

The relationship between the input voltages (Vin), Output voltage (Vo)and duty cycle (D) of the buck converter is given in (1)

$$V_O = D \times V_{in} \quad (1)$$

The output voltage of the converter is controlled by controlling the duty cycle, hence the impedance on the PV panel due to load is controlled.

The gate signals to the synchronous buck converter is generated based on MPPT algorithm and battery charging algorithm using PIC microcontroller. The MPPT is based on well-known Perturb & Observe algorithm and the battery charging profile is implemented with Constant-Current Constant-Voltage (CCCV).

The Flowchart of MPPT algorithm with CCCV charging profile is given in Figure 3. The switching frequency of the PWM is 40 KHz. In order to avoid reverse current flow due to synchronous MOSFET switching, the duty cycle of synchronous MOSFETis limited until the inductor volt – second balance, so that the converter is operated in discontinuous conduction mode until the load current is below DCM-CCM boundary. Duty cycle for the synchronous MOSFET is generated using (2)

$$(1 - D)T = DT \times (V_{in} - V_O) / V_O \quad (2)$$

B. Bidirectional Inverter

The H – bridge topology is selected for the bidirectional inverter, i.e. bidirectional power flow between DC and AC link. A common H – bridge hardware is used to invert DC power into AC power and AC power into DC to charge the battery from grid supply. The Battery Charger mode and Inverter mode are the two normal operating modes of the bidirectional inverter.

1. Inverter mode

If the AC mains voltage is not detected, the battery charger is disabled and the bi directional switches to the Inverter mode. During Inverter mode, the system is running on battery power and produces a clean sinusoidal voltage at the output of the system so that the loads connected at the output can continue operation without interruption. The gating signals for the H – bridge are based on sinusoidal pulse width modulation (SPWM).

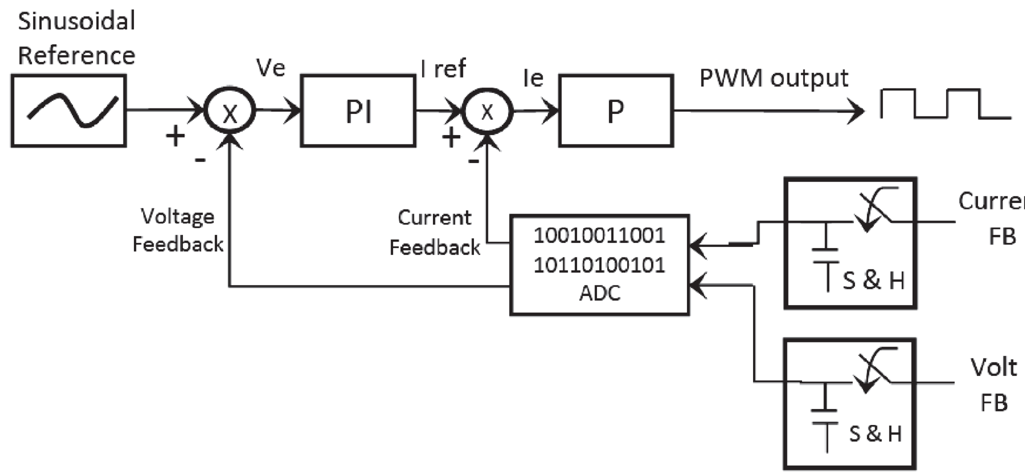

Figure 4: Inverter control scheme

The reference sinusoidal waveform or the modulating signal is generated using a sine lookup table in the data memory. This lookup table serves as the sinusoidal reference voltage for the inverter control loop. The inverter output is regulated to the set value by varying the voltage reference using a sinusoidal lookup table. The measured output voltage (feedback) is subtracted from the present reference value and the voltage error is obtained. The voltage error is fed into the voltage error compensation algorithm within the ADC interrupt service routine. The output of the voltage error compensator produces the current reference value. The measured output current is subtracted from the current reference to obtain the current error. The current error is used as the input to the current error compensation algorithm to produce the command signal for the PWM module [3]. Figure 4 shows the control loop block diagram of bidirectional inverter operation in Inverter mode.

2. *Charger Mode*

If the AC mains voltage is detected, the Inverter mode is disabled (if running) and switches to the Battery Charger mode if,

- State of charge (SOC) is below set threshold and,
- The battery charging rate from the PV is below 0.05C of battery.

