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Transformer less Inverter with Virtual DC Bus Concept for Cost Effective Grid Connected PV Power System

[1]S. Vengatraman and [2]K. Ramesh

[1]Assistant Professor & Head, Department of Electricals and Electronics Engineering,
Sri Rangapoopathi College of Engineering, Anna University, Tamil Nadu, India-604 151
[2]Ph.D Scholar (full time), Department of Electronics and Communication Engineering,
Easwari Engineering College, Anna University, Chennai, India-600 089, India

Abstract: In order to eliminate the common-mode (CM) leakage current in the transformer less photovoltaic (PV) systems, the concept of the virtual dc bus is proposed in this paper. By connecting the grid neutral line directly to the negative pole of the dc bus, the stray capacitance between the PV panels and the ground is bypassed.As a result, the CM ground leakage current can be suppressed completely. Meanwhile, the virtual dc bus is created to provide the negative voltage level for the negative ac grid current generation. Consequently, the required dc bus voltage is still the same as that of the full-bridge inverter. Based on this concept, a novel transformer less inverter topology is derived, in which the virtual dc bus is realized with the switched capacitor technology. It consists of only five power switches, two capacitors and a single filter inductor. Therefore, the power electronics cost can be curtailed. This advanced topology can be modulated with the uni polar sinusoidal pulse width modulation (SPWM) and the double frequency SPWM to reduce the output current ripple.As a result, a smaller filter inductor can be used to reduce the size and magnetic losses.

Key words: Sinusoidal pulse width modulation · Common-mode · Photovoltaic (PV) systems · Inverse Sine Carrier Pulse Width Modulation · MATLAB.

INTRODUCTION

Now a days, the grid-connected photovoltaic (PV) systems, especially the low-power single-phase systems, call for high efficiency [1], small size, light weight and low-cost grid connected inverters. Most of the commercial PV inverters employ either line-frequency or high-frequency isolation transformers. However, line-frequency transformers are large and heavy, making the whole system bulky and hard to install.

Topologies with high-frequency transformers commonly nclude several power stages, which increases the system complexity and reduces the system efficiency. Consequently the transformer less configuration for PV systems is developed [2] to over the advantages of high efficiency, high power density and low cost. Unfortunately, there are some safety issues because a galvanic connection between the grid and the PV array exists in the transformer less systems. A common-mode leakage current flows through the parasitic capacitor between the PV array and the ground once a variable common-mode voltage is generated in transformer less grid-connected inverters.

The common-mode leakage current increases the system losses [3], reduces the grid-connected current quality, induces the severe conducted and radiated electromagnetic interference and causes personal safety problems.To avoid the common-mode leakage current, the conventional solution employs the half-bridge inverter or the full-bridge inverter with bipolar sinusoidal pulse width modulation (SPWM), because no variable common-mode voltage is generated [4]. However, the half-bridge inverter requires a high input voltage which is greater than, approximately, 700V for 220V ac applications. As a result, either large numbers of PV modules in series are involved or a boost dc/dc converter with extremely high-voltage conversion ratio is required as the first power processing stage.

Corresponding Author: S. Vengatraman Assistant Professor & Head, Department of Electricals and Electronics Engineering, Sri Rangapoopathi College of Engineering, Anna University, Tamil Nadu, India-604 151.

The full-bridge inverter just needs half of the input voltage demanded by the half-bridge topology,which is about 350V for 220V ac applications. But the main drawback is that the full bridge inverter can only employ the bipolar SPWM strategy with two levels, which induces high current ripple [5], large filter inductor and low system efficiency. In this paper, an improved grid-connected inverter topology for transformer less PV systems is presented, which can sustain the same low input voltage as the full-bridge inverter and guarantee not to generate the common-mode leakage current.

The Inverse Sine Carrier Pulse Width Modulation (ISPWM) can be applied in the presented inverter. The lower total harmonic distortion and higher fundamental output voltage are obtained by using the Inverse Sine Carrier Pulse Width Modulation (ISPWM). Therefore [6], a smaller filter inductor can be employed and the harmonic contents of the output current are reduced greatly and the grid-connected power quality is improved accordingly.

Transformerless Inverter

PWMtechnique in inverter: Process is Included in Inverter for Switching. A basic of Pulse Width Modulation (PWM) Technique is as. There are many forms of modulation used for communicating information. When a high Frequency signal has amplitude varied in response to a lower frequency signal we have AM (amplitude modulation) [7].When the signal frequency is varied in response to the modulating signal we have FM (frequency modulation.

