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Research Paper

GRID CONNECTED PV POWER GENERATING SYSTEM USING CUK CONVERTER AND TRANSFORMER LESS H5 INVERTER

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This paper presents the PI controller based CUK converter and transformer less H5 inverter for grid connected photovoltaic power generating system. For the maximum power point tracking of the photovoltaic system, P & O based algorithm has been implemented. The Pi controller for the CUK MPPT scheme shows a regulated output in variable load conditions. A classical H-bridge inverter topology with extra fifth switch has been used to connect the single phase grid. For the traditional grid connected PV inverter system, a transformer is utilized to provide the galvanic isolation between the grid and PV system. But Common mode leakage current increases due to the removal of the transformer from the system. Here, this transformer less H5 inverter is used for the proposed system which suppresses the common mode leakage current thereby improving the power conversion efficiency and decreases the grid current distortion. The removal of the transformer from the grid tied PV inverter system will give an improvement in the efficiency factor and reduces the cost of the system. The performance of the proposed system is tested in MATLAB/SIMULINK software and the simulation results are included for the effective demonstration of the converter and inverter efficiency. The results of the grid voltage and grid current have been analyzed and the total harmonic distortion of the PV inverter system has been verified.

INTRODUCTION

Due to the increase in demand on electricity, and the crisis of conventional sources, the photovoltaic (PV) energy is emerging more now. It also becomes a promising alternative as it is omnipresent, freely available, environment friendly, and has less operational and maintenance costs. The photovoltaic modules are used for both grid-connected power generation and off-grid power generation for remote areas and developing countries. Since the demand of PV generation systems seems to be increased for both standalone and grid-connected modes of PV systems there is a need for an efficient maximum power point tracking (MPPT) technique that is expected to track the peak power point at all environmental conditions and then force the PV system to operate at that MPP point. MPPT is an essential component of PV systems.

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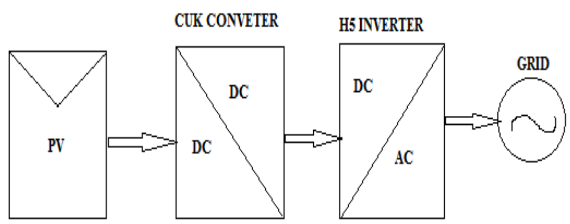
The selection of a proper dc–dc converter plays an important role for maximum power point tracking (MPPT) operation. The criteria for photovoltaic (PV) converter selection depend on many factors, such as cost, efficiency, flexibility, and energy flow. In this case, the flexibility represents the ability of the converter to maintain the output with the input varying, while the energy flow is assured by the continuous current of the converter. Among known converters, the SEPIC, conventional buck–boost, and CUK converters have the ability to step up and step down the input voltage. Hence, this converter can transfer energy for all irradiation levels. Another desirable feature is continuous output current, which allows converter output parallel connection, or conversion to a voltage source with minimal capacitance.

Figure 1: Block diagram of the grid tied power system



The buck or boost converters are not preferable, due to the lack of output voltage flexibility. For example, for PV system battery charging, both buck and boost converters are unable to charge the battery continuously with MPPT operation because the power–voltage curve changes with irradiation level, and hence, the voltage corresponding to maximum power changes. There are many factors that can be considered for proposing the dc–dc converters, such as input/output energy flow, cost, flexibility, and PV array effect. Unlike a buck–boost converter, the SEPIC has a non-inverted output, and it uses a series capacitor to isolate input from output [1]. The buck and buck–boost converters have discontinuous input current, which causes more power loss due to input switching. The boost converter usually has higher efficiency than the SEPIC; however, its output voltage is always larger than the input, which causes inflexibility in maximum power extraction. Both the SEPIC and the CUK converter provide the choice to have either higher or lower output voltage compared to the input voltage. Furthermore, they have continuous input current and better efficiency compared to buck–boost and fly-back converters [2]. There is no general agreement in the literature on which one of the two converters is better, i.e., the SEPIC or the CUK [3]–[10]. This paper seeks to use the CUK converter.

