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A Novel Single-Phase Multilevel Transformerless PV Inverter For Reduced Common-mode current ☆

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Abstract

Transformerless photovoltaic (PV) inverters are vital role in the solar energy market due to reduced cost, weight and high in efficiency. A critical issues and challenges exist in this system such as suppress the ground leakage current, which is harmful to the human with additional ground currents flowing via resonant circuit parameters of the system. In this paper a novel topology introduced with multilevel output voltage using modified sinusoidal multi-carrier based PWM technique for control the inverter. In addition a super junction MOSFETS are consider as main power switches. And the key features of the proposed topology are follows with no reverse recovery issues, operating with high efficiency, low ground current and current distortion is achieved. Finally the proposed topology and its performance evaluation are verified by the simulation results.

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Keywords: Transformerless pv inverters,ground leakage current,multilevel inverters,PWM technique ,control startegy.

Nomenclature

PV	Photovoltaic
Cpv	Parasitic capacitor
EMI	Electromagnetic Interference

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THD	Total Harmonic Distortion
U_{KN}	Voltage between K and N
U_{dm}	Differential mode voltage
CMV	Common mode voltage
PD	Phase disposition
POD	opposite Disposition
PS	Phase shift PWM Alternative
APOD	Phase Opposition and Disposition

1. Introduction

This world demands more energy due to increased population and industries. A several renewable energy sources are available in nature such as coal, wind, solar energy etc. Among them photo-voltaic (PV) energy is popular and free source in nature [1]-[2]. Now a day's PV industry searching for low cost and efficient PV inverter topologies, which is reduce the initial investment for PV generation system. According to that inverters manufactures are improved their products without sacrificing the system efficiency. As a result transformerless PV inverters are introduced with reduced size, weight and higher efficiency compare to conventional isolated inverters [3]-[5]. The standard H-bridge topology as shown in fig.1, which is not considered the transformer between converter and the utility grid such as either low frequency or high frequency. Therefore ground leakage current is carried via stray elements in the circuits, as shown in fig.2.The ground current path includes the parasitic capacitor (Cpv1), embedded between PV cells and grounded frame. These systems are evaluated in two types such as with transformer and without transformer**.**

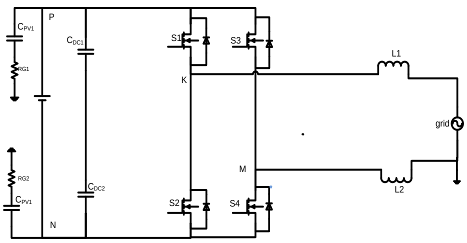
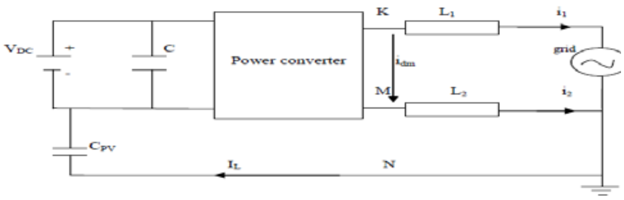


Fig.1. Standard H-bridge topology

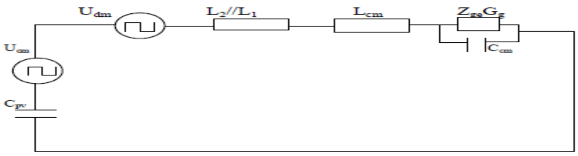
In general most of the grid connected systems are with transformer, which provides the galvanic connection for the safety [3].This types of systems are complex in design, cost and low efficiency. To overcome this issues transformerless PV inverters are comes into picture with reduced size, weight and improved efficiency[4]-[5].The basic topology of the transformerless PV inverter is shown in fig.2,which is not consider either low frequency or high frequency transformer in a system. Due to increased ground currents affect the systems parameters such as losses, reliability, grid current distractions and EMI issues [6] - [7]. Therefore as per the VDE0126-1-1 standards the ground current are not exceed the 300mA, within 0.3s [3] is required to disconnect the PV system. On the other hand the magnitude of the ground leakage current is mainly depending on the inverter topology and control strategy. As per literature several topologies are proposed based on the disconnection of PV array from the grid namely dc-decoupling and ac-decoupling methods [10]-[11].A modified full bridge topology is proposed with reduced leakage currents by Gonzalez et.al [4], And the half bridge family topology is proposed by S Araujo et.al, which needs high input voltage and number of PV strings [9]. The multilevel inverters have been proposed and basic concept is studied in the grid connected PV systems [15]-[17], which is more useful to inject the power towards the grid against for simple networks. In case cascade multilevel inverter topologies do not have boost converters to select proper operation such as generate ac output signal and allow the active power injection.

