

Virtual Implementation of Transformer less Inverter for Grid Connected Photovoltaic Cell

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Abstract: The usual grid-connected renewable energy source inverters have either a line frequency or a high frequency transformer between the source and the grid. This transformer is mainly focused for galvanic isolation between the load and the source. By removing the isolation transformer, we can achieve the effective solution and also reduced size and cost. This elimination produces the common mode ground leakage current, because of parasitic capacitance between the PV panel and ground. The common mode (CM) leakage current will reduce the efficiency of power conversion, and also affects grid current, deteriorate the electric magnetic compatibility and rise the safety threats. To eliminate the common mode (CM) leakage current, the virtual DC bus concept is implemented in this paper. When we connect grid neutral line to DC bus negative pole, the stray capacitance exists between the PV panel and ground is bypassed. The Common mode (CM) ground leakage current would be completely eliminated. To provide negative voltage level for negative AC grid current generation, the virtual DC bus is created. The virtual DC bus is implemented with the switched capacitor topology that uses less number of elements. Hence, the power electronic cost would be reduced. This topology can be implemented with the unipolar SPWM to reduce the output ripple. A small inductor, which can be used as filter will reduce size and magnetic losses. The simulation result of the proposed topology using MATLAB/SIMULINK is presented.

Keywords: Virtual DC Bus; PV cell; SPWM; Transformer less.

1. INTRODUCTION

Renewable energy sources become a more and more important contribution to the total energy production in the world. Today the energy production from solar energy compared to the other renewable energy sources is very low, but the PV systems are one of the fastest growing in the world. The price of PV system components, especially the PV modules are decreasing and the market for PV is expanding rapidly. Solar power will be dominant because of its availability and reliability. Photovoltaic inverters become more and more widespread within both private and commercial circles. These grid-connected inverters convert the available direct current supplied by the PV panels and feed it into the utility grid. According to the latest report on installed PV power, during 2012, there has been a total of 69.3 GW of installed PV systems in power in the world. At the end of 2012, the total installed PV capacity will reach 80.0 GW of which around 90% is grid connected.

There are two main inverter topologies used in the case of grid-connected PV systems, namely, with and without galvanic isolation. Galvanic isolation can be on the dc side in the form of a high-frequency dc-dc transformer or on the grid side in the form of a big bulky ac transformer. Both of these solutions offer the safety and advantage of galvanic isolation, but the efficiency of the whole system is decreased due to power losses in these extra components. In case the transformer is omitted, the efficiency of the whole PV system can be increased with an extra 1%–2%.

2. TRANSFORMERLESS TOPOLOGIES

The efficiency of commercial PV panels is around 15-20%. Therefore, it is very important that the power produced by these panels is not wasted, by using inefficient power electronics systems. The efficiency and reliability of both single-phase and three phase PV inverter systems can be improved using transformerless topologies, but new problems related to leakage

current and safety need to be dealt with. The size and cost of the inverter need to be reduced. The world out of which the majority (35.8%) has been installed in Germany. India has installed 427 MW solar power which is 0.6% of total installed.

The main goal of this project is to analyze and model transformerless PV inverter systems with respect to the leakage current phenomenon that can damage the solar panels and pose safety problems. New topologies and control strategies that will minimize the leakage current, reduce size, cost and exhibit a high efficiency is proposed, and verified.

The traditional grid-connected PV inverter includes either a line frequency or a high frequency transformer between the inverter and grid. The transformer provides galvanic isolation between the grid and the PV panels. In order to increase the efficiency, to reduce size and cost, the effective solution is to remove the isolation transformer. It leads to appearance of common mode (CM) (CM) ground leakage current due to parasitic capacitance exists between the PV panel and ground.

The most important advantages of transformerless PV systems can be observed such as higher efficiency and smaller size and weight compared to the PV systems that have galvanic isolation (either on the dc or ac side). It has been made from the database of more than 400 commercially available PV inverters, presented in a commercial magazine about PV systems.

3. VIRTUAL DC BUS

The common mode (CM) current reduces the efficiency of power conversion stage, affects the quality of grid current, deteriorate the electric magnetic compatibility and give rise to the safety threats. To eliminate the common mode (CM) leakage current in transformer less PV system, the virtual DC concept is proposed here. While connecting grid neutral line to negative pole of DC bus, the stray capacitance exists between the PV panel and ground is bypassed.