The MPPT algorithm represents optimal load for PV array, producing opportune voltage for the load. The PV panel yields exponential curves for current and voltage, where the maximum power occurs at the curve's mutual knee [11], [12]. The applied MPPT uses a type of control and logic to look for the knee, which in turn allows the SEPIC converter to extract the maximum power from the PV array. The tracking method used, i.e., perturb and observe (P&O) [13], [14], provides a new reference signal for the controller and extracts the maximum power from the PV array.

Among different intelligent controllers, the conventional PI controller gives a better response. It takes the advantage of both the P-action and I-action. The advantages are faster response due to the P-action and the zero steady state error due to the I-action. By increasing or decreasing the gain values of the PI controller, the satisfactory response is obtained for any type control either it is machine side or converter-inverter side. The settling period of the controlling system achieves a faster response by varying the proportional gain constant. Simultaneously the transient response of the system can also be improved. The output response of the converter and the inverter is controlled in a better way so as to improve the efficiency of the system. A PI controller based CUK converter is sued so that the overall control system can always provide maximum power transfer from the PV array to the inverter side, in spite of the unpredictable weather conditions. This paper presents a PI-based MPPT operation of the CUK converter for PV inverter applications. As the proposed method always transfers maximum power from PV arrays to the inverter side, it optimizes the number of PV modules. The PI controller for the CUK MPPT scheme shows high precision in current transition and keeps the voltage without any changes, in the variable-load case, represented in small steady-state error and small overshoot. As the H5-inverter is used in a PV system, PI controller is employed for more accurate output sine wave, higher dynamic performance under rapidly varying atmospheric milieu exploiting maximum power effectively, and improved THD with conventional PI-controlled converters.

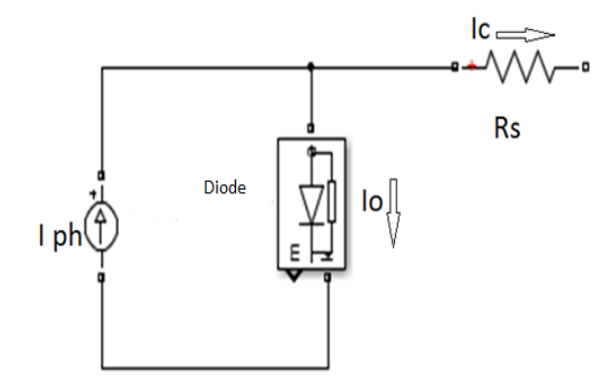
PHOTOVOLTAIC SYSTEM

PV cell is the basic device for the photovoltaic system.This PV cell is similar to the PN jucntion diode.It is made of the semiconductor material either with P-type, N-type silicon or with germanium. A photovoltaic system converts sunlight into electricity.Each photovoltaic cells are grouped to form panels. Panels can be grouped to form large photovoltaic modules.The modules are grouped to form the large photovoltaic arrays.And there are two electrodes which are placed apart which constitutes the two terminlas of the array.

The output of the PV panel is not constant, it is a varying one. This is due to the variation of the temperature and irradiation levels.For a day the intensity of the sun light keeps on the changing, this results in various irradiation levels. And also the temperature of the PV panel varies due to the uneven heating of the panel. This results in decrease in the power output of the PV panel. So it is necessary to track the maximum power from the PV panel in all the load conditions. This leads to give a maximum efficiency from the photovoltaic system.

The electricity available at the terminals of a photovoltaic array may directly feed small loads such as lighting system and DC motors.Some applicaions require electronic converters to process the electricity from the photovoltaic device. These converetrs may be uesd to regulate the voltage and current at the load, to control the power flow in grid connected systems and mainly to track the maximum power point (MPP) of the device.Photovoltaic arrays present a nonlinear I-V characteristic with several parameters that

Figure 2: Electrical Model of Photovoltaic Cell

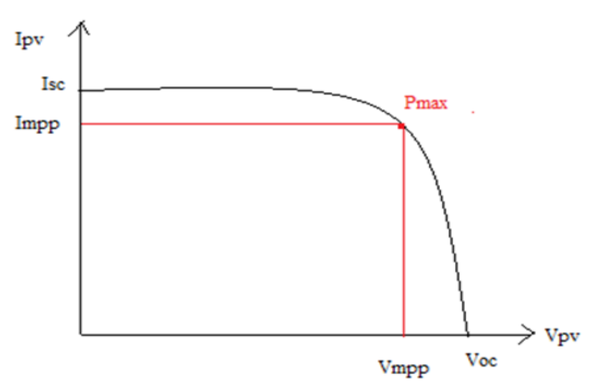


need to be adjusted from experienced data of practical devices.The mathematical model of the photovoltaic array may be useful in the study of the dynamic analysis of converters in the study of MPPT algorithms and mainly to simulate the photovoltaic system and its components using circuit simulators.