This paper is organized as follows: common mode voltage and leakage current analysis is discussed in section 1, proposed multilevel inverter and operating principles are presented in section 2, at the end the simulation results and conclusion are well noticed in section 3, 4.

1.1. Common mode voltage and Leakage current Analysis



(a)



(b)

Fig.2. (a) Basic transformerless PV inverter (b) Simplified common mode voltage

The major issues and challenges are come across the common mode current flowing through parasitic capacitor to the ground, which by means of galvanic isolation problems. This section explains the comprehensive analysis of the ground leakage current with respective to the common mode voltage and differential mode voltage is discussed in detailed, as shown in fig.2 (a),(b). Fig.2 (a) shows the schematic of the transformerless PV inverter with actual stray elements and ground leakage current .Similarly fig.2 (b) shows the equivalent circuits of the basic full bridge PV inverter interms of common mode voltage and differential mode voltage, which are useful notations for ground leakage current. Where positive phase K and the reference ground N terminal voltage is U_{KN} , negative phase M to ground N voltage is $U_{MN.}$

Defined common mode voltage is

$$U_{cm\text{-}KM} = \frac{U_{KN}+U_{MN}}{2} \qquad (1)$$

Differential voltage is defined as

$$U_{dm}= U_{KN}-U_{MN=}U_{KM} \qquad (2)$$

From the above relation explains, how capacitive leakage current depend on the common mode voltage and it concludes that reduced common mode current is possible while the CMV is constant such as exactly half of the input dc voltage[13].

2. Proposed topology

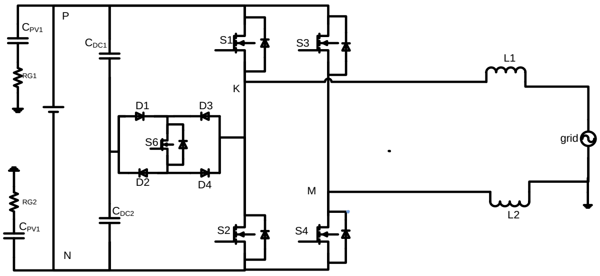


Fig.3. Proposed topology.

The proposed PV multilevel inverter as shown in fig.3, which consist of an basic H-bridge inverter and multilevel output voltage is obtained through bidirectional switch such as active clamping method configured.Fig.2shows the single phase multilevel transformerless PV inverter with six super junction MOSFET such as main switches S1-S4 and novel clamping branch is adopted between the midpoint of the dc-link capacitors such as S5 and D1-D4. In multilevel inverters when number of levels is increased, zero voltage states are reduced. Based on the literature various PWM methods are evaluated but in this paper novel improved sinusoidal Modulation technique is discussed called third harmonic injection method with multicarrier phase shift (THI-PSMPWM) method[18].A third harmonic injection method is analyzed using multilevel transformer less PV inverter in [15]-[17].Therefore various multicarrier techniques are proposed in [19] based on the carrier signal.According to the principle of the converter modified THI and its switching sequence, as shown in Table.1

2.1. Operating principles of proposed Topology

The operating principles of the proposed topology in various voltage levels are explored in Fig.4 As per the operating principle of the proposed inverter is illustrate the various output voltage levels which is shown in figs.4 (a)-(f).In positive half semi cycle the voltages levels are V_{pv}, $V_{pv/2}$ are generated using switching configuration as shown in fig.4 (a)-(b) called mode1 and mode2.

From the fig.4 (a) shows similar in conventional operating principle of full bridge such as S1, S4 are turn on while S3, S5, D1 and D2 turn off. The current flows via S1, load, S4 & dc voltage source. In this case it generates the positive output voltage V_{pv}. From the fig.4 (b) shows the freewheeling case which is generate the half of the input dc voltage $V_{pv/2}$.The current flows via D1,S5,D4 ,inductor,S4 and comeback grid lines and remains are off. It noticed that proper dead time is required to avoid the short circuit between switching signals at dc-link capacitor. Similar way of procedure is followed in negative semi cycle which is shown in fig.4 (d)-(f) called mode4 to mode6.

The switches S2, S3 are turned on while remain off, it generate the output voltage –Vpv, where Current flows via load, S2, dc-link, S3 and comeback to grid line. While it generate the -Vpv/2 output voltage the switches S3,S5, diode D2,D3 is ON and other is turned OFF. The current flows via load, D3, S5, D2, CDC1 and S3. However to avoid the short circuit the dead time must be inserted between the S2 and S5.In addition there are two zero states are possible in discussed topology such as S1,S3 are ON at one time period or S2, S4.Which is shown in fig.4 (c) & (f). The different switching pulses such as S1- S5 are shown in fig.5.