These signals are used for radio modulation because the high frequency carrier signal is needs for efficient radiation of the signal. When communication by pulses was introduced, the amplitude, frequency and pulse width become possible modulation options. In many power electronic converters where the output voltage can be one of two values, the only option is modulation of average conduction time. Sine Modulated, Unmodulated Signal The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration by modulating the duty cycle. Analog PWM control requires the generation of both reference and carrier signals that are feed into the comparator and based on some logical output, the final output is generated.

The reference signal is the desired signal output maybe sinusoidal or square wave, while the carrier signal is either a saw tooth or triangular wave at a frequency significantly greater than the reference.In many industrial applications, it’s often required to control the output voltage of inverters for the following reasons.

Sinusoidal Pulse Width Modulation (SPWM): Instead of, maintaining the width of all pulses of same as in case of multiple pulse width modulation, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. The distortion factor and lower order harmonics are reduced significantly. The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency Fc.The frequency of reference signal Fr,determines the inverter output frequency and its peak amplitude AC, [8] controls the modulation index M,andVrms output voltage VO.The number of pulses per half cycle depends on carrier frequency.Inverters that use PWM switching techniques have a DC input voltage that is usually constant in magnitude. The inverters job is to take this input voltage and output ac where the magnitude and frequency can be controlled. There are many different ways that pulse-width modulation can be implemented to shape the output to be AC power.

A common technique called sinusoidal-PWM will be explained. In order to output a sinusoidal waveform at a specific frequency a sinusoidal control signal at the specific frequency is compared with a triangular waveform. The inverter then uses the frequency of the triangle wave as the switching frequency. This is usually kept constant.

The triangle waveform, is at switching frequency fs; this frequency controls the speed at which the inverter switches are turned off and on. The control signal, control, is used to modulate the switch duty ratio and has a frequency f1. This is the fundamental frequency of the inverter voltage output. Since the output of the inverter is affected by the switching frequency it will contain harmonics at the switching frequency. The duty cycle of the one of the inverter switches is called the amplitude modulation ratio.

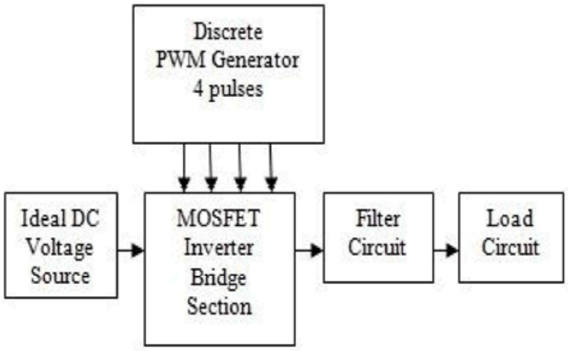

Fig. 2.1: Block diagram

Transformer less (TL) Inverter Appeal: Transformer less inverters is light, compact and relatively inexpensive. Since Transformer less inverters use electronic switching rather than mechanical switching the amount of heat and humidity produced by standard inverters is greatly reduced. TL inverters maintain the unique ability to utilize two power point trackers that allow installations to be treated as separate Solar PV Systems. In other words with TL inverters, Solar PV Panels can be installed in two different directions (i.e. north and west) on the same rooftop and generate DC output at separate peak hours with optimal effects. Traditional inverters work through only one power point, which means panels that are performing at lower frequencies will lower DC output for the entire system.

Transformer less (TL) Inverter Considerations: Transformer less inverters do not have electrical isolation between DC and AC circuits. This may raise some grounding and / or lightning protection concerns. In order for transformer less inverters to comply with NEC specifications specially designed and more expensive PV Wire must be used.Transformer less inverters have been developed for use with Grid-Tie Solar PV Systems, so Off-Grid systems users will not necessarily achieve the same benefit yet.