P&O BASED MPPT ALGORITHM

In the photovoltaic system, considering the Voltage versus power characteristics, at a particular point the voltage will be maximum (V_{MPP}) and the power will be maximum (P_{MPP}). This is the peak power point in the characteristics of the PV panel. It is necessary to track the peak power point of the VI curve to utilize the maximum power output of the photovoltaic cell. We have lot of techniques under MPPT. Under these techniques Perturb and observe algorithm is used. P & O technique is very simple to implement.

Figure 3: Current Versus Voltage Characteristics of Photovoltaic cell



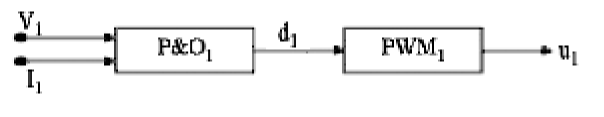
The MPPT control technique is applied to achieve a new reference voltage for the PI controller, which changes the duty cycle of the PWM signal for the CUK converter. The P&O algorithm has a simple structure and requires few parameters (i.e. power and voltage); that is why it is extensively used in many MPPT systems [21]–[24]. In addition, it can be easily applied to any PV panel, regardless of the PV module's characteristics for the MPPT process.

The P&O method perturbs the duty cycle and compares instantaneous power with past power. Based on this comparison, the PV voltage determines the direction of the next perturbation. P&O shows that, if the power slope increases and the voltage slope increases also, the reference voltage will increase; otherwise, it will decrease. The drawback of most of the fuzzy-based MPPT algorithms is that the tracking point is located away from the maximum power point when the weather conditions change. However, a drawback of P&O technique is that, at steady state, the operating point oscillates around the maximum power point giving rise to the waste of available energy, particularly in cases of constant or slowly varying atmospheric conditions. This can be solved by decreasing the step size of perturbation.

The step size of the P&O method affects two parameters: accuracy and speed. Accuracy increases when the step size decreases. However, accuracy leads to slow response when the environmental conditions change rapidly. Larger step size means higher speed for the MPPT operation, but this will lead to inaccuracy and larger intrinsic oscillations around the maximum power point in steady state. Step sizes should, thus, be chosen well to achieve high speed and accuracy. The step-size rate for the voltage reference signal used is 0.5V/ms.

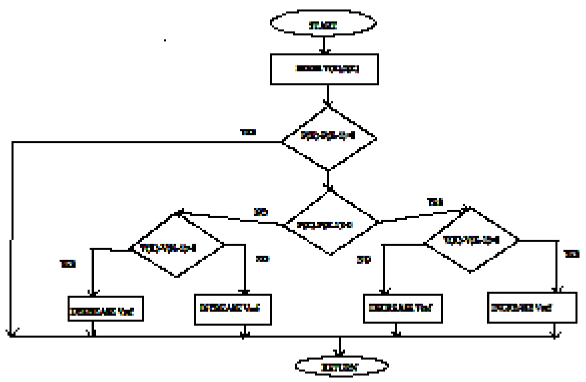
This is the following general rule used in the P & O method, in which the slope of the PV curve at the MPP is equal to zero.

Figure 4: Traditional P & O technique



$$\frac{dP}{dV} = 0 \qquad (1)$$

Figure 5: Classical CUK Converter Circuit



SELECTION OF DC – DC CONVERTER

For the MPPT operation, the major part is the selection of the DC-DC converter. Since the output of the PV is not constant and a varying one, it is a challenging job to select a highly efficient converter for the MPPT system. Among all the topologies available, CUK, SEPIC, Buck-Boost converters provide the opportunity to have their higher or lower the output voltage compared with the input voltage. Although the buck-boost configuration is cheaper than the CUK converter, some disadvantages such as the discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient. On the other hand, The CUK converter has low switching losses and the highest efficiency among non-isolated dc-dc converters. It can also provide a better output-current characteristic due to the inductor on the output stage. Thus, the CUK configuration is a proper converter to be employed in designing the MPPT.

