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The State of Art of Reduction of Leakage Current in Grid Connected Inverters for PV System

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Abstract — Depletion of fossil fuel, unremitting increase in power demand and environmental concern develops a thought among power community to adopt new sources of power generation i.e. renewable energy sources. Due the abundance of solar energy PV systems are more popular, which can isolate from grid with the help of transformer. These transformers increase the cost and make the system more complex with decrease of efficiency. At the same time absence of transformer in grid connected system injects the leakage current in the inverter and increases the electromagnetic emissions, harmonics and losses in the system. To address the above many research have been done related to eliminate this leakage current. In this paper an exhaustive review has been done in the subject area.

Keywords — leakage current, photovoltaic (PV) systems, transformerless inverter.

I. INTRODUCTION

Form the long time, Fossil fuels, such as coal, natural gas, and petroleum are main supplier of energy to the world. But these are available with limited stock and non renewable sources of energy. And their use gives increased carbon dioxide emissions, environmental pollution, global warming and climate change. But with all above mentioned problems the energy demand of world is still increasing and fulfilling of these higher energy demands is the main problem for the power suppliers or worldwide.

Now it is very much necessary to find some new alternative energy sources with long time availability and environment friendly. The renewable energy sources like solar power (PV modules), hydropower, geothermal and wind energy have the largest utilization nowadays [3],as they are long time available, much cleaner and more cost-effective sources of energy[13]. Among all renewable energy sources, Hydropower generation requires large capital cost, a huge amount of water storage and has limited generating capacity, wind power generation requires flow of high winds to rotate the windmills which makes it applicable only for hilly areas or sea costs .Due to all these limitations, these power generation units cannot be installed near or within every residential area/city. On the other hand in solar power generation or photovoltaic (PV) generation the energy is generated by direct sun radiations falling at PV panels [13] .So these generating units can easily be installed at any place near or within the city, terrace of houses, over the canals etc..Due to this advantage and with the help of government incentives the use of PV generation is becoming more and more widespread all over the world [6].

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Earlier a line frequency or high frequency transformer is used to isolate the PV panels from the grid. This isolation transformer gives personnel safety, reduces electromagnetic interference (EMI) noise and steps up or step down the voltage levels. But line-frequency transformer increases the weight and the high-frequency transformer requires more switching devices and conversion stages, hence both reduces the overall system efficiency, performance, and reliability [4], [5].and increases the cost, makes the system more complex. Hence many topologies use transformer less inverter for getting increased efficiency and reliability, reduced losses, costs and size. But when no transformer is used in a grid-connected photovoltaic (PV) system a common mode voltage between the PV panels and ground appears, which injects an additional leakage current (common-mode currents) in the inverter/grid and increases the electromagnetic interference, harmonics and losses in the system [4],[7],[8],[15]. Many researches had been done related to this ground current elimination in transformer less photovoltaic system, in this paper review of some of these are presented.

II. REVIEW

As transformerless PV inverters connected to grid has fastest payback time with more reliability. But due to galvanic connection an earth parasitic capacitance (common mode voltage) between PV arrays and ground appears. This common mode voltage injects leakage current into the utility grid and this current increases the noises, losses and saturates the core of the transformers connected for distribution purposes in the grid. Amplitude and spectrum of this ground current depends on the converter topology, switching strategy and the resonant circuit formed by the ground capacitance. Many researches for reduction and suppression of this leakage current have been done by researchers. For finding best of them, some of those topologies are reviewed and compared here.

Kjaer *et al.* [1], reviewed the inverter technologies for connecting photovoltaic (PV) modules to a single-phase grid. In this authors have classified the inverters based on their number of power processing stages in cascade, type of power decoupling between the PV module and the single-phase grid, utilization of transformer (either line or high frequency) and the type of grid-connected power stages. Finally some topologies are evaluated based on their demand, lifetime, components ratings and its cost.