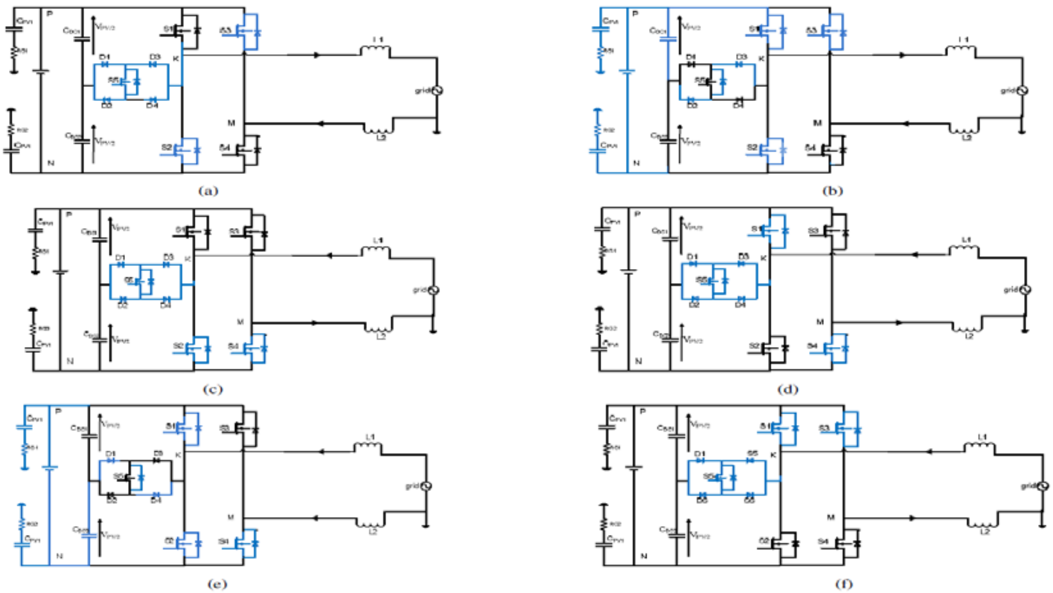


Fig.4 (a)-(f).Modes of operation as per Table 1

2.2. Concept of Third harmonic injection PWM:

In modulation techniques SPWM is suitable method for analysis but it is not fully utilize the available dc bus voltage. To eliminate these issues and improve the system performance via third harmonic injection pulse width modulation (THI-PSPWM) technique was employed in converters. From the reference [19] waveform include it fundamental component and third frequency term, which is presented as follows: From above ϴ=wt and A represents the parameter with optimize while the maximum peak amplitude. In third harmonic injection method, low frequency 50Hz signal is added to the third harmonic signal, which is 1/6 of the Fundamental component magnitude. Therefore modified modulating signal is rectified and compared to the high frequency signal with phase shift of 180 degrees t/2 time interval. The following equations' are required to develop the THI-PSMPWM (Third harmonic injection using phase shifted Multi carrier pulse width modulation).
Primary reference signals is given by

$$Y=\sin\Theta+A\sin3\Theta \quad (3)$$

$$V_{ref}=A\sin\Theta \quad (4)$$

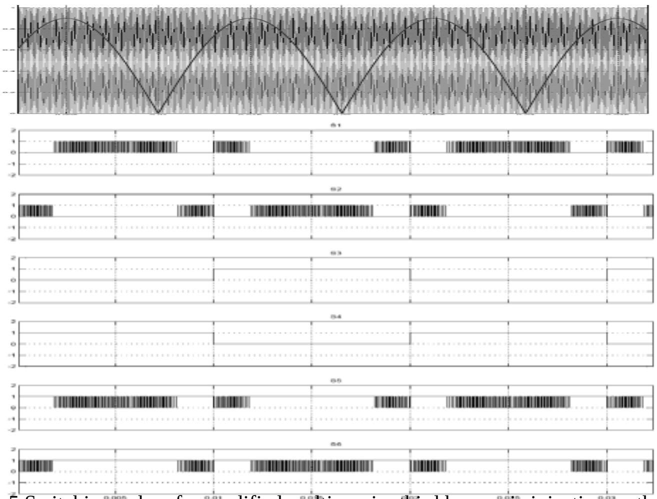


Fig.5.Switching pulses for modified multi carrier third harmonic injection method.