CUK converter is type of dc-dc to converter that has the either a high or low output voltage magnitude with the input voltage magnitude. It is a boost converter followed by the buck converter. In this converter, the capacitor acts as the major element for the energy storage component where as in other converters, inductors are used. This CUK converter is classified into two categories:

- Non-isolated CUK Converter.
- Isolated CUK Converter.

Non-isolated CUK converter is found without the transformer. It is an inverting converter i.e. the output voltage is negative with respect to the input voltage. Isolated CUK converter is isolated with the isolation transformer. The ac transformer and a capacitor is additionally connected to the CUK converter circuit. Since the circuit is isolated, the polarity of the output voltage is free to chosen. In this paper non isolated CUK converter is used. The converter circuit consists of two inductors, two capacitors, one transistor and one diode. the capacitor is used for the energy transfer in the circuit components and it is alternately connected between the input and output of the converter through the commutation of the switch and the diode elements. The inductors L1, L2 in the circuit which convert the voltage sources V_I and V_{CO} to current sources and these current sources are maintaining constant current. Charging the capacitor with the current source limits the resistive current and the associated energy loss. The CUK converter operates either in continuous or discontinuous current mode. It also operates in discontinuous voltage when the voltage across the capacitor drops to zero during commutation cycle.

With the CUK converter, energy is transferred when the switch opens and closes. CUK Converter uses L-C type filter, so the peak-peak ripple current of inductors are less as compared to the buck-boost converter. In CUK converter, when the switch is closed then capacitor 'C' provides energy to the load as well as inductive filter. But when the switch is open then the energy stored in the filter inductor is fed back to the load. The advantages of the CUK converter are:

- Continuous input current.
- Continuous output current.
- Output voltage can be either higher or lower than the input voltage.

Figure 6: Classical CUK Converter Circuit

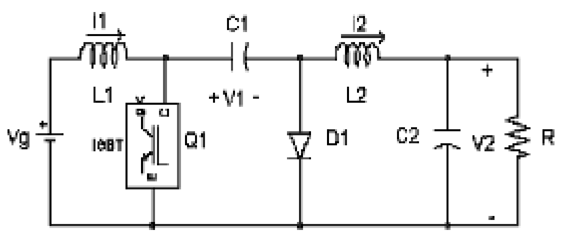
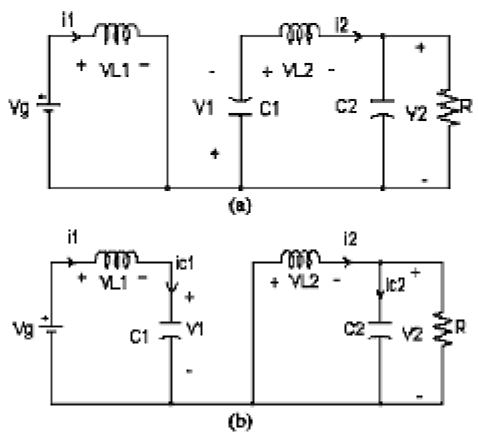


Figure 7: Operating modes of CUK Converter Circuit (a) mode 1(ON) (b) mode 2(OFF)



Figs. 6 and 7 show a CUK converter and its operating modes. The CUK converter has two modes of operation. The first mode is when the switch is closed (ON) and it is conducting as a short circuit. In this mode, the capacitor C releases energy to the output. The equations for this mode are as follows:

$$v_{L1} = V_g \quad (2)$$

$$v_{L2} = - v_1 - v_2 \quad (3)$$

$$i_{c1} = i_{c2} \quad (4)$$

$$i_{c2} = i_2 - v_2/R \quad (5)$$

On the second operating mode when the switch is open (OFF), the diode is forward biased and conducting energy to the output. Capacitor C1 is charging from the input. The equations for this mode of operation are given by:

$$v_{L1} = V_g - v_1 \quad (6)$$

$$v_{L2} = - v_2 \quad (7)$$

$$i_{c1} = i_1 \quad (8)$$

$$i_{c2} = i_2 - v_2/R \quad (9)$$

The principles of CUK converter operating conditions state that the average values of the periodic inductor voltage and capacitor current waveforms are zero when the converter operates in steady state.

