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Analysis of Leakage Current in a Transformerless PV Inverter Connected to the Grid

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ABSTRACT

Analysis of a leakage current in transformerless photovoltaic inverter (PV inverter) connected to the grid. In order to analyze the leakage current many inverter topologies have been proposed. In this paper examine the leakage current in a transformerless PV connected to the single phase grid system. For low power grid connected application a single phase converter can be used and it is possible to remove the transformer in the inverter in order to reduce losses, cost and size. Galvanic connection of the grid and the DC sources in transformerless system can introduce additional leakage current due to parasitic capacitance. This can also be prevented by using various topologies and pulse width modulation (PWM) techniques. Full bridge configuration with bipolar pulse width modulation has constant common mode voltage but with a reduced efficiency and large output current ripple. Full bridge with unipolar pulse width modulation has many advantages of increased efficiency and three level output to minimise the leakage current and improve the efficiency, the various topology for the transformerlessphotovoltaic applications and developed. In addition, the full-bridge inverter with bipolar, unipolar and hybrid modulation scheme is investigated.

Keywords: Transformerless, photovoltaic cell (PV), Leakage current, parasitic capacitance, H-Bridge

I. INTRODUCTION

Photovoltaic (PV) power systems are very attractive and widely used in recent years. the proposed inverter circuit Photovoltaic (PV) energy is generally believed to be one of the most valuable renewable energies for reasons several. In order to integrate the PV systems into grid, a power electronic component should be required to convert DC energy source generated by PV arrays to AC component, which is fed into grid.

In general, a transformer is installed between PV arrays and grid for galvanic isolation. The transformer is heavy with large volume, along with the copper and iron losses during transformer operation. Furthermore, there are no limits on the installation area Therefore, the transformerless PV system is popular and received more and more attention, due to its low cost, small size, and high efficiency. Furthermore, there are no limits on the installation area. However, a technical challenge arises for transformerless PV systems.

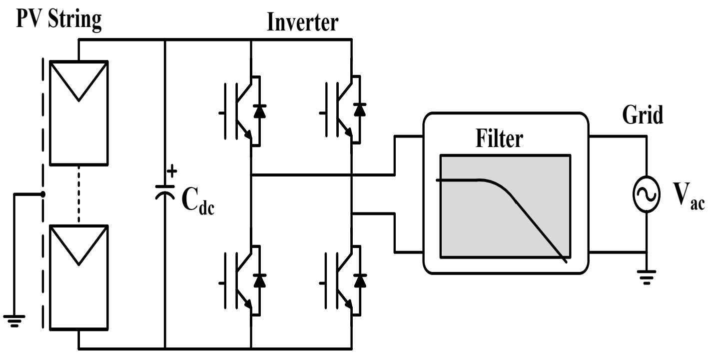

Figure 1. Voltage source transformerless inverter connected to the grid

More specifically, the capacitive leakage current is generated between photovoltaic modules and the ground. In practice, this capacitive leakage current is very difficult to handle, because the capacitance between photovoltaic modules and ground is usually highly unpredictable, and it varies significantly with temperature or humidity. The presence of leakage currents is very harmful, since they could put the life of a photovoltaic module installer at risk if he touches the photovoltaic module. Additionally, they will bring high-frequency harmonics, which may lead to problems with electromagnetic compatibility.In contrast, stand-alone systems are connected to the load and electric applications Grid-connected systems account for a large proportion ofinstalled PV energy systems according to the latestinternational energy agency (IEA) PV power systems report.

A grid connected PV system consist of a solar panel inverter a power conditioning unit and grid connection equipment. In this paper, the full-bridge inverter with bipolar, Unipolar and hybrid modulation scheme is investigated.

In addition, leakage current in thetransformer less PV inverter topology is analysed.

II. SOLAR PHOTOVOLTAIC

The word "photovoltaic" combines two terms, "photo" means light and "voltaic" means voltage.