The Common mode (CM) ground leakage current can be bypassed completely. To provide negative voltage level for negative AC grid current generation, the virtual DC bus is created. The virtual DC bus is implemented with the switched capacitor topology that uses less number of elements. Hence, the power electronic cost would be reduced. This topology can be implemented with the unipolar SPWM to reduce the output ripple. A small inductor, which can be used as filter will reduce size and magnetic losses. The simulation result of the proposed topology using MATLAB/SIMULINK is presented.

4. SOLAR CELL

Photovoltaic allow the consumers to generate electricity in a clean, reliable and quiet manner. Photovoltaic are often abbreviated as PV. Photovoltaic cells combine to form photovoltaic systems. Photovoltaic cells are devices that convert light energy or solar energy into electricity. As the source of light is usually the sun, they are often referred to as solar cells. The word photovoltaic is derived from “photo,” meaning light, and “voltaic,” which refers to production of electricity. Hence photovoltaic means “production of electricity directly from sunlight.” Usually, a PV system is composed of one or more solar PV panels, an AC/DC power converter (also known as an inverter), and a rack system that holds the solar panels, and the mountings and connections for the other parts. A small PV system can provide energy to a single consumer, or to isolated devices like a lamp or a weather device. Large grid-connected PV systems can provide the energy needed to serve multiple customers.

Modeling of Solar cell:

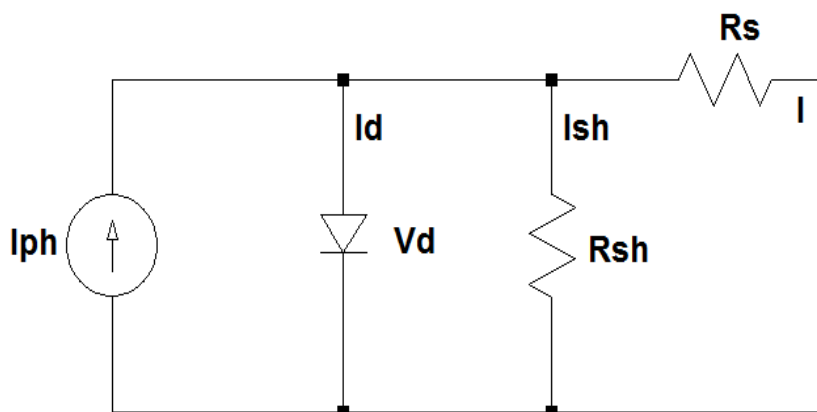


Fig 1: Single diode model of a solar cell

The characteristic equation for a photovoltaic cell is given by,

$$I = Ilg - Ios * \left[\exp \left\{ q * \frac{V+I*Rs}{A*k*T} \right\} - 1 \right] - \frac{V+I*Rs}{Rsh} \quad \text{---(1)}$$

Where,

$$Ios = Ior * \left(\frac{T}{Tr} \right)^3 * \left[\exp \left\{ q * Ego * \frac{1}{A*k} * \left(\frac{1}{Tr} - \frac{1}{T} \right) \right\} \right] \quad \text{--- (2)}$$

$$Ilg = \{Iscr + Ki * (T - 25)\} * Lambda \quad \text{---(3)}$$

- Ilg : Cell output current and voltage
- Ios : Cell reverse saturation current
- T : Cell temperature in Celsius;
- k : Boltzmann's constant, $1.38 * 10^{-19}$ J/K;
- q : Electron charge, $1.6 * 10^{-19}$ C;
- Ki : Short circuit current temperature coefficient
- Lambda : Solar irradiation in W/m^2 ;
- Iscr : Short circuit current at 25 degree Celsius;
- Ilg : Light-generated current;
- Ego : Band gap for silicon;
- A : Ideality factor;
- Tr : Reference temperature;
- Ior : Cell saturation current at Tr;
- Rsh : Shunt resistance;
- Rs : Series resistance;

5. COMMON MODE (CM) CURRENT

A. Circuit Explanation:

If the transformer is omitted, the common mode (CM) (CM) ground leakage current may appear on the parasitic capacitor between the PV panel and ground [2] [3]. The existence of the CM current may reduce the power conversion efficiency, increase the grid current distortion, deteriorate the electric magnetic compatibility, and more importantly, give rise to the safety threats [4]. The CM current path in the grid-connected transformerless PV inverter system is illustrated in Fig.2. It is formed by the power switches, filters, ground impedance ZG and the parasitic capacitance CPV between the PV panel and ground. According to [5], the CM current path is equivalent to an LC resonant circuit in series with the CM voltage. The CM voltage Vcm is defined by

$$Vcm = \{Iscr + Ki * (T - 25)\} * Lamda \quad \text{---(4)}$$

Where VAO is the voltage difference between point A and O,

VBO is the voltage difference between point B and O, and L1 and L2 are the output filter inductors.