The relations between output and input currents and voltages are given in the following:

$$\frac{Vo}{Vin} = \left(\frac{D}{1-D}\right) \quad (10)$$

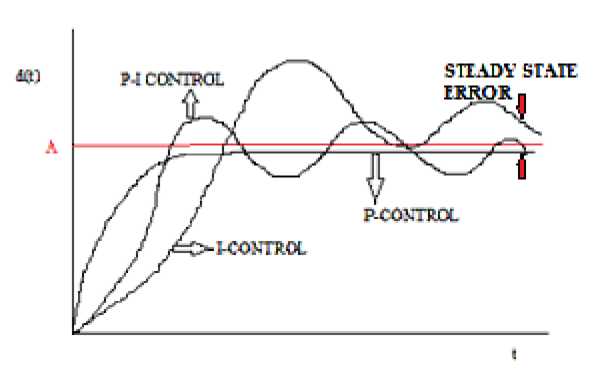
$$\frac{Iin}{Io} = \left(\frac{D}{1-D}\right) \quad (11)$$

PI CONTROLLER

Conventional PI controllers have been used in the grid tied PV generating systems [12-14]. A controller may have different structures. Different design methodologies are there for designing the controller on order to achieve the desired performance level. But most of the environments are initially tested using the PI controller. But the choice of P-D, P-I, PID depends on the type of process we intend to control. They have the advantage to be relatively simple to design.

Proportional plus Integral controllers were developed because of the desirable property that systems with open loop transfer functions of type-1 or above have zero steady state error with respect to step input. This controller does not cause offset associated with the proportional control. And also it yields much faster response than the integral action alone. It is widely used for process industries for controlling variables like level, flow, pressure, etc., those do not have large time constants.

Figure 8: Comparison among the Transient Responses with P, I, P-I Controllers



TRANSFORMER LESS H5 INVERTER

Inverters used in the photovoltaic systems can be grouped into two categories:

- Isolated inverters.
- Non-isolated inverters

Traditionally in order to create a galvanic isolation between the input and the output include a transformer that limits the whole system performances in terms of efficiency, weight, size and cost. On the contrary, in transformer less inverters there is no isolation and are characterized by little size, lower cost and higher efficiency (more than 2% higher). In grid tied PV inverter system, PV inverter representing the 25% of the whole system cost. There are different PV inverter topologies. They are given by

- Full H-Bridge inverter
- Half H-Bridge inverter
- NPC inverter
- HERIC inverter
- H-5 inverter

Compared to the full H-bridge, this topology presents an additional transistor, and that is the main difference. The H5 topology is patented by SMA in 2005 and it is based on the same concept as the HERIC topology, i.e. to disconnect the PV panels from the grid during current freewheeling periods, thus having an almost constant common mode voltage. In Fig.8 it is shown the H-5 topology that uses a full bridge consisting of the four switches T1, T2, T3 and T4, and the DC bypass switch T5. The switches T1 and T2 are operated at grid frequency whereas T3, T4 and T5 are operated at high frequency. During current freewheeling period, T5 is open, disconnecting PV panels from the inverter full H-bridge. The freewheeling path is closed by the transistor T1 and the inverse diode of T3 for the positive half cycle of the electrical grid, and by the transistor T3 and the inverse diode of T1for the negative half cycle.

The classical H-bridge with an extra fifth switch in the positive bus of the DC link which provides two vital functions:

- It prevents the reactive power exchange between L1 and C_{PV} during the zero voltage state, thus eliminating the high-frequency content of $V_{PE.}$.
- And also it isolates the PV module from the grid during the zero voltage state, thus eliminating the high frequency content of $V_{PE.}$

The main features of this inverter are:

- T5 and T4 are switched at high frequency and S1 (S3) at grid frequency.
- Two zero output voltage states are possible: S5 = OFF and S1=ON.