Advantages of MOSFETs: Thyristors and Bipolar Junction Transistors (BJT) were the only power swtches until the MOSFETs wre introduced in the late 1970s. The BJT is a current-controlled device; whereas the MOSFET is a voltage-controlled device. In the 1980s, the IGBT was introduced, which is also a voltage controlled device. The MOSFET is a positive-temperature-coefficient device whereas IGBT may or may not be a positive-temperature-coefficient device.The MOSFET is a majority carrier device making it ideal for high frequency applications. Inverters, which change DC to AC electricity, can be operated at ultrasonic frequencies to avoid audible noise. The MOSFET also has high avalanche capability compared to the IGBT. Operating frequency is important in choosing a MOSFET. The IGBT has lower clamping capability compared to the equivalent MOSFET. DC bus voltage at the inverter input, power rating, power topolg and frequency of the operation must be considered when choosing between IGBT and MOSFET. An IGBT is generally used for 200V and above applications; whereas the MOSFET can be used in applications from 20V to 1000V. Newer MOSFETs have lower conduction loss and switching loss and are replacing IGBTs in medium voltage applications up to 600V. generally, IGBTs are used for high-current and low-frequency switching; whereas MOSFETs are used for low-current

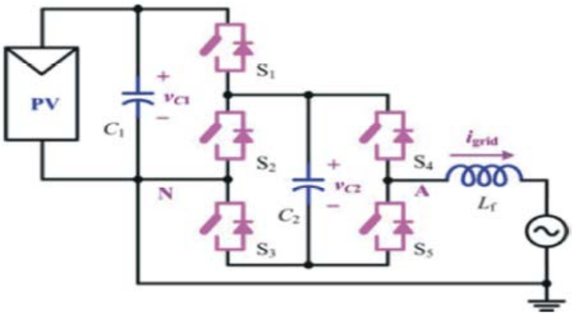

Fig. 2.2: Circuit Diagram

It consists of five power switches S1~S5 and only one single filter inductor Lf. The PV panels and capacitor C1 form the real DC bus while the virtual DC bus is provided by C2. With the switched capacitor technology, C2 is charged by the real DC bus through S1 and S3 to maintain a constant voltage.

