Transformerless Inverter for Smart Grid Based On Photovoltaic Systems

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***Abstract-* In this paper we have done the Transformerless Inverter Modeling which is used for smart Grid Technology with Phasor measurements units & two way communications systems. We are taken the stand alone Transformer less Inverter for home appliances. That Inverter is modeling by using Matlab/Simulink.**

Keywords: Photovoltaic inverter, Transformer less inverter, modeling, MATLAB/SIMULINK

I. INTRODUCTION

Growing demand and advancement in semiconductor technology and magnetic material had significant impact on PV inverter topology. In the past few years the market share for transformerless inverters has steadily increased. Topologies without transformer generally have higher efficiencies and may be cheaper than comparable inverters with transformers.

In this paper a DC-DC boost converter which is used to obtain the stable high input voltage from unstable low input voltage from photovoltaic system and a line transformer in the power-conversion stage, which guarantees galvanic isolation between the grid and the PV system, thus providing personal protection. Due to elimination of transformer there will be a dangerous leakage currents can appear through stray capacitance. In order to avoid these currents and to achieve higher efficiency the circuit is modified. The conversion stages are more advantageous power conversion stage for transformerless grid connected PV systems. I am initially selected a bipolar PWM full-bridge inverter with six switches and two diodes out. The advantage of full bridge bipolar PWM inverter avoids the varying common-mode voltage and achieves a high efficiency and avoids the losses across stray capacitance i.e, stray losses and there will be low ripple currents

The literature survey is done to collect material, which would focus on the basic theory of PV's with different inverter. Grid connected photovoltaic (PV) systems, in particular low power, mostly single-phase PV systems and their contribution to clean power generation is recognized more and more worldwide. Grid connected PV systems are generally privately owned, single-phase systems in a power range of up to 10 kW. The main aim of a private operator who owns such a system is to maximize its energy yield i.e. it issues long life time (20 years and longer), high efficiency and good environmental conditions (availability of solar radiation) are hence of importance to the private operator. Other important requirements for these PV systems are the fulfillment of standards concerning power quality, electromagnetic compatibility, acoustic noise limitations as well as safety and protection requirements topology.

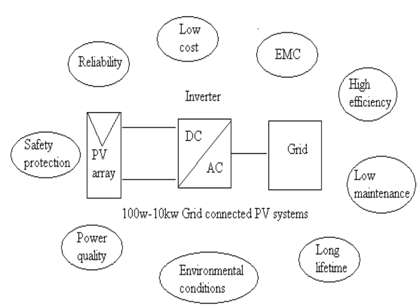


Figure (1.1) shows issues regarding grid connected PV systems for the low power range.

First commercially available grid connected PV inverters were line commutated inverters, followed by self commutated, Pulse Width Modulation inverters including either line or high frequency transformers. Newest trends in this field are string based units with a power rating around 1 kW and transformerless concepts. For larger systems the overall efficiency can be increased through application of several, small, string inverters replacing a single unit which avoids losses through module mismatch and decreases the DC wiring effort. Transformerless concepts (in particular inverters with high input voltages) are advantageous regarding their high efficiencies. Their peak efficiencies of up to 97% are equivalent to efficiencies reached in drives applications.

Avoiding the transformer has the additional benefits of reducing cost, size, weight and complexity of the inverter. However, the removal of the transformer and hence its isolation capability has to be considered carefully. Multilevel converter topologies are especially suitable for PV applications since due to the modular structure of PV arrays different DC voltage levels can easily be provided. Multilevel voltage source inverters offer several advantages compared to their conventional counterparts. By synthesizing the AC output terminal voltage from several levels of voltages, staircase waveforms can be produced, which approach the sinusoidal waveform with low harmonic distortion, thus reducing filter requirements. The need of several sources on the DC side of the converter makes multilevel technology attractive for photovoltaic applications. This paper provides an overview on different multilevel topologies and investigates their suitability for single-phase grid connected photovoltaic systems. Several transformerless photovoltaic systems incorporating multilevel converters are compared regarding issues such as component count and stress, system power rating and the influence of the photovoltaic array earth capacitance.