Xue *et al.* [2], presented an overview of single-phase Inverters developed for small distributed power generators. Authors have compared the single stage and multistage inverter circuit topologies based on two ways, firstly the comparison based on their circuit topologies, cost, efficiency and tolerance for input voltage and Secondly.

based on the requirements of power decoupling, dual-grounding, capabilities for Stand-alone operations, and specific DG applications. Finally it has been observed that buck-boost topology is most suitable to get the high efficiency for Distributed generation (DG) applications.

Teodorescu *et al.* [3], gave an overview for the structures, synchronization methods and control strategies for the Distributed power generation systems (DPGSs). The overview of structures is based fuel cell, photovoltaic, and wind turbines. In addition, different control structures for compensating low-order harmonics with implementation in different reference frames are also presented. Apart from this four different control strategies for a DPGS system during an unbalanced grid fault were also discussed.

González *et al.* [4], described the half-bridge and bipolar pulse width modulation (PWM) full-bridge topologies which generate no varying common-mode voltages. Authors have observed that half bridge topology has the drawback of necessity of high-input voltage, whereas full-bridge topology requires low input voltage but exhibits low efficiency. Hence the authors have proposed bipolar PWM full bridge topology which gives less current ripples with higher efficiency.

Araujo *et al.* [5], done some frame work on the present inverter topologies available in the market for photovoltaic applications. Such framework based on parameters like system voltage levels, compatibility with cell technologies, efficiency-curve characteristic, grid regulations, and some others. Based on these researches author proposed a new inverter circuit with two step-down converters each one modulates a half-wave of the output current, as the correct polarity of the connection to the grid is provided by low-frequency Switches .Laboratory prototype of such project is presented and evaluated with experimental results and this new topology gives a high level of efficiency, simple design, and reduced cost.

Kerekes *et al.* [6], analyzed and compared the three transformerless photovoltaic inverter topologies named as full-bridge dc/ac voltage-source inverter (VSI)(3FB) , three-phase full-bridge VSI with a split capacitor on the input side (3FB-SC),three-phase-modularized neutral-point-clamped VSI topology (3xNPC). Finally simulation and experimental results for leakage current of above are studied and observed. the comparison of three topologies done not only for the leakage current issue, but also for the number of switching devices, filter size ,adopted modulation, effects of unbalance conditions, output voltage levels, connection of the neutral and its inductance. And finally concluded that both 3FB-SC and 3xNPC topologies give small value of leakage current due to low ripple voltage and presence of inductance in the neutral line leads to a high-frequency component in the common-mode voltage, which leads the value of leakage currents. Hence for obtaining lower leakage currents the neutral line should have very low inductance in case of transformerless PV systems.

Teodorescu *et al.* [7], presented a analytical approach based common mode model for frequency lower than 50 kHz. Which helps us to understand the common mode behavior of some selected topologies and finally the experimental results are verified for NPC topology through simulation and found a lower value of leakage currents in case of transformerless inverters.

Lopez *et al.* [8], identified the effect of inverter topologies and strategies on magnitude of leakage current for a 1.5 kW photovoltaic system in NPC clamped inverters. And Finally authors found that the neutral point clamped (NPC) inverters are more beneficial than unipolar and bipolar PWM inverters for those applications where higher dc ground capacitance appears.

Lopez *et al.* [9], compared and overviewed on various multilevel topologies for transformerless single-phase grid connected systems regarding their modulation strategy, output levels, filter requirements, switches count, ground voltage and leakage current. Authors have observed that full bridge topology gives low leakage current with bipolar modulation and gives fewer harmonic with unipolar modulation but due to high frequency ground voltage leakage current and EMI disturbance increases a lot. In Half bridge neutral point clamp topology the ground voltage remains constant so it has minimum leakage current. The main drawback of this topology is difficult to expand the number of levels and control complexity. In cascaded topology bipolar PWM does not have any advantage over unipolar PWM because a high frequency ground voltage appears in both cases. Finally it is clear that for lower ground currents the half bridge neutral point clamp topology is the best choice.