STATE	SWITCHES				
	S_1	S_2	S_3	S_4	S_5
1	ON	OFF	ON	ON	OFF
2	ON	OFF	ON	OFF	ON
3	OFF	ON	OFF	OFF	ON
4	OFF	ON	OFF	ON	OFF

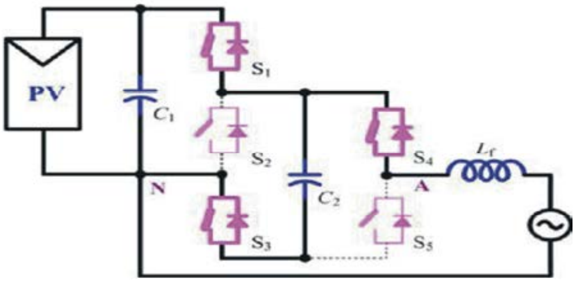

Fig. 2.3(a): Operating state 1

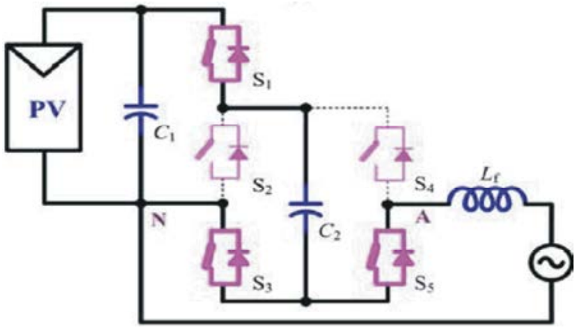

Fig. 2.3(b): Operating state 2

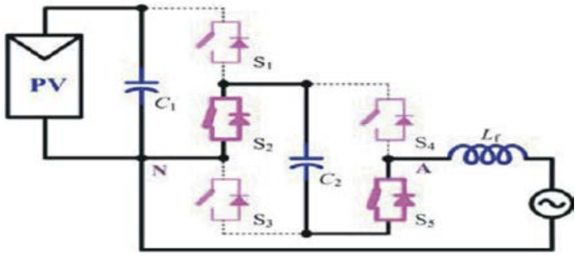

Fig. 2.3(c): Operating state 3

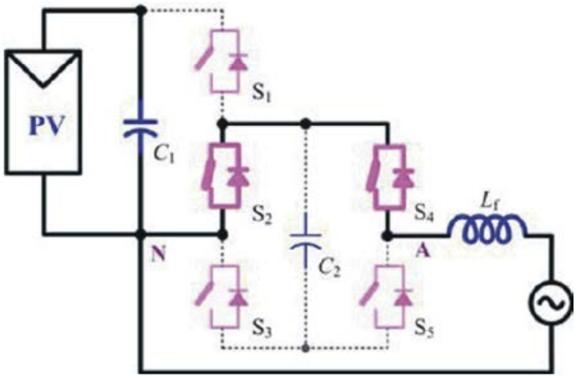

Fig. 2.3(d): Operating state 4

For all of the four operation states, there is no limitation on the direction of the output current igrid, since the power switches with antiparallel diodes can achieve bidirectional current flow. Therefore, the proposed topology has the capability of feeding reactive power into the grid to help support the stability of the power system. The proposed topology is also immune against transient overvoltage of the grid.

During the mains positive voltage spikes, the voltage at point A is clamped at Vdc by C1 and the anti parallel diodes of S1 and S4. Similarly, during the negative voltage spikes, the voltage at point A is clamped at Vdc by C2 and the ant parallel diodes of S2 and S5. Therefore, the Mains transient overvoltage does not pose a safety threat for the inverter.

Power Supply and Control Unit

Power Supply Unit: A power supply is an electronic device that supplies electric energy to an electricalload. The primary function of a power supply is to convert one form of electrical energy to another. A Power supplies are sometimes referred to as electric power. converter Some power supplies are discrete, stand-alone devices, whereas others are built into larger devices along with their loads.Depending on its design, a power supply may obtain energy from various types of energy sources, including electrical energy transmission systems, energy storage devices such as batteries and fuel cells, electromechanical systems such as generators and alternators, solarpower converters or another power supply. All power supplies have a powerinput, which receives energy from the energy source, a poweroutput that delivers energy to the load. In most power supplies the power input and output consist of electricalconnectors or hardwired circuit connections, though some power supplies employ wireless energytransfer of galvanic connections for the power input or output. Some power supplies have other types of inputs and outputs as well, for functions such as external monitoring and control. For example, a regulated powersupply is one that maintains constant output voltage or current despite variations in load current or input voltage. An integrated circuit is a chip in that contains all the amenities of a normal circuit board. These components include capacitors, resistors, transistors and many others. These components are condensed into a single chip in micro-electronics

Introduction of ic 7805: IC 7805 is a 5V fixed three terminal positive voltage regulators IC. The IC has features such as safe operating area protection, thermal shut down, internal current limiting which makes the IC very rugged.Output currents up to 1A can be drawn from the IC provided that there is a proper heat sink. A 9V transformer steps down the main voltage, 1A Bridge rectifies it and capacitor C1 filters it and 7805 regulates it to produce a steady 5Volt DC. If more than 400mA current is supposed to be taken from the circuit, fit a heat sink to the 7805 IC. The circuit schematic is given below.

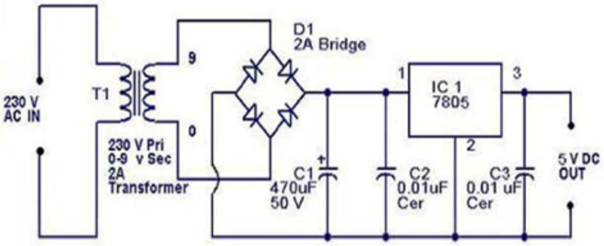

Fig 3.1 Circuit diagram of IC 7805

7805 is an easy to use voltage regulator IC which output 5 volts and 1A max. It takes an unregulated voltage input which can be fluctuating within its input limits and converts this fluctuating voltage input into a perfectly regulated 5 volts power output. For example, a 12 volt lead acid battery when fully charged gives out approximately 12.70 volts and when fully discharged, it gives out 10.50 volts. This difference can be even more under load or under charging state. If we use this battery as an input source for our 7805, output voltage will remain 5 regardless of that voltage difference of battery during charging and discharging phases. The Pin Diagram is given below.