Else the bidirectional inverter switches to the standby mode. The MCU provides the reference current level with a variable duty cycle PWM signal. The battery voltage is measured to ascertain the state of charge of the battery. Depending on the battery state, the value of the charging current is modified so as to achieve the fastest charging time and also to prolong the life of the batteries. If the measured charging current is less than the reference,the duty cycle is incremented by a fixed step. Conversely, if the charging current exceeds the reference,the duty cycle is reduced by the same fixed step. This process continues until the current error reduces to a negligible value [3]. The battery charging current control scheme is illustrated in Figure 5.

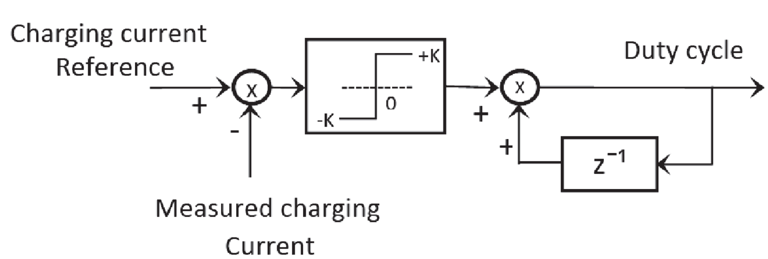

Figure 5: Charger control scheme

4. EXPERIMENTAL VERIFICATION

To verify the practical feasibility and effectiveness of the proposed system experimental tests have been carried out in the laboratory. PIC24FJ16MC102 microcontroller from microchip is used to generate all the required control signals.

A. Settings of Experimental Setup

Figure 6 shows the experimental setup of the system. The experimental setup includes the Solar Array simulator (SAS), MPPT charge controller board (PCBA), Bidirectional Inverter board, 12V 150AH battery, Mains/Inverter changeover board.

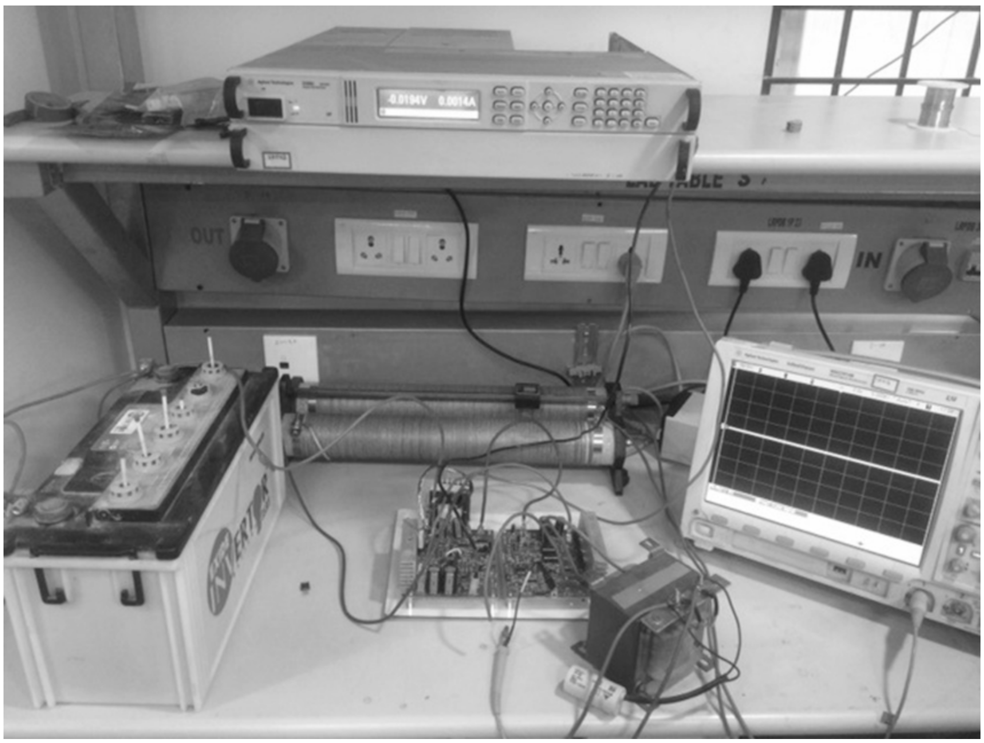

Figure 6: Experimental setup

Table 2
Solar Array simulator settings

Parameter	*Value*
Open circuit Voltage V_{OC} (V)	38
Maximum power point voltage V_{mpp} (V)	30.5
Short circuit current I_{SC} (A)	6.8
Maximum power point current I_{mpp} (A)	5.9

Table 2 shows the setting of solar array simulator used for the experiment and Figure 7 shows the corresponding PV curve captured in the user interface. Charge current to the battery is set to 0.1C of 150AH battery.