PV power system. The photovoltaic effect was experimentally demonstrated by French physicist Edmond Becquerel. The world's first photovoltaic cell was developed by him in 1983. A photovoltaic system in this discussion uses photovoltaic cells to directly convert sunlight into electricity. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include mono crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Due to the increased demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. Solar photovoltaics is a sustainable energy source where 100 countries are utilizing it. solar photovoltaics is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. Installations may be ground-mounted or built into the roof or walls of a building.

There are two main types of PV energysystems; grid-connected systems and stand-alone systems. The grid-connected systems are in parallel with the utility grid and provide PV to an increased acceptance of the grid-connected PV inverter technology. In the grid-connected PV system, the DC power of PV array should be converted into the AC power with proper voltage magnitude, frequency and phase to be connected to the utility grid. Under this condition, a DC to AC converter which is better known as inverter. The inverter is therefore an important component in grid- connected PV systems. There are various kinds of grid-connected PV inverters as shown in Fig.

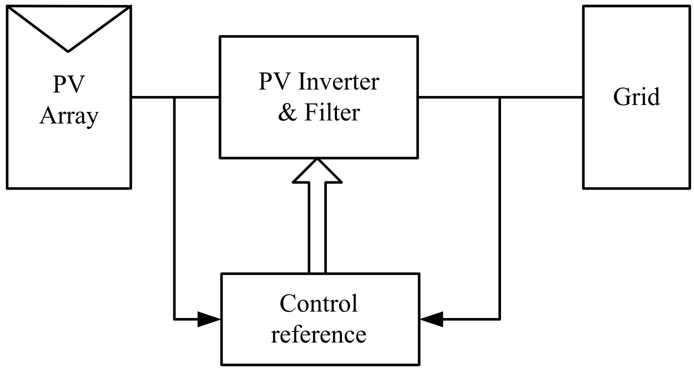

Figure 2. Power Electronic System with the grid, source (PV array), power converter and control

III. TRANSFORMERLESS PV INVERTER

The PV Inverter is the prime element of grid connected C Willough by Smith first discussed it as the effect of light on selenium during the passage of electric current in a 20th February 1873 issue of nature. Recently, the transformerless-type inverter has become more popular owing to its small system volume, low weight and low cost. As photovoltaic (PV) module prices become cheaper, the reduction of manufacturing costs of PV inverters becomes a must. The largest recent shift in inverter technology is the availability of transformer less inverters in the United State. Without heavy transformer, they weight about 50% to 70% less than a transformer-based inverter of similar output, and the size of the inverter housing can be reduced. Inverter efficiency is also increased there are no longer losses associated with having a transformer to step up the voltage. And because the transformer losses (which is comprised of copper windings on an iron or steel core) is eliminated, they are less expensive to produce. The majority of inverter manufacturers are now including a transformer less inverter line.

Transformerless concept is advantageous regarding to their high efficiency, reduced cost and weight of transformer. Topologies that use high frequency transformer in the DC-DC converter have a reduction in the overall efficiency, due to the leakage in the transformer.

These transformerless solutions offer all the before mentioned advantages, but there are some safety issues due to the solar panel parasitic capacitance. This resulting leakage capacitance value depends on many factors; some of these are enumerated below: PV panel and frame structure, surface of cells, distance between cells, module frame, weather conditions, humidity and dust covering the PV panel. It is mentioned that a typical value of 100-200pF was measured between the PV cells and the grounded palm of a person. But in case the surface of the panels was covered with water, this capacitance increased to 9nF, 60 times its previous value. In case of a solar array having a considerable surface, the resulting capacitance has values between 50-150 nF/kW, depending on the weather conditions and panel structure. This leads to leakage currents between the panel terminals and ground, depending on inverter topology and switching strategy. The level of the leakage current depends mostly on the amplitude and frequency content of the voltage fluctuations that are present at the PV panel terminals, but it also depends on the value of the parasitic capacitance.