Photovoltaic (PV) power supplied to the utility grid is gaining more and more visibility, while the world's power demand is increasing. Not many PV systems have so far been placed into the grid due to the relatively high cost, compared with more traditional energy sources such as oil, gas, coal, nuclear, hydro, and wind. Solid-state inverters have been shown to be the enabling technology for putting PV systems into the grid. The price of the PV modules were in the past the major contribution to the cost of these systems.

The photovoltaic system has been growing the demand for improving the system efficiency and reducing the size, weight and cost have been becoming significant. The high-frequency transformer utilized system is an attractive one to obtain isolation between the solar-cells side and the utility side.

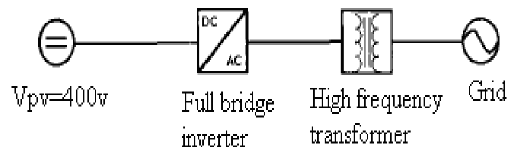


Figure (1.2) shows PV inverters with self commutated full bridge and high frequency Transformer

However, the transformerless type is much more attractive from the viewpoint of improving the efficiency, size, weight and cost. Thus, the transformerless type has been becoming the dominant one. In this transformerless system, a boost-type dc-dc converter and an inverter scheme is chosen usually. The boost dc-dc converter is for obtaining a stable and higher dc-input voltage of the inverter from an unstable and lower voltage fed from the solar-cells. The high DC input is fed to the inverter which converts the DC high input voltage to the AC voltage. This dc-dc converter is a two-quadrant type, and it feeds the power obtained from the solar-cells to the inverter with boost-mode operation. On the other hand, it feeds the energy back from the utility to the dc capacitor C, with buck-mode operation. The energy feedback with the buck-mode operation is rarely utilized to control the power factor of the utility to reduce the utility voltage. Under a condition with a higher original voltage of the utility and a high feeding power to the utility, the utility voltage can exceed a limitation. The function is applied in such a condition to reduce the utility voltage. Since this case is occurred very rarely and is not focus here, the detail is omitted in this paper. Since the voltage produced by the solar-cells is not high enough to obtain certain level of ac-voltage through the inverter, a boost-mode dc-dc converter is necessary to connect between the solar-cells and the inverter in the transformer-less system. In this project, however, the solar-cells unit is designed to produce the output voltage of approximately 200 [V] in the maximum output power condition (i.e., 4.5kW). A higher voltage can be obtained depending on solar-cells arrangement but it affects reasonable system designing. On the other hand, the inverter needs approximately 400 [V] or more in the conventional system since the utility voltage is up to 280 [V_{RMS}] and the maximum value reaches almost 400 [V].Figure(1.3) shows the transformerless inverter with Dc-DC boost converter and single phase full bridge inverter.

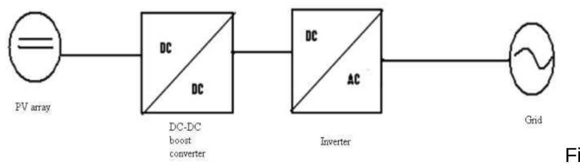


Figure (1.3) shows transformerless inverter with DC-DC boost converter

In such single-phase system, a large capacitance capacitor is connected in the input of the inverter to trap the ripple energy fed from the utility so that the input voltage is kept constant or stable. Further, both the dc-dc converter and the inverter operate with high-frequency switching at all the time and a high amount of switching losses is produced. To overcome the problems, a theory of novel and smart solution was developed. In the proposed utility interactive inverter system, the waveform of the input current of the dc-dc converter (i.e., the waveform of the dc-inductor current in the input) is wave shaped by bang-bang control so that the dc-inductor traps the ripple-power fed back from the utility. This control is available in the period where the solar-cells output-voltage is lower than the absolute-value of the utility voltage.

II. PHOTOVOLTAIC SYSTEMS

2.1 Introduction:

Photovoltaic is the field of technology and research related to the devices which directly convert sunlight into electricity. The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon.

One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice. For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity. Demands Defined by the Photovoltaic Module(s):

A model of a PV cell is sketched in Fig.2.1 (a), and its electrical characteristic is illustrated in Fig2.1 (b).