Kerekes *et al.* [10], done simulation and experimental measurements with different single-phase and three-phase transformerless PV inverter topologies for verifying their leakage current levels and the analysis shows that

For single phase inverters, full-bridge(FB) inverter topology with unipolar switching gives large leakage current in comparison to bipolar switching where as neutral point clamped (NPC) topology gives lowest value of leakage current as compared to FB. And for three phase inverters, full-bridge topology is not suitable due to its large leakage current and the problem with the DC-to-earth voltage, where as the other topology like NPC (3xNPC) and (3xHB) again gives very small leakage ground(below 30mA) as compared to FB. And finally the authors concluded that all the above mentioned comparisons are very helpful for selection of topology which can give lower leakage ground current.

Murai *et al.* [11], analytically Investigated and modeled leakage current loop for induction motor connected with PWM inverters. The author proposed an equivalent circuit and method for investigation and suppression of leakage current by using invaliant law of magnetic flux linkage. And finally found that the proposed circuit is not only able to suppress the leakage current but also becomes a high performance filter for the output voltage.

Ogasawara *et al.* [12], proposed an equivalent series resonant circuit for reduction of RMS value of leakage current, this equivalent circuit (named as a common-mode transformer) was designed by using a common mode choke in series with a damping resister. This equivalent circuit or common-mode transformer is able to damp the oscillations of common-mode voltages and currents. For verification a prototype model was made and found the results that, the peak and rms values of the leakage current are at reduced level,also the size of core used for this common-mode transformer is very small as compared to the conventional common-mode chokes.

Monge *et al.* [13], highlighted that the generated power is reduced due to partial shades and the mismatching of the arrays in photovoltaic array (PVA) systems and then proposed a multilevel diode-clamped converter with pulsewidth-modulation and control to overcome these problems. This method can control the operating voltage of each PVA independently. Performance analysis of this method particularly for a four-level three-phase diode clamped Inverter was obtained by using simulation and experiments. And found that use of this diode-clamped converter increases the generated power and efficiency by reducing the harmonic distortion, count and voltage rating of the devices.

González *et al.* [14],pointed that injection of direct current (dc) to the grid, causes the saturation of the transformers along the distribution network and then proposed a modified single-phase three level diode-clamped inverter which generates no common-mode voltage and guarantees non injection of dc current to the grid, thus improving efficiency of inverter. For verification of this proposed topology a 5-kW prototype was made and analyzed which results a higher maximum efficiency of 98.16%.

Cavalcanti *et al.* [15],proposed a remote-state PWM (RSPWM) techniques to eliminate the leakage current. By Using this proposed PWM method(with constant CM voltage) lower leakage currents were obtained with a gain of 50% of the maximum amplitude of the voltages .The technique improves the behavior of the two and three-level inverters by providing constant CM voltage and lowers leakage current without using any additional hardware and modification on the converter. The result and comparison for leakage currents was done by using Matlab/Simulink and to validate the simulations model a three-phase inverter prototype is made. Which verified that the proposed PWM technique gives best results specially for three-phase inverters.

Cacciato *et al.* [16], introduced a new approach related to sequence of inverter states to limit the common-mode currents. By using this approach it is possible to control the number and amplitude of the variations of the common-mode voltage by selecting the sequence of the inverter states, this proposed technique can also be said as a modification of the standard adjacent states space-vector modulation (SVM) strategy. And finally from the experimental results it can be observe that common-mode currents are limited by using this method and there is no need of any bulky and costly filters.