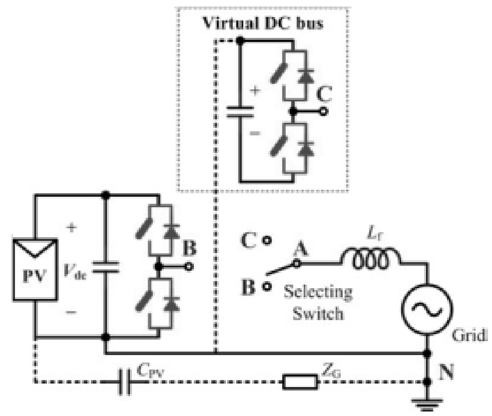
The advantage of this inverter:

- Voltage across the filter is unipolar ($0 \rightarrow +V_{PV} \rightarrow 0 \rightarrow -V_{PV} \rightarrow 0$), yielding lower core losses.
- Higher efficiency of up to 98% is due to no reactive power exchange between L_1 and $C_{PV.}$

VIRTUAL DC BUS CONCEPT

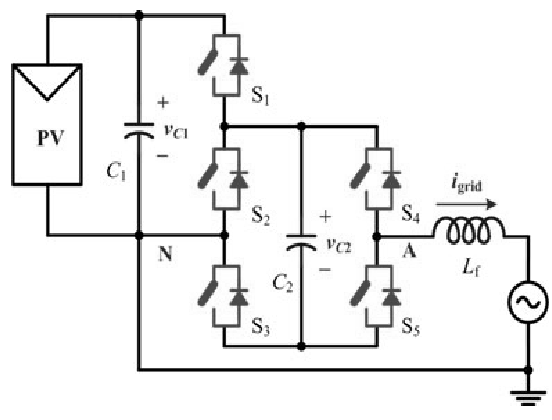
A virtual dc bus concept is introduced to avoid the increase in common mode voltage current due to the transformer less H-bridge inverter. The grid neutral line is directly connected to the negative pole of the PV panel, so that the voltage across the parasitic capacitance is clamped to zero. This concept prevents any leakage current flowing across the grid terminals. The Fig. 9 shows the concept of the virtual dc bus introduced in the H-bridge inverter. In this, with respect to the ground point N, the voltage at the midpoint is either zero or $+V_{DC}$. This is according to the switching states in the H-bridge inverter. This virtual dc bus is mainly to generate the negative output voltage which is necessary for the inverter operation. The voltage across the real bus and virtual bus is maintained as same one by designing the proper switching method.

Figure 9: Virtual DC Bus Concept Circuit



As shown in Fig. 9, when the positive pole of the virtual bus is connected to the ground point N, the voltage at the midpoint C is either zero or $-V_{DC}$. The dotted line in the figure indicates that this connection may be realized directly by a wire or indirectly by a power switch. With the points B and C when joined together by a smart selecting switch, the voltage at point A can be of three different voltage levels, namely $+V_{DC}$, zero, and $-V_{DC}$. By this way the CM current is eliminated with simple switching structure.

Figure 10: Proposed H-bridge Inverter Topology Circuit



The proposed methodology consists of five switches and one filter inductor. The converter terminals and the capacitor C1 form the real bus and the C2 forms virtual bus. With the switched capacitor technology, C2 is charged by the real dc bus through S1 and S3 to maintain a constant voltage. This topology can be modulated with the unipolar SPWM and double-frequency SPWM.

RESULTS AND DISCUSSION

The CUK converter is designed with the values for Li = 6.61 mH, C1 = 0.3 ìF,Lo = 0.82 mH, and Cd = 1590 ìF. For the MPPT tracking P&O algorithm has been modeled.