A PV Inverter has to fulfil three main functions in order to feed energy from a PV array into the utility grid:

1. To shape the current into a sinusoidal waveform;
2. To invert the current into an AC current, and
3. If the PV array voltage is lower than the grid voltage, the PV array voltage has to be boosted with a further element.

IV. LEAKAGE CURRENT AND RESONANCE FREQUENCY

Removal of the transformer and hence its isolation capability and grounding of the PV panel frame is a requirement then PV earth parasitic capacitance needs to be considered in transformerless topologies. Due to the capacitance between the PV panel and earth, potential differences imposed by the switching actions of the inverter injects a capacitive ground current. This ground capacitance is part of a resonant circuit consisting of the PV panels, the AC filter elements and the grid impedance. Due to necessary efficiency optimization of systems, the damping of this resonant circuit can be very small so that the ground current can reach amplitudes well above permissible levels. Without transformer, there is a galvanic connection of the grid and the DC source and thus a leakage current appears. Disadvantages of the appearing leakage current are increased system losses, impairing of electromagnetic compatibility and safety problems.This resulting leakage capacitance value depends on many factors; some of these are enumerated below: PV panel and frame structure, surface of cells, distance between cells, module frame, weather conditions, humidity and dust covering the PV panel.This leads to leakage currents between the panel terminals and ground, depending on inverter topology and switching strategy. The level of the leakage current depends mostly on the amplitude and frequency content of the voltage fluctuations that are present at the PV panel terminals, but it also depends on the value of the parasitic capacitance. Ground current is limited by standards. In general, the leakage current is superimposed to the line current therefore the harmonic content is increased compared with inverters without transformer. In transformerless grid connected systems a resonant circuit is created if the DC source is not grounded. This resonant circuit includes the ground capacitance, the filters, the inverter and the impedance of the connected utility grid. Magnitude of the mentioned capacitance depends on the DC source and on the environmental conditions. capacitances isvery small so leakage currents with this kind of sources is not a topic. For fuel cells this ground Nevertheless, in photovoltaic applications the panels ground capacitance goes from nano-farads up to microfarads and here leakage current is an important topic., the first measure to reduce the ground currents is to decrease the excitation of the resonant circuit. A problem arises due to the great dependence of the ground capacitance with environmental conditions, and hence the resonant frequency of the system.

Also, the resonant frequency is not fixed due to the varying, on environmental conditions dependent PV array earth capacitance. Depending on the topology, switch states and environmental conditions the capacitive earth current can cause more or less severe (conducted and radiated) electromagnetic interference, distortion of the grid current and additional losses in the system. Measures to minimize this current are mention.

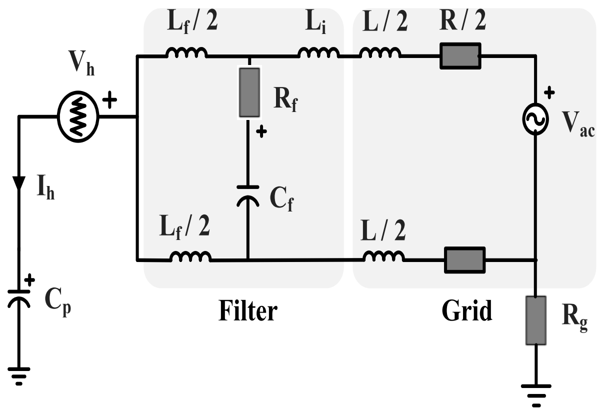

Figure 3. Model of resonant circuit

V. TRANSFORMERLESS MODULATION TECHNIQUE

This section gives an analysis of leakage current flowing through the parasitic capacitance.