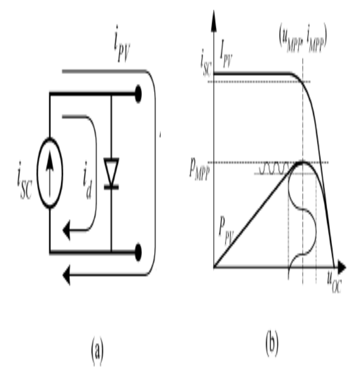


Fig (2.1) Model and characteristics of a PV cell. (a) Electrical model with current and voltages defined. (b) Electrical characteristic of the PV cell, exposed to a given amount of (sun) light at a given temperature.

As indicated, ripple at the PV module's terminals results in a somewhat lower power generation, compared with the case where no ripple is present at the terminals.

Where P_{MPP}, V_{MPP} and i_{MPP} are the power, voltage and current at MPP.

I_{PV} and P_{PV} are the photovoltaic current and power.

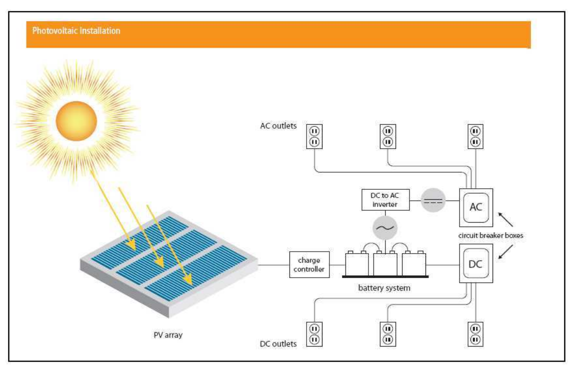


Fig. (2.2). Photovoltaic installations

2.2 Maximum Power Point Tracking (MPPT):

Power electronic circuits are key elements for renewable energy power generation. The power electronics for solar power conversion shall have the ability of automatically tracking the maximum power point in order to achieve the maximum efficiency of the solar cells and inject sinusoidal and in-phase current to the grid so that power quality complies with the power system requirements. Conventionally, these two functions are realized by two-stages, one is a dc/dc converter with maximum power point tracking (MPPT) and the other dc/ac converter for sinusoidal current injection. This kind of two-stage approach typically requires real-time power, voltage or current measurement, and logic procedures to judge the MPP in the dc/dc stage, then a separate dc/ac inverter output the sinusoidal current to the grid. A simple low-cost one-stage inverter with MPPT accuracy is proposed. It has two functions: automatically adjusting output power according to the sunlight level and outputting a sinusoidal current to the grid.

It has the following features.

1) Constant switching frequency.

2) Low output current harmonics and high power factor, i.e.,

$$PF \approx 1..$$

3) Simple main circuit with one stage power conversion.

4) A simple controller that only needs some linear components,

i.e., no DSP and no multipliers are necessary. If

DSP is desirable, a low cost one can be used.

5) Maximum power point tracking accuracy.

6) Low cost and high efficiency

Maximum power point trackers utilize some type of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell. Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows though all panels in the string. But because different panels have different IV curves, i.e. different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy

At night, an off-grid PV power system uses batteries to supply its loads. Although the battery pack voltage when fully charged may be close to the PV array's peak power point, this is unlikely to be true at sunrise when the battery is partially discharged. Charging may begin at a voltage considerably below the array peak power point, and a MPPT can resolve this mismatch. When the batteries in an off-grid system are full and PV production exceeds local loads, a MPPT can no longer operate the array at its peak power point as the excess power has nowhere to go.

The main disadvantage, however, is the direct connection of the PV array to the grid without galvanic isolation. Depending on the inverter topology this may cause fluctuations of the potential between the PV array and ground.

Tests relating to leakage currents:

Avoiding the transformer in PV grid connected inverter topologies results in the galvanic connection of the grid and the PV array.The potential differences imposed on the capacitance between the PV array and earth, through switching actions of the inverter can inject a leakage or capacitive earth current, leakage as shown in Figure (5.2). The PV array earth capacitance, C earth, is then part of a resonant circuit consisting of the PV array; DC and AC filter elements and the grid impedance. Due to efficiency optimization of PV systems the damping of this circuit can be very small. The leakage currents are driven by topology and control dependent voltages present between the PV array's active conductors and earth (v+ and v-). The magnitude of the leakage currents depends not only on Cearth, but also on the magnitude, waveform and frequency of v+ and v-. Note that for an earthed array frame, C_{earth} consists of C_{FRAME} (the capacitance between cell area and array frame) in parallel with C_{stray} (the stray capacitance between cell area and earth).