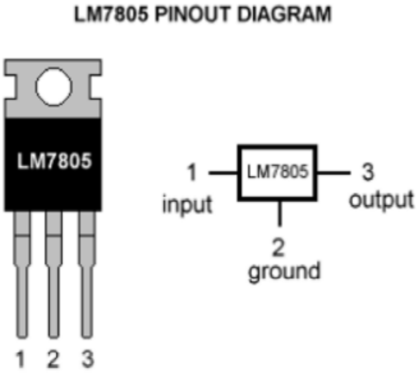

Fig 3.2: Pin Diagram of IC 7805

Introduction of IC 7812: The ±12 V supply required by the OP amps is provided by the 12V supply. The circuit diagram of ±12V power supply unit is shown in figure. Initially 230 V AC supply is reduced to (15V-0-15V) with the help of a step down transformer having a capacity of 1A and the center tap of the transformer is grounded. This low voltage is rectified with the help off bridge rectifier. Since the input voltage to the regulator IC should be more than its output voltage, transformer secondary voltage is 15V-0-15V.The ripples are minimized with the help of capacitor filter to get a smooth DC supply. The rating of the chosen capacitor filter is 1000µF.

The regulated DC output voltage is obtained by using regulator ICs. For regulated +12V DC supply, IC 7812 is used and for regulated -12V DC supply, IC 7912 is used. In the case of IC 7812 the unregulated DC voltage is applied to Pin 1 and the output is taken at Pin 3 and Pin 2 is grounded. In the case of 7912, the unregulated DC voltage is applied to Pin 2, the output is taken at Pin 3 and Pin 1 is grounded. The pair of capacitors of 10µF is connected at the output as shown in figure to eliminate the voltage oscillations at the output due to the large voltage oscillations at the input of the regulator.

7812 is a famous IC which is being widely used in 12V voltage regulator circuits. Truly speaking it is a complete standalone voltage regulator. We only need to use two capacitors, one on the input and second one on the output of 7812 in order to achieve clean voltage output and even these capacitors are optional to use. To achieve 12V 1A current, 7812 should be mounted on a good heatsink plate. Thanks to the transistor like shape of 7812 which makes it easy to mount on a heatsink plate. 7812 has built in over heat and short circuit protection which makes it a good choice for making power supply.

Control Unit: The control unit (CU) is a component of a computer's centralprocessingunit(CPU) that directs operation of the processor. It tells the computer's memory, arithmetic/logic unit and input and output devices how to respond to a program's instructions. It directs the operation of the other units by providing timing and control signals. Most computer resources are managed by the CU. It directs the flow of data between the CPU and the other devices.

The Control Unit (CU) is digital circuitry contained within the processor that coordinates the sequence of data movements into, out of and between a processor's many sub-units. The result of these routed data movements through various digital circuits (sub-units) within the processor produces the manipulated data

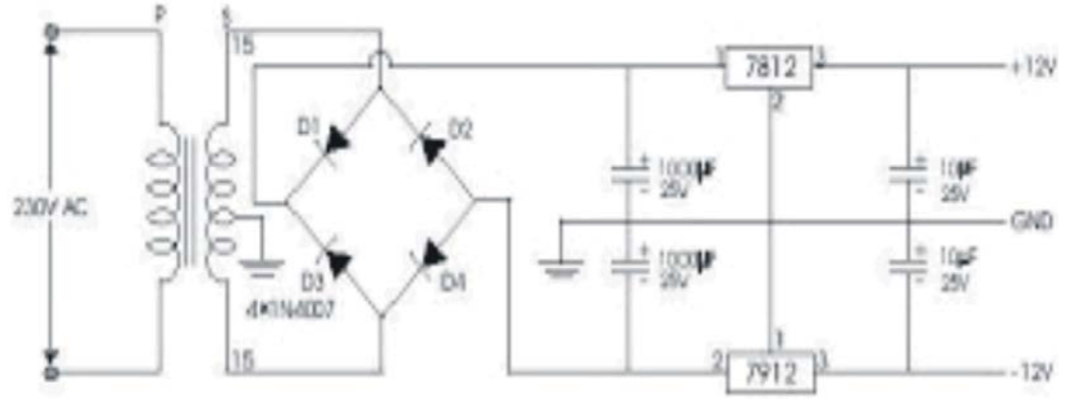

Fig. 3.3: Circuit diagram of 7812

expected by a software instruction (loaded earlier, likely from memory). In a way, the CU is the "brain within the brain", as it controls (conducts) data flow inside the processor and additionally provides several external control signals to the rest of the computer to further direct data and instructions to/from processor external destinations (i.e. memory). Examples of devices that require a CU are CPUs and graphics processing units (GPUs).