1. Full-bridge topology

The full-bridge PV inverter is widely used in the PV power generation system. In the full-bridge inverter, three modulations schemes can be used:

1.1. Bipolar modulation
1.2. Unipolar modulation

2. Hybrid modulation.

1. Full Bridge Topology

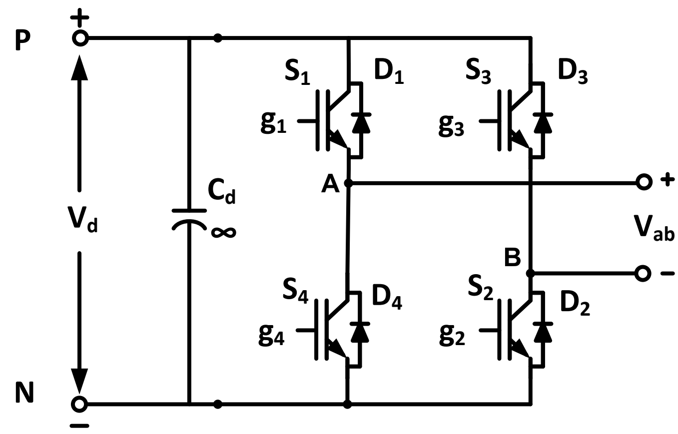

Figure 4. Full Bridge Topology

Figure 4. shows a simplified circuit diagram of a single-phase H-bridge inverter.

It is composed of two inverter legswith two IGBT devices in each leg. The inverter dc bus voltage *Vd*is usually fixed, while its ac output voltage *VAB* can be adjusted by either bipolar or unipolar modulation schemes.

1.1 Bipolar Pulse-Width Modulation

It shows a set of typical waveforms of the H-bridge inverter with bipolar modulation, where V_m is the sinusoidal modulating wave, V_{cr} is the triangular carrier wave, and v_{g1} and v_{g3} are the gate signals for the upper switches S_1 and S_3, respectively. The upper and the lower switches in the same inverter leg operate in a complementary manner with one switch turned ON and the other turned OFF. Thus, we only need to consider two independent gate signals, v_{g1} and v_{g3}, which are generated by comparing v_m with v_{cr}. Since the waveform of v_{AB} switches between the positive and negative dc voltages $+V_d$ and $-V_d$ this scheme is known as Bipolar modulation. Thus we need to consider only two independent gating signals vg1 and vg3 which are generated by comparing sinusoidal modulating wave vm and triangular carrier wave Vcr. The inverter terminal voltages are obtained denoted by VAN and VBN and the inverter output voltage VAB = VAN-VBN. Since the waveform of VAB switches between positive and negative dc voltages this scheme is called bipolar PWM.

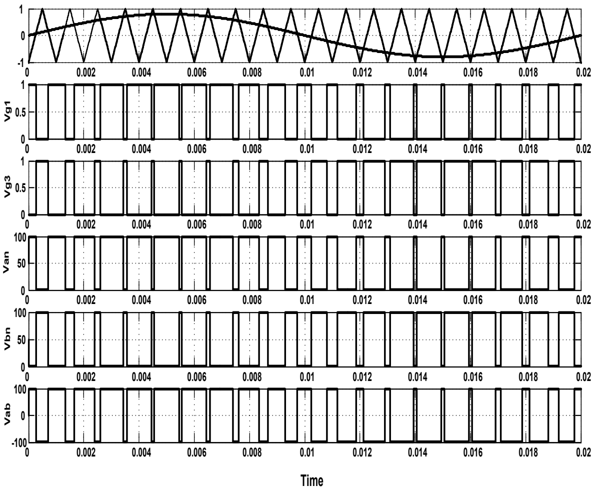

Figure 4. Waveform of Bipolar Modulation technique

1.2. Unipolar Pulse-Width Modulation

The unipolar modulation normally requires two sinusoidal modulating waves Vm and –Vmwhich are of same magnitude and frequency but 180 out of phase. The two modulating wave are compared with a common triangular carrier wave Vcr generating two gating signals Vg1 and Vg3 for the upper two switches S1 and S3. It can be observed that the upper two devices do not switch simultaneously, which is distinguished from the bipolar PWM where all the four devices are switched at the same time. The inverter output voltage switches between either between zero and +Vd during positive half cycle or between zero and –Vd during negative half cycle of the fundamental frequency thus this scheme is called unipolar modulation. The unipolar switched inverter offers reduced switching losses and generates less EMI.