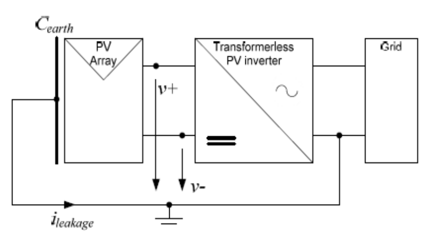


Figure (2.3) Grid connected PV system without transformer (using *non-earthed* array

conductors) including the PV array earth capacitance

The capacitance depends on the type of PV module technology as well as environmental conditions, with humidity significantly increasing the value of *Cearth*. The highest maximum efficiencies are achieved with line commutated and self-commutated transformerless inverter is increasing day by day. From 1994 to 2003 their average maximum efficiency increased from 93.5% to 96.5% and from 93.4% to 95.8%, respectively. However, a PV inverter rarely operates at maximum efficiency due to the varying intensity of solar radiation.Only a truly transformerless design allows direct facility connection without any additional transformer equipment, customization. Although the price of solar PV power is becoming more and more competitive, it is vitally important for the industry to continue to find ways to enhance performance, improve efficiency, and drive down costs. Evaluating the quality and performance of large capital equipment is one way to continue to make gains, and just as significant as PV modules and arrays is the performance and efficiency of inverters.

III. PULSE WIDTH MODULATION

Introduction:

The energy that a switching power converter delivers to a motor is controlled by Pulse Width Modulated (PWM) signals, applied to the gates of the power transistors. PWM signals are pulse trains with fixed frequency and magnitude and variable pulse width. There is one pulse of fixed magnitude in every PWM period. However, the width of the pulses changes from period to period according to a modulating signal. When a PWM signal is applied to the gate of a power transistor, it causes the turn on and turns off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the motor and its load depends mostly on the modulating signal.

. The pulses of an asymmetric edge-aligned PWM signal always have the same side aligned with one end of each PWM period. Both types of PWM signals are used in this application. It has been shown that symmetric PWM signals generate fewer harmonic in the output current and voltage. Different PWM techniques, or ways of determining the modulating signal and the switch-on/switch-off instants from the modulating signal, exist. The Technique that we use is Natural PWM technique. This technique is commonly used with three phase Voltage Source power inverters for the control of three-phase AC induction motors.

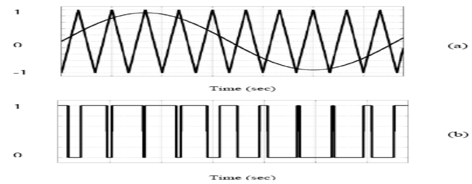


Figure 3.1 : PWM illustration by the sine-triangle comparison method

(a)Sine-triangle comparison (b) switching pulses.

As is explained the output voltage from the inverter is not smooth but is a discrete waveform and so it is more likely than the output wave consists of harmonics, which are not usually desirable since they deteriorate the performance of the load, to which these voltages are applied. The modulation signals are thus selected so meet some specifications, like harmonic elimination, higher fundamental component and so on.

IV. PHOTOVOLTAIC INVERTER

4.1 Introduction:

In photovoltaic applications the grid interface between source (solar array) and load (utility grid) consists of the inverter. To maximize the system efficiency the inverter must be optimized in design and control. For a 5Kw photovoltaic power system a single phase full bridge inverter is developed which requires only a minimum number of components. Most commercial inverters for photovoltaic applications include a transformer and several sections of power conversion. To reduce the degree of complexity it is proposed to omit the transformer and to use only one section of power conversion. Thereby system losses, size and costs decrease.

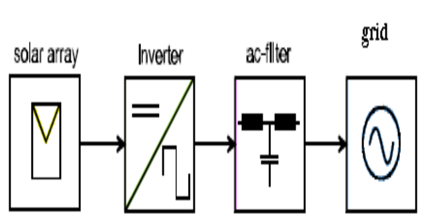


Figure (4.1) Main structure of the PV-system

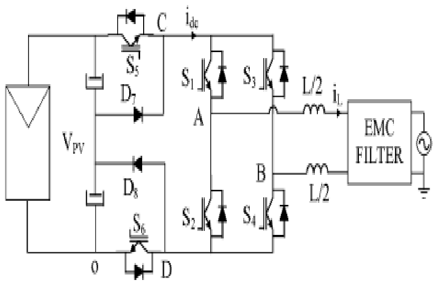


Figure (4.2) shows proposed topology with Full bridge inverter.

