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DESIGN AND SIMULATION OF TRANSFORMERLESS INVERTER FOR 3MW GRID CONNECTED SOLAR PV PLANT AT KOLAR

(Under KPCL - A govt. of Karnataka undertaking)

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Abstract— **Presently in the grid, twelve inverters followed by twelve transformers of 720/415V have been used. This combination results in very less efficiency of the existing plant. In this paper, a prototype of single phase grid connected transformerless inverter is designed to overcome the problems associated by their combination.**

From solar panel of 720V DC output is given to Buck converter which further reduces the output to 415V DC. Buck converter is followed by single phase inverter of 250 kW. The inverter topology is a full bridge inverter with addition of two more switches after the input stage. High efficiency of this proposed inverter is achieved by using Unipolar Sinusoidal Pulse Width Modulation switching strategy.

Keywords—Transformerless, inverter, Unipolar,pwm.

I. INTRODUCTION

This paper describes the design and analysis of the grid-connected single-phase inverter for photovoltaic (PV) application. This research has been carried out at 3MW Grid Connected Solar Power plant at Kolar. The plant is undertaken by Karnataka Power Corporation Limited (KPCL) involved in the provision of power generation services to the state of Karnataka.

The primary objective of the paper is to effectively demonstrate the use of renewable solar energy to meet the rising demand of energy in INDIA and to improve the quality of electricity supply. Grid-connected photovoltaic (PV) systems usually include a line transformer in their power conversion stage. Presently in the grid, a step down transformer is used which steps down the voltage and also guarantees galvanic isolation between the grid and the PV system, as the transformer is huge, heavy, and expensive and due to the losses associated with the transformers the efficiency of the grid is reducing. Hence as an alternative to the grid-connected transformers, a new transformerless inverter topologies are studied. The Transformers in the inverter panels are replaced by an improved grid-connected inverter which is having high efficiency, smaller in size & weight, lesser price inverter which can sustain the same low input voltage as the full-bridge inverter.

This paper describes the design and analysis of the grid-connected single-phase inverter for photovoltaic (PV) application. The single phase full bridge inverter is simulated for unipolar-sinusoidal pulse-width modulation (SPWM) control technique. A comparative analysis is made between Unipolar and Bipolar SPWM methods of switching.

II. TRANSFORMERLESS INVERTERS

The differences between conventional inverters and transformerless inverters are: Conventional inverters are built with an internal transformer that synchronizes the DC voltage with the AC output.
Transformerless (TL) inverter does not include transformer in it. Since transformerless inverters use electronic switching rather than mechanical switching the amount of heat and humidity produced in the inverter is greatly reduced.

A. *Pulse Width Modulation (PWM) Technique*

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 fed 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. PWM provides a way to decrease the Total Harmonic Distortion (THD) of load current.

B. *Sinusoidal Pulse Width Modulation*

In this modulation technique, a multiple number of output pulse per half cycle are obtained and pulses are of different width. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. The gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal.

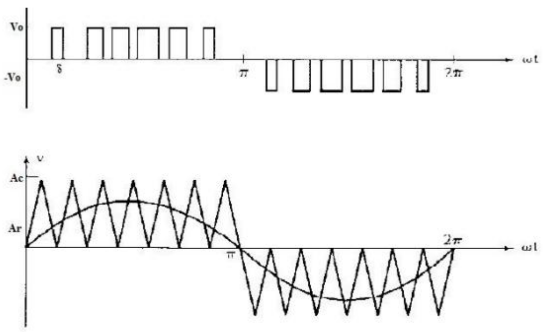

Fig.1.Waveform of SPWM technique

Control of the switches for the sinusoidal PWM output requires a reference signal (modulating or control signal) which is a sinusoidal wave and a carrier signal which a triangular wave that control the switching frequency.

There are two types of the switching techniques for SPWM, Unipolar switching and Bipolar switching.

C. *SPWM with Unipolar Voltage Switching*

In this scheme, the triangular carrier waveform is compared with two reference signals which are positive and negative signal. The process of comparing these two signals to produce the unipolar voltage switching signal is graphically illustrated in Figure. In unipolar, the output voltage switches between 0 and Vdc , or between 0 and –Vdc.

The effective switching frequency is seen by the load is doubled and the voltage pulse amplitude is halved. Due to this, the harmonic content of the output voltage waveform is reduced compared. . In Unipolar voltage switching scheme, the amplitude of the significant harmonics and its sidebands is much lower for all modulation indexes thus making filtering easier, and with its size being significantly smaller.