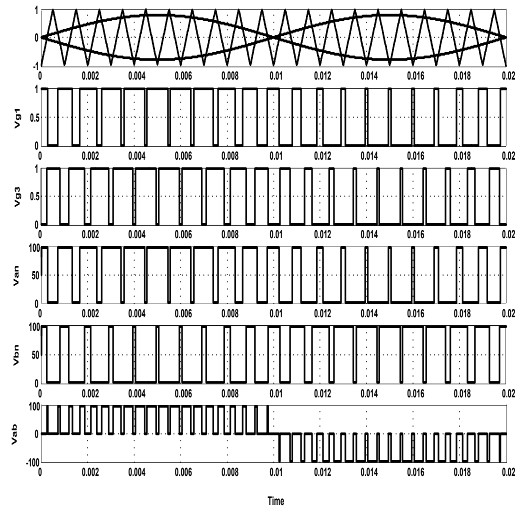

Fig.5. Waveform of Unipolar Modulation technique

2. HERIC TOPOLOGY

The HERIC (Highly Efficient and Reliable Inverter Concept) topology is another structure that avoids a fluctuating potential on the DC terminals of the PV generators by means of disconnecting the converter from the load (utility grid). In this case the zero voltage level is obtained using a bidirectional switch during freewheeling periods This topology is shown in figure.

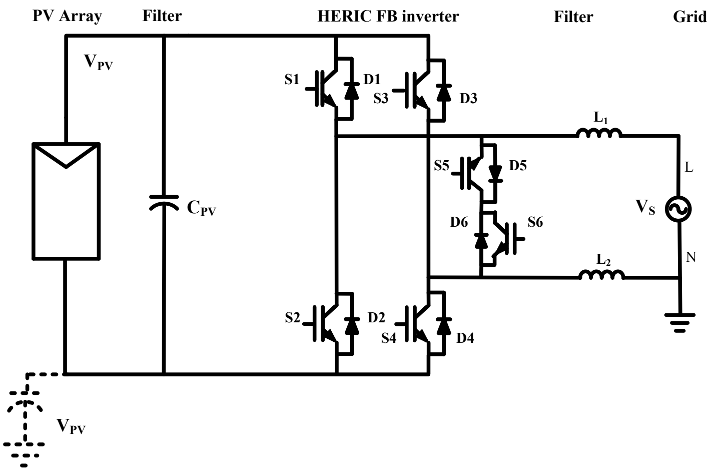

Figure 6. Heric inverter topology

This modulation technique is often used in the CHB multilevel inverters. HERIC topology in Fig. consists of a full-bridge with two extra switches in filter inductors L1 and L2. All switches independently operate with the high or grid frequency according to the polarity of vg. In the positive half-cycle,the switch

S5 is turned on and the switches S2, S3, S6 are turned off. The switches S1 and S4 are switched with the high-frequency.In the negative half-cycle, the switch S6 is turned on and the switches S1, S4 and S5 are turned off. The S2 and S3 are switched with the high-frequency. VAB has the three-voltage levels including the zero-output-voltage state. It leads to lower core losses and prevents the reactive power exchange during the freewheeling operation. Moreover, this scheme has low leakage current and EMI.

VI. MATLAB SIMULATION

In order to verify the level of leakage currents of different topologies simulations and experimental measurements have been done. Simulations were done using MATLAB used for simulation of electrical circuits within the Simulink environment. All simulation results are based on the general simulation model presented for the single-phase topologies.

A triangular generator and a sine wave generator are used for generating the carrier wave and the modulating wave respectively.