If the switching action of the inverter generates high frequency CM voltage, the CM current Icm may be exited on the LC circuit. From this point of view, the topology and modulation strategy adopted for the transformerless PV power system should guarantee that Vcm is constant or only varies at low frequency, such as 50Hz/60Hz line frequency.

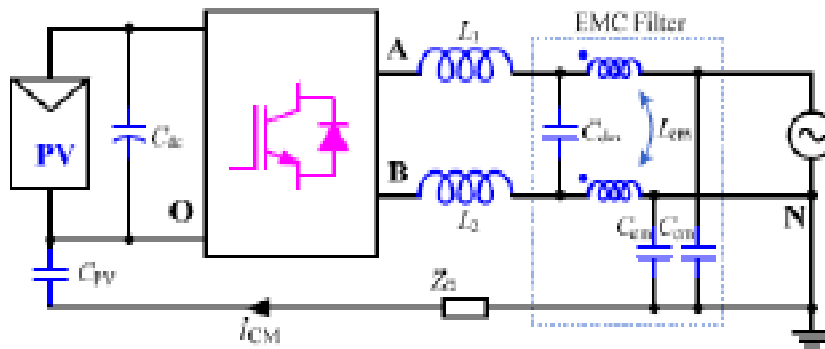


Fig 2 : CM Current Path for transformerless PV Inverter

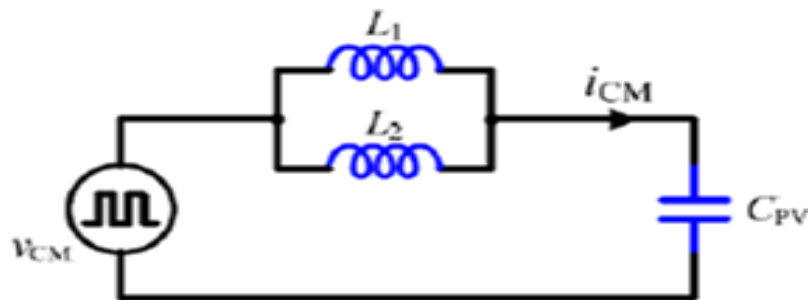


Fig 3: Equivalent circuit for current path

B. Negative Voltage Generation:

The concept of the negative voltage generation is depicted in Figure.4. While connecting grid neutral line to negative pole of the PV panel directly, the voltage across the parasitic capacitance C_{PV} is clamped to zero. This prevents any leakage current flowing through it. With respect to the ground point N, the voltage at midpoint B is either zero or $+V_{dc}$, according to the state of the switch bridge. The purpose of introducing virtual DC bus is to generate the negative output voltage, which is necessary for the operation of the inverter. If a proper method is designed to transfer the energy between the real bus and the virtual bus, the voltage across the virtual bus can be kept the same as the real one. As shown in Fig.4, the positive pole of the virtual bus is connected to the ground point N, so that 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 points B and C joined together by a smart selecting switch, the voltage at point A can be of three different voltage levels, namely $+V_{dc}$, zero and $-V_{dc}$. Since the CM current is eliminated naturally by the structure of the circuit, there's not any limitation on the modulation strategy, which means that the advanced modulation technologies such as the unipolar SPWM or the double frequency SPWM can be used to satisfy various PV applications.