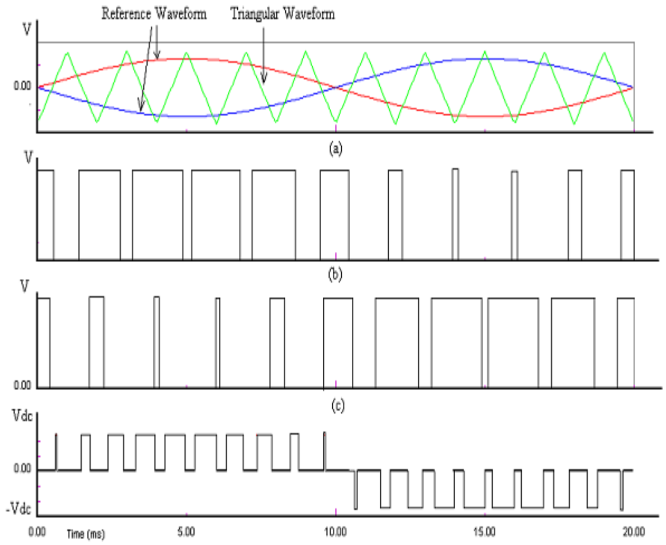

Fig 2. Waveform of Unipolar SPWM

D. *PWM with Bipolar Voltage Switching*

It comprises of a comparator used to compare between the reference voltage waveform Vr with the triangular carrier signal Vc and produces the bipolar switching signal. Here the output swings between Vdc and −Vdc If this scheme is applied to the full bridge single phase inverter as shown in Figure, all the switch S1, S2, S3 and S4 are turned on and off at the same time. The output of leg A is equal and opposite to the output of leg B. The output voltage is determined by comparing the reference signal, Vr and the triangular carrier signal,Vc.

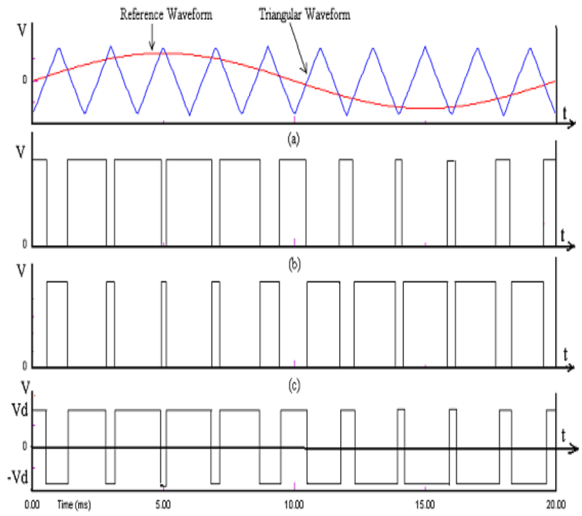

Fig 3. Waveform of Bipolar SPWM

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SPWM is considered as the best PWM technique for the reasons mentioned below.

- Low power consumption.
- High energy efficient upto 90%.
- High power handling capability.
- No temperature variation-and ageing-caused drifting or degradation in linearity.
- Easy to implement and control.
- Compatible with today's digital microprocessors

E. *SPWM Harmonic Elimination:*

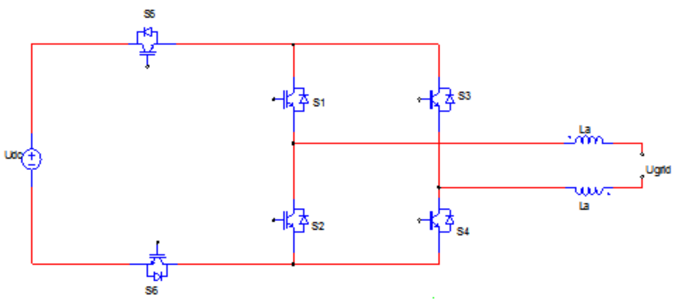
The SPWM waveform has harmonics of several orders in the phase voltage waveform , the dominant ones are the fundamental and other of order of n and n±2 where n=fc/fm. With the method of Selective Harmonic Elimination, only selected harmonics are eliminated with the smallest number of switching.

F. *Analysis of Single phase transformerless inverters topology*

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. However, the half-bridge inverter requires a high input voltage which is greater than, approximately 700 V for 220 Vac applications.