More precisely, The Control Unit (CU) is generally a sizable collection of complex digital circuitry interconnecting and controlling the many execution units (i.e. ALU, data buffers, registers) contained within a CPU. The CU is normally the first CPU unit to accept from an externally stored computer program, a single instruction (based on the CPU's instructionset). The CU then decodes this individual instruction into several sequential steps (fetching addresses/data from registers/memory, managing execution [i.e. data sent to the ALU or I/O] and storing the resulting data back into registers/memory) that controls and coordinates the CPU's inner works to properly manipulate the data. The CU's orderly hardware coordination properly sequences these control signals then configures the many hardware units comprising the CPU, directing how data should also be moved, changed and stored outside the CPU (i.e. memory)·This one feature, that efficiently uses just software instructions to control/select/configure a computer's CPU hardware (via the CU) and eventually manipulates a program's data, is a significant reason most modern computers are flexible and universal when running various programs. This CU instruction decode process is then repeated when the Program Counter is incremented to the next stored program address and the new instruction enters the CU from that address and so on till the programs end.

PIC 16F877 is one of the most advanced microcontroller from Microchip. This controller is widely used for experimental and modern applications because of its low price, wide range of applications, high quality and ease of availability. It is ideal for applications such as machine control applications, measurement devices, study purpose and so on. The PIC 16F877 features all the components which modern microcontrollers normally have.