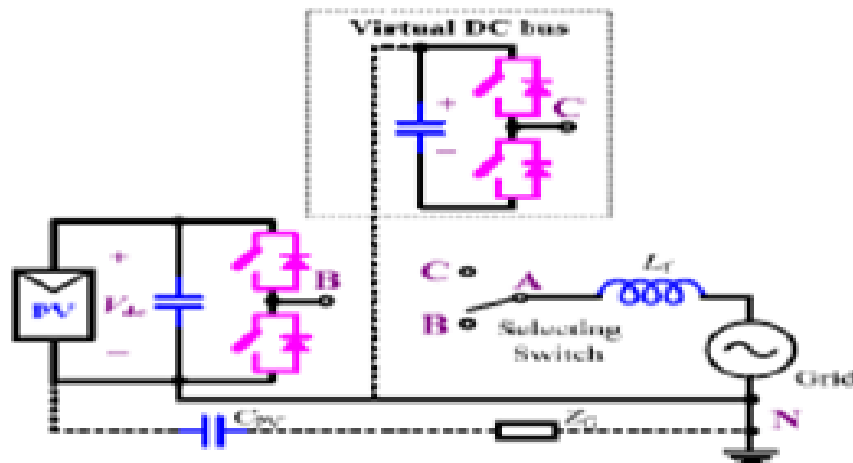


Fig 4: Negative voltage generation

C. Unipolar SPWM:

The waveform for the unipolar SPWM of the proposed inverter. The gate drive signals for the power switches are generated according to the relative value of the modulation wave u_g and the carrier wave u_c . During the positive half grid cycle, $u_g > 0$. S1 and S3 are turned on and S2 is turned off, while S4 and S5 commutate complementally with the carrier frequency. The capacitors C1 and C2 are in parallel and the circuit rotates between state 1 and state 2 as shown in Fig.6 &7. During the negative half cycle, $u_g < 0$. S5 is turned on and S4 is turned off. S1 and S3 commutate with the carrier frequency synchronously and S2 commutates in complement to them. The circuit rotates between state 3 and state 2. At state 3, S1 and S3 are turned off while S2 is turned on.

The negative voltage is generated by the virtual DC bus C2 and the inverter output is at negative voltage level. At state 2, S1 and S3 are turned on while S2 is turned off. The inverter output voltage V_{an} equals zero, meanwhile C2 is charged by the DC bus through S1 and S3. The summary of operation state of the switches for proposed topology is shown in Table,

Table 1. Switching Operation

STATE	SWITCHES				
	S1	S2	S3	S4	S5
1	ON	OFF	ON	ON	OFF
2	ON	OFF	ON	OFF	ON
3	OFF	ON	OFF	OFF	ON
4	OFF	ON	OFF	ON	OFF

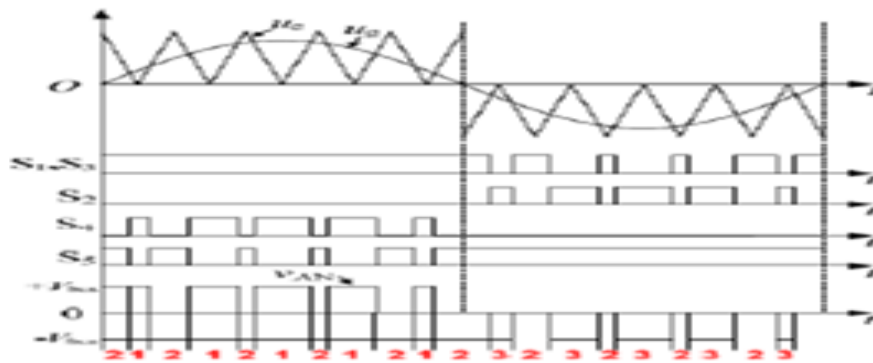


Fig 5: Unipolar SPWM

D. SIMULATION:

The SPWM and the PV system is given to the inverter. The virtual DC concept is made by the capacitor connected between the source and the switches, and positive and negative terminals as depicted in the following figure as C2 and C1.