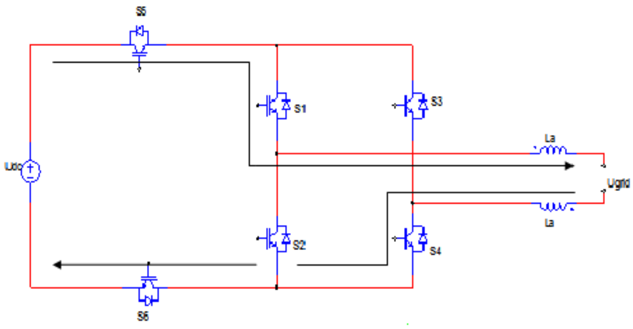
The full-bridge inverter just needs half of the input voltage demanded by the half-bridge topology, which is about 350 V for 220 Vac applications. But the main drawback is that the full bridge inverter can only employ the bipolar SPWM strategy with two levels, which induces high current ripple, large filter inductor, and low system efficiency. Therefore, many advanced inverter topologies for transformerless PV applications were developed such as H5 inverter, HERIC inverter, etc. These topologies need the same low input voltage as the full-bridge inverter and can adopt the unipolar SPWM strategy with three levels. In the simulations, IGBT switches are used for switching of inverters.

G. *Operating modes of Unipolar SPWM Inverter*

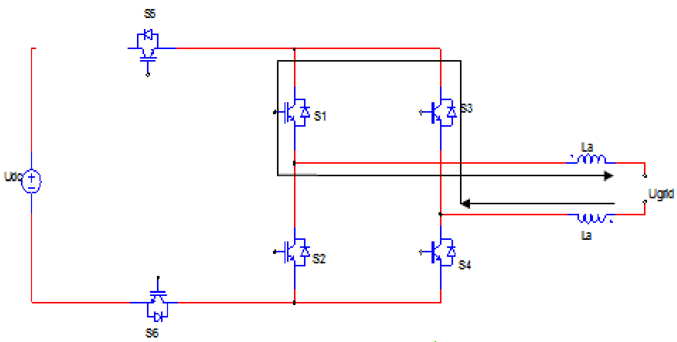


In this topology, two additional switches S5 and S6 are symmetrically added to the conventional full-bridge inverter. The switches S1 and S2 operate at the grid frequency, and switches S3 and S4 commutating at the switching frequency. The two additional switches S5 and S6 commutate alternately at the grid frequency. The Inverter operates in four different modes and generates the voltage states +Udc and –Udc.

- ***Mode 1 :*** During positive half cycle S1 and S6 are always ON. The switches S4 and S5 commutate at the switching frequency. When S4 and S5 are ON, *u*AB= +Udc . The inductor current increases through S5, S1, S4 and S6



- ***Mode 2:*** (Positive Half cycle) When S4 and S5are turned OFF, the voltage uAN falls and uBN rises until their values are equal, and the antiparallel diode of S3 starts conducting. Therefore, uAB=0 V and the inductor current decreases through the switch S1 and the antiparallel diode of S3.



- ***Mode 3***: (negative Half cycle) When S3 and S6 are ON, uAB= −Udc and the inductor current increases reversely through the switches S5, S3, S2, and S6.

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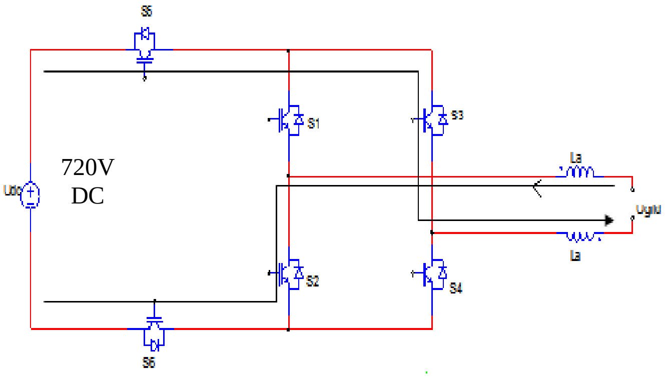
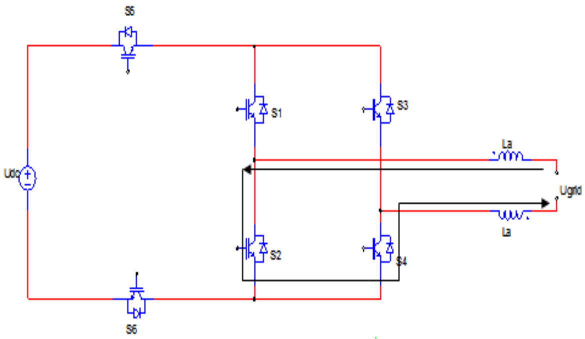


TABLE 1: SWITCHING STATUS DURING POSITIVE AND NEGATIVE HALF CYCLE (APPENDIX 1)

Mode 4 : (negative Half cycle) When the switches S3 andS6 are turned OFF, the voltage uAN Starts rising and *u*BN falls until their values are equal, and the antiparallel diode of S4 conducts. Similar as to Mode 2, uAB=0 V and the inductor current decreases through the switch S2 and the antiparallel diode of S4. The switching voltages of all commutating switches are half of the input voltage Udc/2, and thus, the switching losses are reduced compared with the full bridge inverter.