Figure 11: Simulink Model of the grid connected system

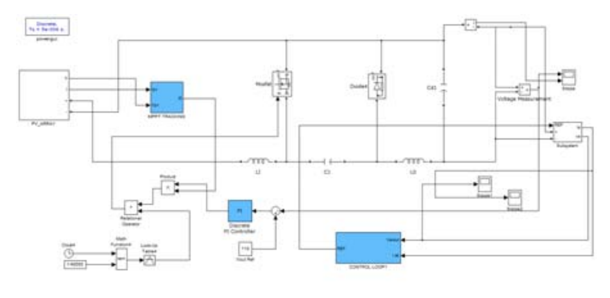
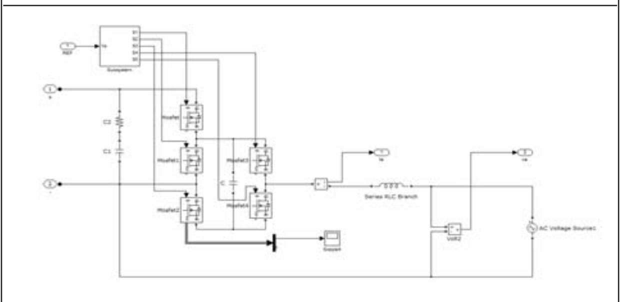


Figure 12: Simulink Model of H-bridge Inverter



For the H-5 inverter, Unipolar SPWM technique is used to generate pulses for the five switches

The Photovoltaic array has been modeled for one irradiance level and one temperature rating. The equations used for PV model are:

where the symbols can be defined as

I Cell output current

V Cell output voltage

Io Cell saturation current

T Cell temperature in K

k/q Boltzmann's constant divided by electronic 8.62 x 10-5 eV/K,

Tc Cell temperature in °C

KI short circuit current temperature coefficient 0.0017 A/°C

λ Cell illumination

I_{SCR} cell sort circuit current at 28°C and 100 m 2.52 A

I_{LG} light-generated current

E_{GO} band gap for silicon = 1.11 eV,

B = A ideality factor,1.92

Figure 13: Simulink Model of PV Module

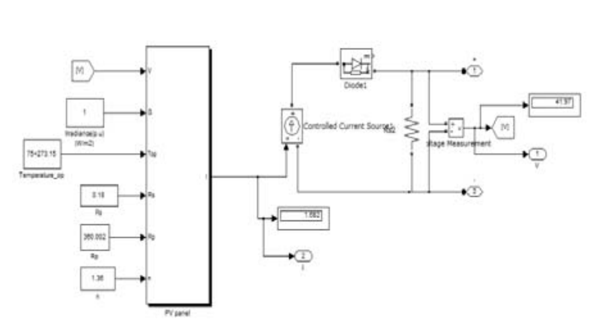


Figure 14: CUK Converter Voltage and Current Waveform

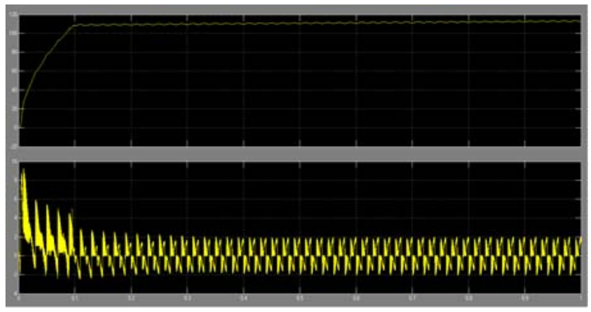


Figure 14: Grid Voltage

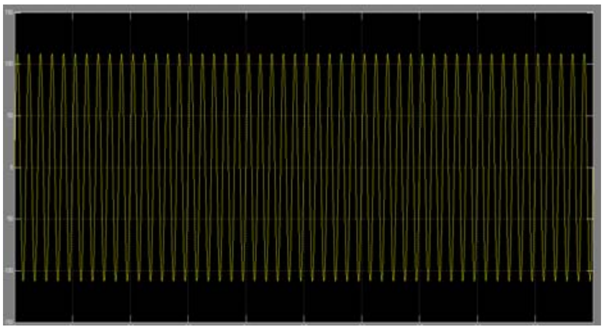


Figure 16: Grid Current

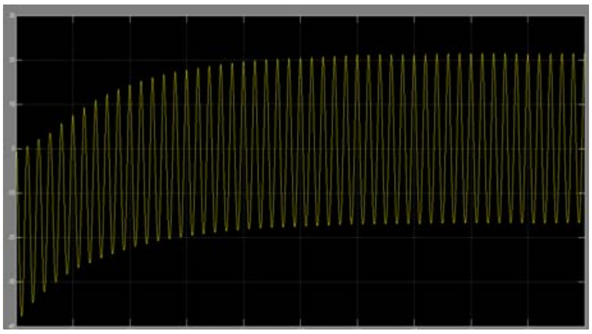


Figure 17: Current Stress across Switches in H-bridge Inverter

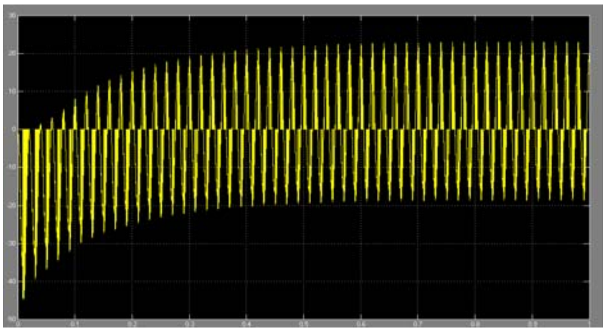


Figure 18: Pulses For the Switches in H-bridge Inverter

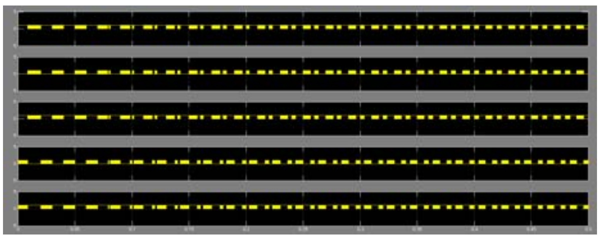


Figure 19: PV Output Voltage and Current

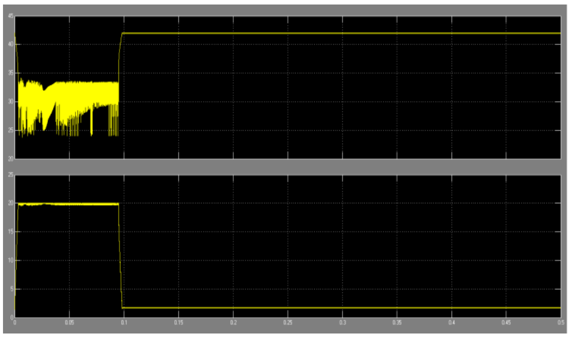
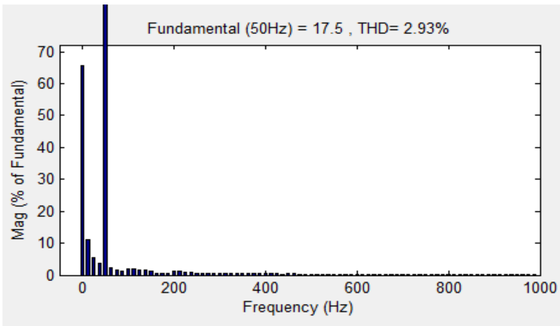


Figure 20: THD of the Grid System



T_r Reference temperature,308.18 K

I_{or} Saturation current at $t_{r,=19.963 \times 10-6}$

R_s Series resistance=0.001

CONCLUSION

The concept of selecting a proper dc-dc converter for the MPPT tracking of the photovoltaic system, a CUK converter has been designed and implemented for the boost voltage regulation of the PV model. The conventional PI controller used to regulate the converter voltage. Simultaneously, P&O algorithm is implemented for the maximum power point tracking for the PV model designed. And then a virtual dc bus concept is used for the grid tied system. This virtual dc bus concept with the proposed H-bridge inverter topology eliminates the common mode leakage current flowing through it. This proposed inverter topology in the grid connected system is suitable for single phase small power applications where the output current is small so the extra stresses due to the switched capacitor technology does not cause serious reality problem for the power devices and capacitors. A novel inverter topology proposed with the virtual dc bus concept consisting of only five power switches and one filter inductor eliminates the common mode current and provides a promising solution for the transformer less grid connected system.

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