MATLAB Simulation

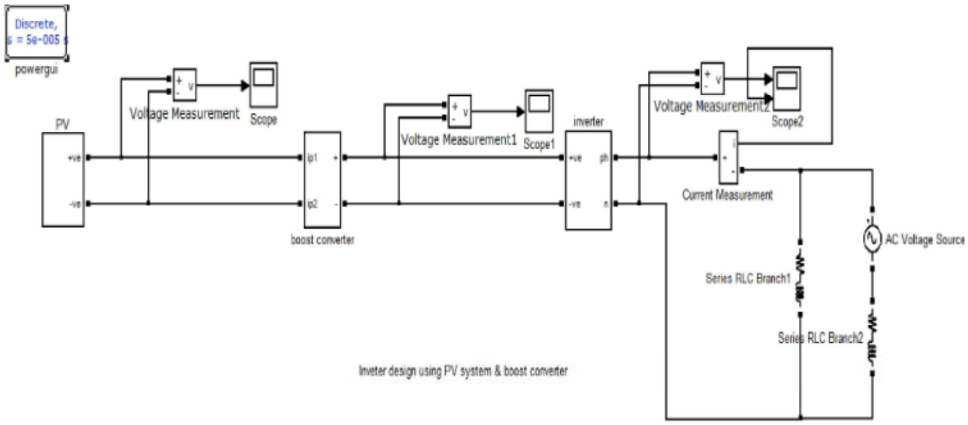

Fig. 4.1: Boost converter

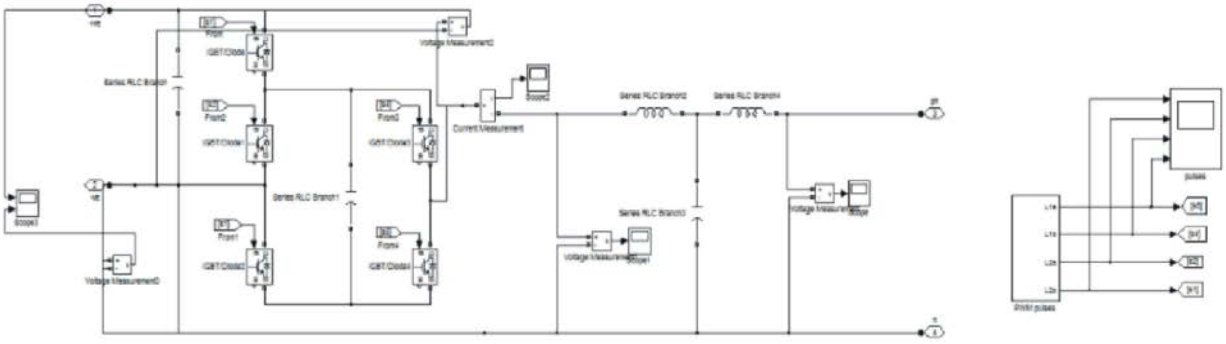

Fig. 4.2: Inverter simulink diagram

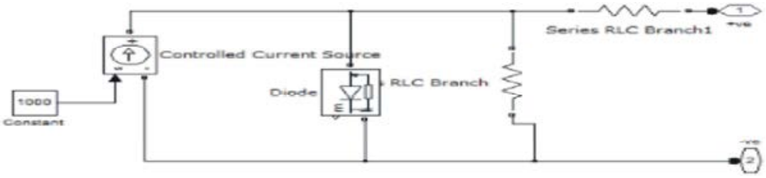

Fig. 4.3: PV array

Gate Signals and Output Waveforms

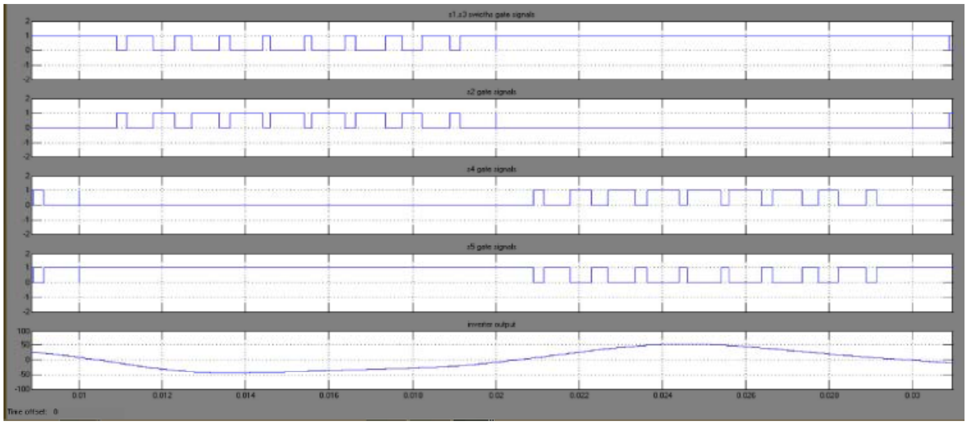

Fig. 4.7: Gate signals

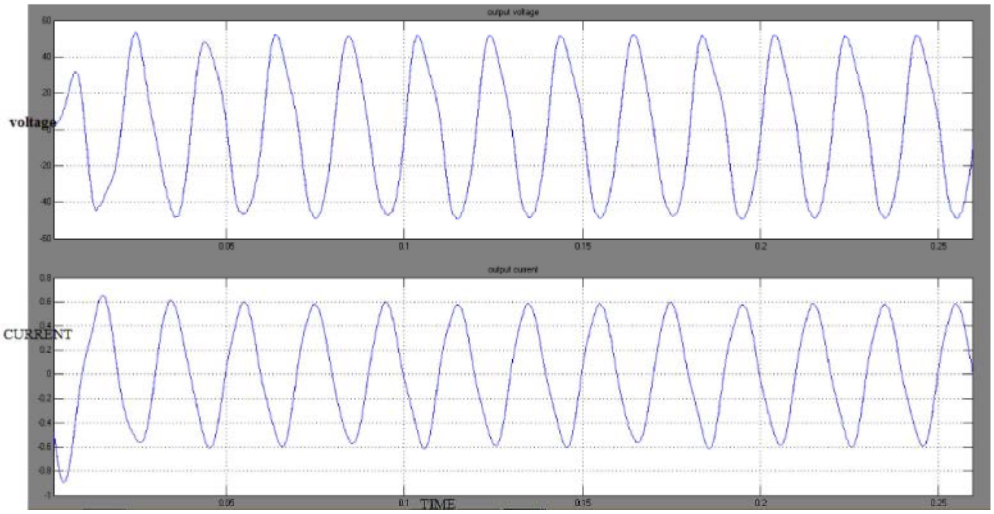

Fig. 4.8: Inverter output voltage

CONCLUSION

This work introduces a simulink model for transformerless single-phase grid-connected photovoltaic system with a cascaded inverter and its different aspects have been discussed in this paper. Advantageous transformerless concepts along with attractive features of multilevel inverters and control and grid synchronization were studied in this report. The gating signals for the eight inverter switches are generated by using an optimised cyclic switching sequence which ensures minimum switching frequency, low DC bus capacitor ripple and equal stress on each switch.The proposed topology is especially suitable for the small-power single-phase applications, where the output current is relatively small so that the extra current stress caused by the switched capacitor does not cause serious reliability problem for the power devices and capacitors.

With excellent performance in eliminating the CM current, the virtual dc bus concept provides a promising solution for the Transformerless grid-connected PV inverters.

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