The details of new topology and operating modes are explained in the earlier sections. Simulation is carried out using Unipolar SPWM method- a high efficient method.

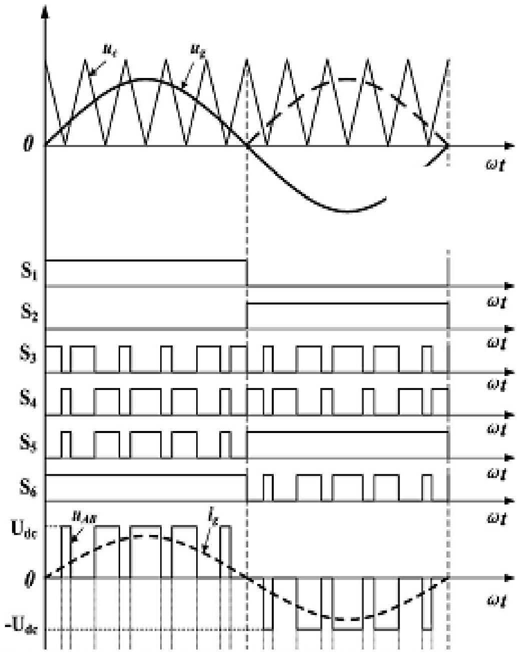


Fig 4. Waveforms of the gating pulses of improved inverter with unipolar SPWM

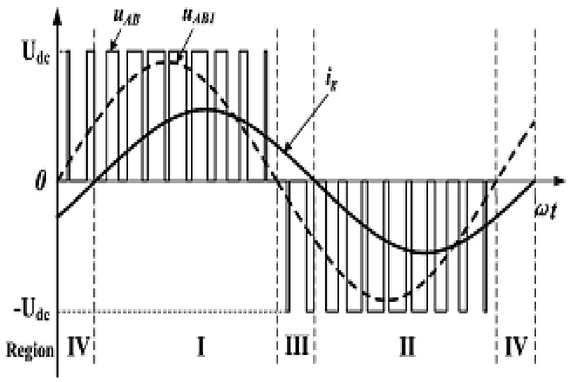


Fig.6. Multi pulse output of Single phase Unipolar Inverter, Ideal output and Simulation output.

The AC output of the Unipolar SPWM inverter in MATLAB Simulation is given below. For an input of 720V DC the output obtained in Mat lab is 415V AC.

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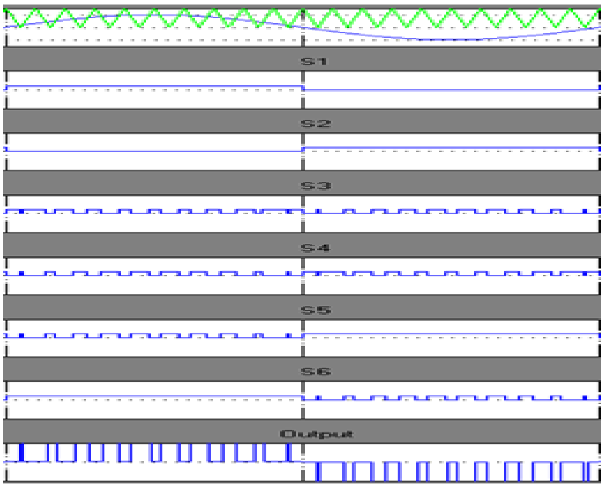

Fig.5. Simulation outputs of inverter with unipolar SPWM

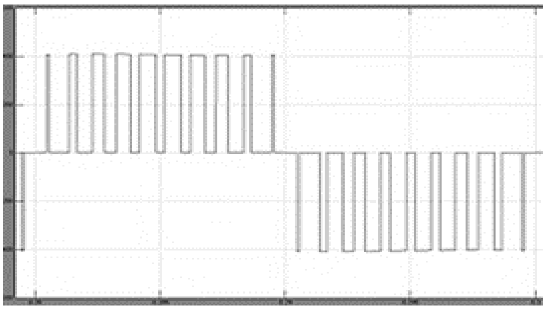

Fig.7. Multi pulse output of Single phase Unipolar Inverter, Ideal output and Simulation output.

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APPENDIX 1

Switches	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**Uab**	**Ucm**	
+Ve Half cycle	MODE 1	ON	OFF	OFF	ON	ON	ON	+Udc	Udc/2
	MODE	ON	OFF	OFF D3-	OFF	OFF	OFF	+Udc	Udc/2
-Ve Half cycle	MODE 3	OFF	ON	ON	OFF	ON	ON	-Udc	Udc/2
	MODE	OFF	ON	OFF	OFF D4-	OFF	OFF	-Udc	Udc/2