B. Experimental Result of MPPT Charge Controller

Figure 8 shows the charge controller (synchronous buck) switching waveform.

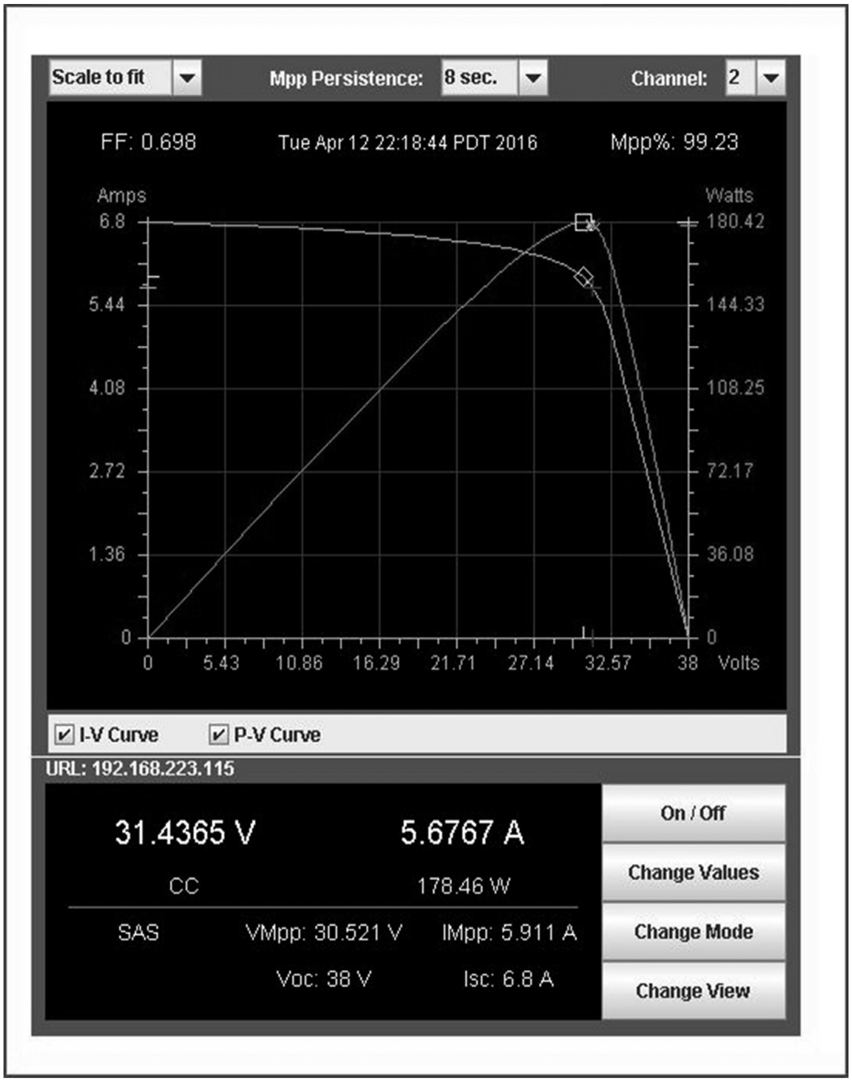

Figure 7: PV curve setting in Solar Array Simulator

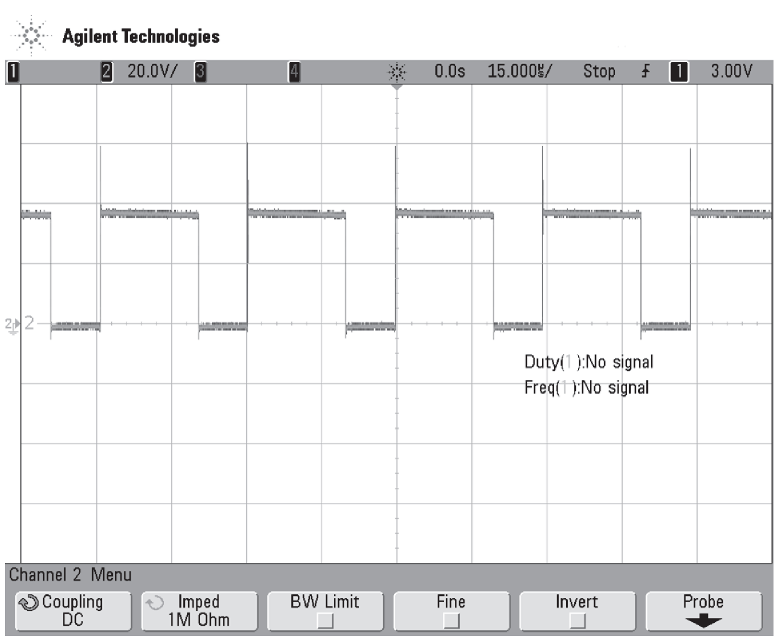

Figure 8: Switching waveform of Synchronous Buck converter

C. Experimental Result of Inverter

Figure 9 shows the inverter output voltage waveform. The switchover waveforms from inverter to mains operation is shown in Figure 10.

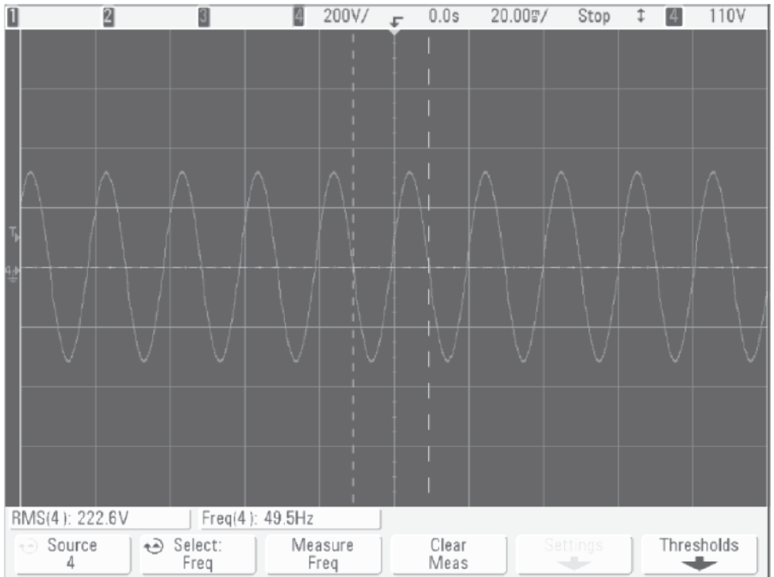

Figure 9: Inverter output voltage waveform

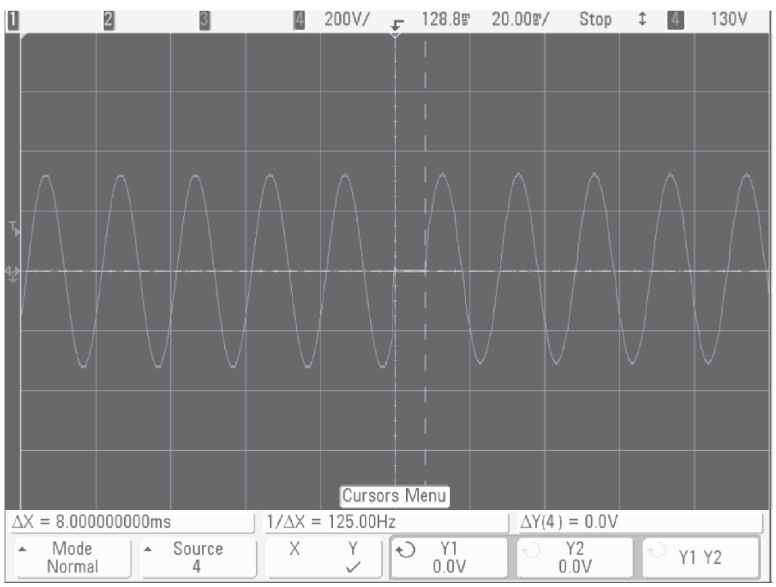

Figure 10: Inverter to mains switchover waveform

5. CONCLUSION

Considered as a renewable energy source, PV is a good solution for the standalone system, this paper presented the integration of solar energy with the Home inverter. The generated power from the PV is strongly dependent on the actual weather conditions. A Solar irradiance and temperature are the main parameters, which determine how much power will be generated in the installed PV capacity. The performance of P & O based MPPT algorithm along with the CCCV battery charge algorithm is validated using the synchronous buck converter. The main objective of the proposed solution is to reduce the electricity drawn from the grid and the second objective is to provide an uninterrupted solution. The different modes of operations of bidirectional inverter are also validated.

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