Hava *et al.* [17], analyzed and introduced a new reduced common mode voltage PWM (RCMV-PWM) methods for three phase voltage source inverters, then by using analytical methods and simulations RCMV-PWM methods are compared with the standard PWM method for their AC output current ripple, DC link input current ripple, and output voltage linearity characteristics.The classification of standard Continuous PWM (CPWM) methods are Sinusoidal PWM (SPWM) and Space Vector PWM (SVPWM), and the Discontinuous PWM (DPWM) methods such as DPWM1 and Depending on the choice of the voltage vectors, the RCMVPWM methods can be classified as Remote State PWM (RSPWM) methods Active Zero State PWM (AZSPWM) methods. And finally the comparison gives the results that the standard PWM methods have less DC link and AC output current ripple than the RCMV-PWM methods. As an exceptional case the AZSPWM1 method exhibits superior overall performance at high modulation index. And this complete analysis between RCMV-PWM and standard PWM methods are very helpful in selection of appropriate PWM methods in drives that gives lower common mode voltages.

Seok Lee *et al.* [18], proposed the switching modulation techniques such as LMZVM (large, medium, and zero vectors modulation) and LMSVM (large, medium, and small vectors modulation) for reduction of leakage current and balance of neutral-point voltage in the three-level inverter .the simulation and experiment results concluded that the proposed LMZVM method not only reduces the common mode voltage but also balances the dc-link voltages more sharply than convectional PWM method.

Julian *et al.* [19], proposed the concept of fourth "pseudophase" in a three-phase system to reduce the common mode (CM) voltage. This strategy gives balanced sinusoidal three-phase-output voltage with respect to ground and gives no CM voltage between the earth and PV panels. Simulation is used to study behavior of the system than comparison of the experimental results for a four-phase hard-switching pulse width modulated inverter and a four-phase resonant dc link (RDCL)inverter is done. and observed that common-mode voltage is much smaller than typical three phase inverters.

Wang *et al.* [20], proposed a method to cancel the common-mode (CM) parasitic capacitance of boost power factor correction (PFC) converters. This (CM) parasitic capacitance is cancelled by using negative capacitance method. Authors first made a CM noise model for a boost PFC converter. Based on this model the parasitic capacitance between the drain of the MOSFET and heat-sink are identified. If parasitic capacitance between the drain of the main switch and the ground, and the parasitic capacitance between the printed circuit board (PCB) traces and the ground is minimized, then CM noise can also be minimized. Than for finding results theoretical analysis and experiments were carried out and found that proposed method gives lower values of CM noise by cancelling the parasitic capacitance between the drain of the MOSFET and heat-sink.

Twining *et al.* [21], discussed that a LCL filter network is used to reduce the harmonic distortion at lower switching frequencies. But this LCL filters require more complex control strategies. And than proposed a robust control strategy for regulating the grid current of a converter connected to an electrical network through a LCL filter. The scheme uses a synchronous frame PI (SRFPI) controller to regulate the grid current and a inner capacitor current regulating loop to stabilize the system. To determine the transient performance of the system, a P+Resonant controller is also used because during stability analysis it can easily reduce to a single-phase equivalent system as compared to SRFPI controller. Then quality current regulation caused by grid supply voltage harmonics is investigated by determining the harmonic impedance of the proposed control strategy.

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Liserre *et al.* [22], presented a design procedure for an *LCL* filter with control of an active rectifier to reduce the switching frequency and current ripple. The proposed filter is designed by using simple control method with a little increase in hardware and adapting the parameters of the PI-based control, which are already used for the L-filter configuration .The study of stability and dynamic response of the overall system for the dc voltage and ac current is also presented. The design procedure has been tested in simulation and with an experimental set up and found that the filter gives a stable system and lower harmonic contents for both low and high-frequency ranges and in addition it gives half value of current ripple as compared to conventional *L* filter configuration.

III. CONCLUSIONS

Due to the availability of solar energy percentage of power generation from solar PV system is increasing day by day. These systems can be an isolated and grid connected. In grid connected system PV arrays are isolated from grid without transformer which increases the leakage current and reduces the efficiency. Hence lot of work has been done by the researchers which has been sussesfully reviwed in the above sections.and it has been observed that neutral point clamp (NPC) topologies with suitable filter circuit gives small value of leakage current.

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