Table 1

Modes	Switching state					Output voltage
	S1	S2	S3	S4	S5	
			Positive semi cycle			
Mode1	1	0	0	1	0	V_{pv}
Mode2	0	0	0	1	1	$V_{pv/2}$
Mode3	0	1	1	0	1	0
			Negative semi cycle			
Mode4	1	0	1	0	0	0
Mode5	0	0	1	0	1	$-V_{pv/2}$
Mode6	0	1	1	0	1	$-V_{pv}$

If third harmonic signal is added to the primary reference signal

$$V_{3rd}=B\sin(3\Theta) \quad (5)$$

As a result modified signal is obtained by

$$V_{mod}=V_{ref}+V_{3rd} \qquad (6)$$

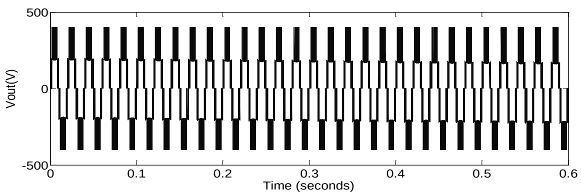
Let B=A/6

Finally the modified new reference signal will be presented as

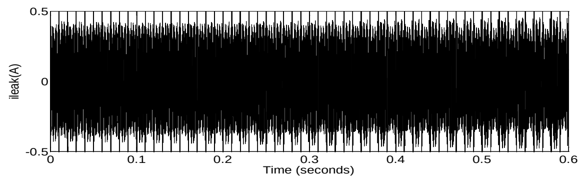
$$V_{mod}=A\left(\sin\Theta+\frac{1}{6}\sin 3\Theta\right) \qquad (7)$$

3. Simulation Results

The proposed multilevel inverter topology is evaluated using simulation. And the selected parameters of the system is follows such as switching frequency is 10 kHz, instead of PV panel a dc power supply is selected as 400V, Dc link capacitor ($C_{DC1,2}$) is 1000µF, output filter inductors (L_1, L_2) is 1.8mH, Filter capacitors (C_f) 2µF, parasitic capacitor ($C_{pv1,2}$) 75nF, ground resistance (R_G) is 11Ω respectively. Fig.6 shows the performance parameters of the proposed multilevel transformerless pv inverter .Fig.6 (a) shows the five level output voltage of the proposed multilevel transformerless PV inverter with given input voltage of 400V. In Fig.6.(b) presents the common mode current of system which is below 300mA and follows as per the german standards it is allowable for safer in limits. It is evident that proposed multilevel inverter achieves quality of output current with low harmonic content which is followed as per the IEEE-519 standards,as shown in Fig.7[16]. Therefore the proposed inverter with THI-PSMPWM is suitable for elimination of the ground leakage current instead of conventional PWM techiques.

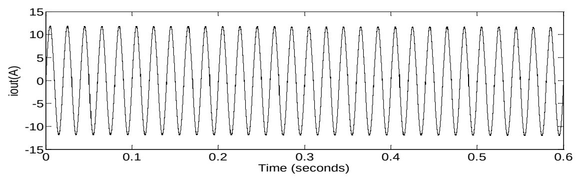


(a)

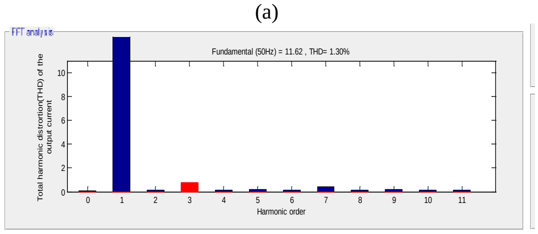


(b)

Fig.6. Performance parameters of the proposed multilevel inverter (a) Output voltage (b) leakage current



(a)



(b)

Fig.7 .(a)Output current (b)FFT analysis.

4. Conclusion

In this paper a novel multilevel transformerless PV inverter is proposed with modified third harmonic injection multicarrier phase shift pulse width modulation technique (THI-PSMPWM) with reduced capacitive leakage current. It is configured based on the standard H-bridge topology with an auxiliary circuit. Proposed topology consisted in bidirectional switch formed by one MOSFET and four diodes. The bidirectional switch was connected between the midpoint of the first leg in the H-bridge and second terminal connected to the mid-point of the spilt capacitor. According to other commercial single phase topologies, proposed inverter provided with five output voltage levels. Besides, this control strategy was proposed based on the multicarrier modulation technique, which controlled the power flowing from DC source. The proposed topology and PWM were aimed to suppress the ground leakage current issue in low power transformerless PV applications. The proposed inverter and its PWM strategy are validated through numerical simulations, which confirmed that common mode current is follows as per the German standard. Furthermore, due to five output voltage levels, the THD content low and follows as per the IEEE-519.From analysis and simulation results, it is concluded that the proposed topology and modulation technique is extremely suitable for grid connected PV applications.

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