The proposed topology with the modulation technique described below can operate with power factors other than unity. In these cases, the operation analysis would similar.

4.2 MODES OF OPERATION:

To generate the positive half cycle S1 and S4 are on. In order to modulate the input voltage, S5 and S6 commutate at the switching frequency with the same commutation orders. S2 and S3 commutate at the switching frequency together and complementarily to S_5 and S6.

. In this situation, when S_5 and S6 are on V_{AB} = V_{PV} and the inductor current, which flows through S_5, S1, S4 and S6 increases (i.e., From source to S5-S1_load-S4-S6) as shown in figure(4.2) .

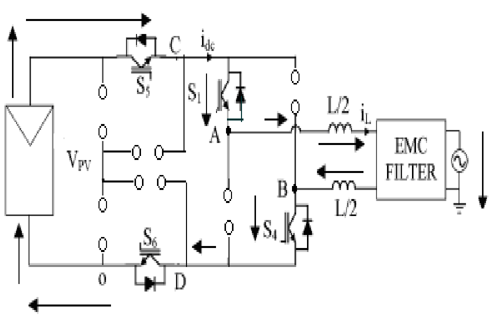


Figure (4.3) shows Full bridge inverter in proposed topology with S5, S1, S4 and S6 on.

In this case the common mode voltage is:

$$Vcm = V_{AO} + V_{BO} / 2$$

$$\text{Since } V_{PV} = V_{AO} + V_{BO}$$

$$\text{Therefore } V_{PV} = V_{AO} + 0$$

$$\text{i.e. } V_{PV} = V_{AO}$$

The common mode voltage is Vcm = V_{AO}+0 / 2

$$Vcm = V_{AO} / 2$$

$$Vcm = V_{PV} / 2 \text{ ----------------------------- } \mathbf{(1)}$$

When S5 and S6 are turned off and S2 and S3 are turned on turned on, the current splits into two paths as shown in figure (4.3).

1. S1 and the freewheeling diode of S3 (S1-load-at point B the current splits into two paths.
2. S4 and the freewheeling diode of S2 (From point B to S4 and D2 and at point A and repeats so on).

Thus S2 and S3 are turned on without no current. Therefore there will be no switching losses appear. In this situation voltages V_{AB} and V_{CD} tend to zero and diode D7 and D8 fix the voltages V_{AO} and $V_{BO\ to}$ V_{PV} / 2.since V_{AB} is clamped to zero the current decreases. Now the common mode voltage is:

$$V_{AO} = V_{BO} = Vcm = V_{PV} / 2 \text{ --- } (2)$$

To generate negative half cycle S2 and S3 are turned on as shown in Figure (4.3). In this situation again S5 and S6 commutate at the switching frequency in order to modulate the input voltage. S1 and S4 commute at the switching frequency together and complementarily to S5 and S6. In this situation when S5 and S6 are on V_{AB} = -V_{PV} and the inductor current which now flows through S5, S2, S3 and S6 decreases.

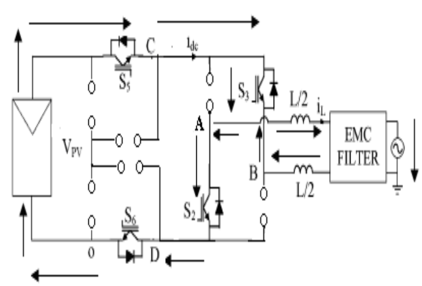


Figure (4.4) shows the proposed topology full bridge inverter with switch S2 and S3 on.