The carrier frequency is 1KHZ and the reference wave frequency is 1Hz. The modulation index can be varied by changing the amplitude of sinusoidal modulating wave. The waveforms are for modulation index of 1.0

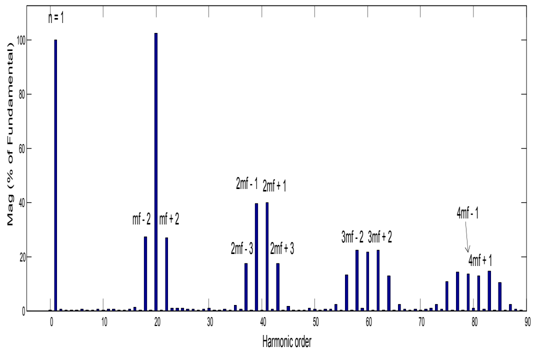

Figure 7. FFT Analysis of Bipolar PWM for full H-bridge

Figure 7 shows the FFT analysis of bipolar modulation technique for H-bridge inverter. It shows the harmonic spectrum of the inverter output voltage VAB. The harmonics appear as sidebands centered around 2*mf* and 4*mf*. The lower order harmonics generated by the bipolar modulation, such as mf and mf ± 2, are eliminated by the unipolar modulation. The unipolar modulation can also be implemented by using only one modulating wave vm but two phase-shifted carrier waves, Vcr and -Vcr. This modulation technique is often used in the CHB multilevel inverters.

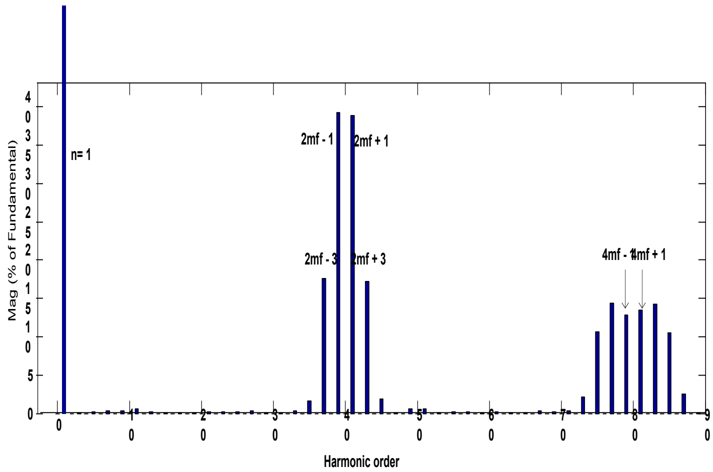

Figure 8. FFT Analysis of Unipolar PWM for full H-bridge

Figure 8 shows the harmonic spectrum of the inverter output voltage *VAB*. The harmonics appear as sidebands centred around 2*mf* and 4*mf*. The low-order harmonics generated by the bipolar modulation, such as *mf* and *mf* ± 2, are eliminated by the unipolar modulation.

VII. TRANSFORMERLESS MODULATION ANALYSIS

In order to verify the level of leakage currents of different topologies simulations and experimental measurements have been done. Simulations were done using MATLAB and PLECS toolbox, used for simulation of electrical circuits within the Simulink environment. All simulation results are based on the general simulation model presented on Fig. 1 for the single-phase topologies. Same filter and grid parameters have been used throughout the simulations, these are listed below. For the experimental measurements a single phase setup was used, made up of a DC power supply, with a direct connection to the utility grid. In case of the single-phase setup only 2 legs of the inverter have been used. For these single-phase measurements the 100W PV installation has been used, having the frame of the panels connected to ground, thereby creating a path for the flow of the leakage current. As seen on Fig. 3, representing the experimental scope data in the case of the full-bridge topology with bipolar switching, the PV terminals are fluctuating with the grid frequency and the fluctuations have half the amplitude of the grid voltage. Due to this sinusoidal fluctuation and the low frequency content of the fluctuation, the leakage current towards ground is small.

VIII. CONCLUSION

Based on the previously detailed comparison and the simulation and experimental results, it can be concluded that the single phase full-bridge topology with bipolar switching is suitable for transformer PV inverter because the leakage current is much lower than in case of the unipolar switching.
Besides this, harmonic issues are analyzed using fast Fourier transform.

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