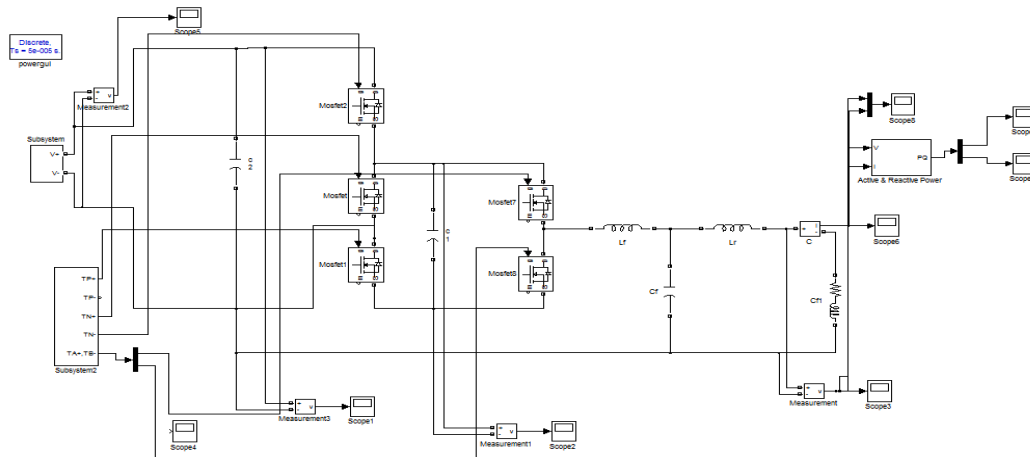


Fig 6: Simulation model of overall system

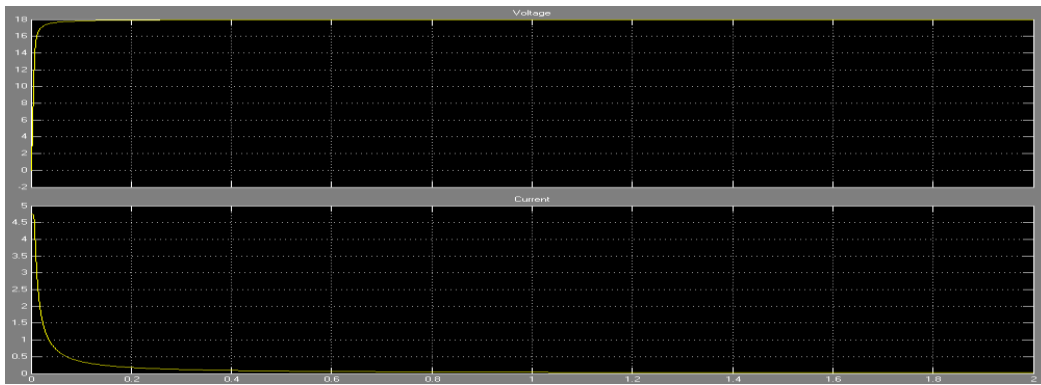


Fig 7: Voltage and Current waveform output of solar panel

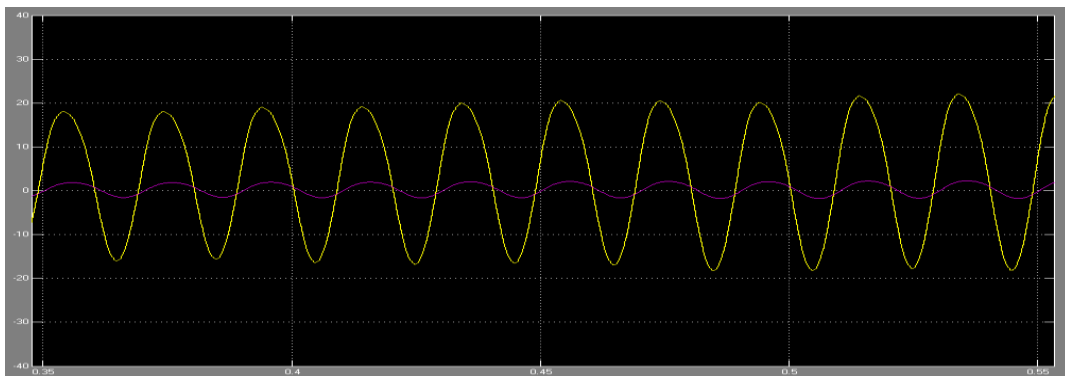


Fig 8: Grid connected voltage and Current Waveform

6. CONCLUSION

The virtual DC concept is subjected to solve Common Mode (CM) current problem for the transformerless Grid Connected PV inverter. When connecting negative pole of DC bus to grid neutral line directly, the voltage on the stray capacitor is maintained as zero. This will eliminate the common mode (CM) current completely. At the same time, a virtual DC is created for providing the negative voltage level. While the elimination of CM current is better than the full bridge inverters, the required DC bus voltage will equal to half of the half bridge inverter. On behalf of this proposal, a novel inverter design is proposed with the virtual DC bus, based on switched capacitor topology. It consists of five power switches and an inductor. This topology is applicable only for the single phase small power applications, where the output current is apparently small so the power devices and capacitors will not be affected by the extra current stress which will produce serious reliability problems. Due to this better performance in eliminating the CM current, the virtual DC bus design produces the exact result for the transformerless grid-connected PV inverters. The software tool used in this project is MATLAB 2012b.

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K. Priyanka did her Bachelor of Engineering in Electrical & Electronics Engineering at Tamilnadu college of Engineering, Coimbatore and doing Master of Engineering in Power Electronics & Drives at Sri Shakthi Institute of Engineering and Technology, Coimbatore, India. Her research interests involve PV application to Grid. She published three journals in the area of Multi level Inverter and Three phase Induction Machines.