In this situation the common mode voltage is

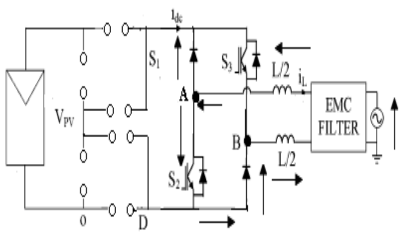
$$Vcm = V_{AO} + V_{BO} / 2$$

Since $V_{PV} = V_{AO} + V_{BO}$
Therefore $V_{PV} = 0 + V_{BO}$

$V_{PV} = V_{BO} / 2$

Vcm = V_{PV}/ 2------------------------------------(3)

When and are turned off S5 and S6 and S1 ,S4 are turned on the current splits into two paths as shown in figure(4.4). The first path consists of S3 and the freewheeling diode of S1, and the second of S2 and the freewheeling diode of S4. Consequently, S1 and S4 are turned on with no current, so no switching losses appear. In this situation, voltages V_{AO} and V_{BO} tend to zero and diodes D7 and D8 fix the voltages VAB and VCD to V_{PV}/ 2. The current decreases because VAB is clamped to zero.



Figure(4.5) shows the proposed topology with S5 ,S6 turned off and S1 and S4 Turned on.

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Now, the common-mode voltage

$V_{AO} = V_{BO} = Vcm = V_{PV} / 2$-------------------(4)

From equations (1) –(4), it is clear that the common-mode voltage remains constant during the four commutation states of the converter. Therefore, no varying common-mode voltage is generated by the proposed topology and, hence, no leakage currents appear. The common-mode voltage remains constant during all commutation states. Additionally, voltage and therefore the inductor current, have the same waveforms as those obtained in the unipolar PWM full bridge. Assuming unity power factor, S5 and S6 commutate at the switching frequency with half of the input voltage Vpv, and the corresponding two freewheeling diodes of the full bridge commutate with Vpv but with half of the current. Therefore, switching losses will be lower than those of the bipolar PWM full bridge and can be expected to be similar to those of the unipolar PWM full bridge. Since the blocking voltage of S5 and S6 is only half of the input voltage, switches with lower rated blocking voltage can be used and thus will exhibit lower switching losses for the same operating conditions.The IGBT switching losses of the full bridge are neglected, since they switch at the grid frequency. When the power factor decreases, the losses of the proposed topology increase because the switching losses of the full bridge increase. Conduction losses are expected to be greater in the proposed topology, because when S5 and S6 are on current flows through four switches instead of two, as in the full bridge (regardless of the PWM technique used). However, this increment is limited by the fact that and have lower saturation voltages because they have lower rated voltages.

From this we concluded that the switching losses are neglected in the proposed topology.

V. MATLAB SIMULINK DIAGRAMS & RESULTS OF FULL BRIDGE INVERTER

Simulation model of Full bridge inverter:

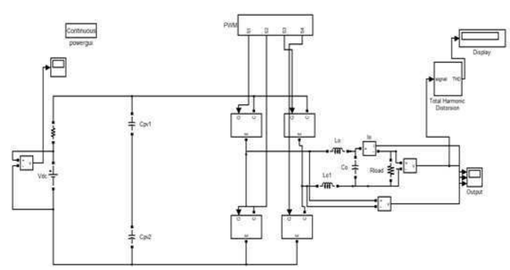


Fig 5.1 Simulation model of full bridge inverter

Output voltage and current waveforms:

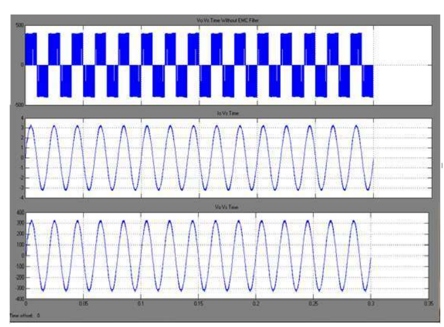
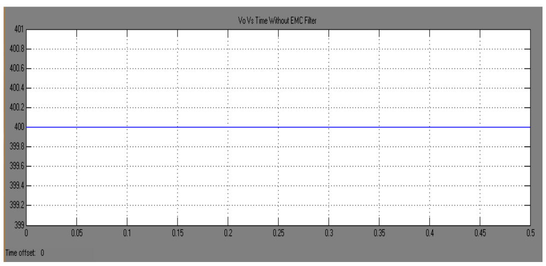


Figure 5.2 output voltage and current waveforms

Matlab/simulink diagrams & results of proposed topology:

The performance of the proposed Full bridge inverter topology is simulated with the Matlab/Simulink software. In the simulation, the utility supply is rated at 400 V and 50 Hz with a load inductance of Lo = 3 mH. The inverter is rated at 5 kw and is driving a R load of R =100Ω. The two dc capacitor(photovoltaic capacitor) Cpv is 1000 μF. SPWM method is used to modulate the inverter with unity power factor. The inverter output voltage is not detected, and therefore,is not tightly controlled. The switching frequency of inverter is 25Hz.

Single phase dc input with frequency 50Hz



Figure(5.3) shows single phase dc input with frequency 50Hz

Output waveforms of proposed topology:

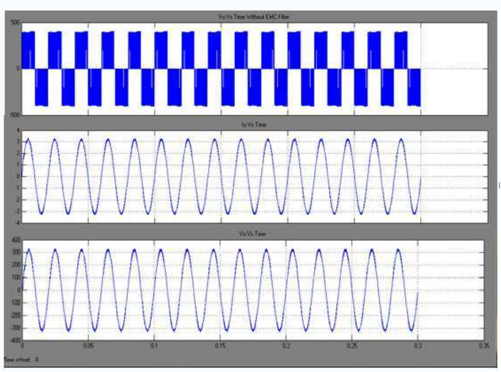


Figure (5.4) output waveforms of proposed topology:

FFTAnalysis:

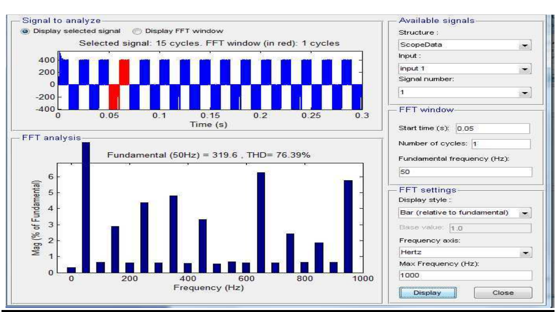


Figure (5.5) FFT analysis for output voltage without EMC filter of XY phase at 50 Hz frequency

FFTAnalysis:

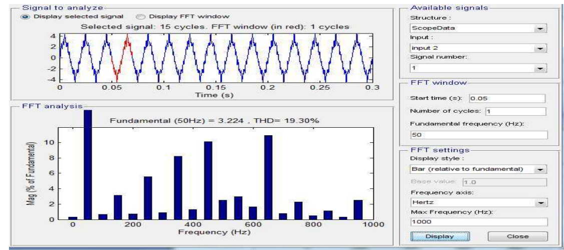


Figure (5.6) FFT analysis for output current of XY phase at 50 Hz Frequency

FFTAnalysis:

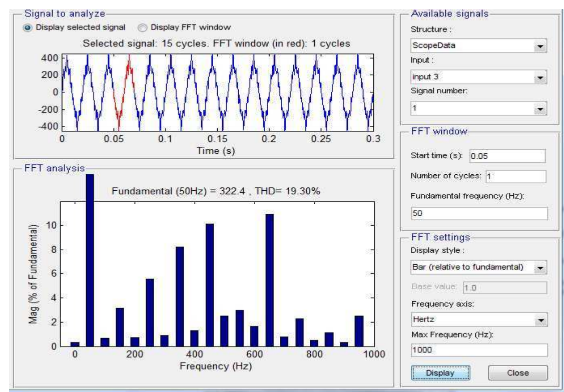


Figure (5.7) FFT analysis for output voltage of XY phase at 50 Hz frequency

VI. CONCLUSIONS & FUTURE SCOPE:

A Single-phase PV Full bridge inverter proposes a new transformerless, with six switches and two diodes inverter topology was proposed in this paper. The topology uses only six IGBT devices for dc to ac conversion. The proposed inverter Compared with the conventional Full bridge inverter with bipolar PWM using 6 switches and 2 diodes. The proposed inverter features sinusoidal inputs and outputs, unity input power factor, and low manufacturing cost.The proposed topology generates no common-mode voltage, exhibits a high efficiency, and can operate with any power factor. It has been compared to other topologies and valn this paper comparison between Full bridge inverter with four switches and Full bridge inverter with six switches topology using sinusoidal Pulse Width Modulation technique. Furtherly this project can be helpful in eliminating the selected harmonics of 3rd order produced in this method by using selective harmonic elimination method .If in case, there are harmonics even after using this method then any other advanced PWM techniques can be followed to overcome the problem.

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