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Mitigation of the DC Component in Transformer less Three-Phase Grid-Connected PV Inverters

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Abstract: The dc component can cause line-frequency power ripple, dc-link voltage ripple, and a further Second-order harmonic in the ac current. This paper has proposed an effective solution to minimize the dc component in three-phase ac currents and developed a software-based approach to mimic the blocking capacitors used for the dc component minimization, the so-called virtual capacitor. The "virtual capacitor" is achieved by adding an integral of the dc component in the current feedback path. A method for accurate extraction of the dc component based on double time integral, as a key to achieve the control, has been devised and approved effective even under grid-frequency variation and harmonic conditions. A proportional integral- resonant controller is further designed to regulate the dc and line-frequency component in the current loop to provide precise control of the dc current. The total harmonic distortion and the second-order harmonic have also been reduced as well as the dc-link voltage ripple. The system is proposed through MATLAB/SIMULINK. Finally, it is verified by simulation results.

Keywords: Controller, Dc Component, Proportional-Integral Resonant (PIR) Transformer Less Three-Phase PV Inverters, Virtual Capacitor

. I. INTRODUCTION

With Grid-connected photovoltaic (PV) systems often include a line transformer between the power converter and the grid. The transformer guarantees galvanic isolation between the grid and the PV systems, thus fulfilling safety standards. Furthermore, it ensures that no direct current (dc) is injected to the grid. However, the low-frequency (50

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Among them, the dc component can affect the normal system operation and cause safety concerns. Standards have therefore been established in many countries to limit the level of the dc component, for example, below 0.5% of the rated output current (e.g., IEEE Standard 1547-2003). Therefore, this paper will investigate effective solutions to minimize the dc component in a PV system.

One way to block the dc component is to put a capacitor C in series with the ac side of the inverter as shown in. However, in order to reduce the capacitive reactance at other frequencies, the capacitor value needs to be large, which increases the size and cost of the system. This series capacitor may also affect the system dynamic response and reduce transmission efficiency. Nevertheless, the physical capacitor can be replaced by software-based method and advanced control strategy which mimics the operation of the series capacitor in a single phase PV system.

II. PROPOSED SYSTEM CONFIGURATION

A typical three-phase transformer less PV inverter system. The PV array is connected to the grid via a three phase voltage-source two-level inverter and an LCL filter. The capacitors of the LCL filter can be configured with a delta or star connection. In this paper, a delta connection is used to reduce the required capacitor and cost as opposed to the star connection, which has the benefit of smaller short-circuit current. The dual closed-loop control strategy, which comprises a current loop and a dc-link voltage loop in the synchronous rotational frame, is a relatively common control strategy in three-phase PV inverters. In order to analyze the impact of dc components on the three phase PV systems, the dc components have been added in the system model in addition to the line (fundamental)-frequency components. If other harmonics are neglected and only the dc and line-frequency components are

Systems Virtual Capacitor Concept of Single-Phase Grid-Connected PV Inverters is One way to block the dc component is to put a capacitor C in series with the ac side of the inverter However, in order to reduce the capacitive reactance at other frequencies, the capacitor value needs to be large, which increases the size and cost of the system. This series capacitor may also affect the system dynamic response and reduce transmission efficiency Nevertheless, the physical capacitor can be replaced by software-based method and advanced control strategy which mimics the operation of the series capacitor in a single phase PV system

III. RELATED WORK A. Transformer less Single-Phase Multilevel-Based Photovoltaic Inverter

The elimination of the output transformer from grid- connected photovoltaic (PV) systems not only reduces the cost, size, and weight of the conversion stage but also increases the system overall efficiency. However, if the transformer is removed, the galvanic isolation between the PV generator and the grid is lost. This may cause safety hazards in the event of ground faults. In addition, the circulation of leakage currents (common-mode currents) through the stray capacitance between the PV array and the ground would be enabled. Furthermore, when no transformer is used, the inverter could inject direct current (dc) to the grid, causing the saturation of the transformers along the distribution network. While safety requirements in transformer less systems can be met by means of external elements, leakage currents and the injection of dc into the grid must be guaranteed topologically or by the inverter's control system. This paper proposes a new high-efficiency topology for transformer less systems, which does not generate common-mode currents and topologically guarantees that no dc is injected into the grid. The proposed topology has been verified in a 5-kW prototype with satisfactory results.

B. “Design Optimization of Transformer Less Grid-Connected PV Inverters Including Reliability”

This paper presents a new methodology for optimal design of transformer less photovoltaic (PV) inverters targeting a cost-effective deployment of grid-connected PV systems. The optimal switching frequency as well as the optimal values and types of the PV inverter components is calculated such that the PV inverter LCOE generated during the PV system lifetime period is minimized. The LCOE is also calculated considering the failure rates of the components, which affect the reliability performance and lifetime maintenance cost of the PV inverter. A design example is presented, demonstrating that compared to the non optimized PV inverter structures, the PV inverters designed using the proposed optimization methodology exhibit lower total manufacturing and lifetime maintenance cost and inject more energy into the electric-grid and by that minimizing LCOE.

C. High Reliability and Efficiency Single-Phase Transformerless Inverter for Grid Connected Photovoltaic Systems

This paper presents a high-reliability single phase transformer less grid-connected inverter connected inverter that utilizes super junction MOSFETs to achieve high efficiency for photovoltaic applications. The proposed As seen in (7) and (8), line-frequency fluctuations will appear in both active power pac and reactive power qac when the dc components in the ac voltage and ac current are considered. The reactive power only circulates in the inverter phase legs at the ac side and does not affect the dc side. In comparison, the line-frequency active power fluctuations will impact the dc-link. Therefore, the R controller and PI controller are combined into a PIR controller to provide a precise control for both the dc and line-frequency (negative sequence) signals for the current loop. The virtual capacitor concept is implemented by integrating the measured dc component, which is added as a feed- forward term on the feedback path. The outer voltage loop, uses a PI controller is used to enable the dc link voltage udc to track the reference voltage udc* thus achieving maximum power point tracking (MPPT).power, e.g., causing voltage ripple in the dc-link which in return will generate a second-order harmonic in the ac current Therefore, effective solution to minimize the dc component is important apart from the reasons given in the introduction part. The impact of dc components on PV systems is illustrated.

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D. "A Review Of Minimization Of Output Dc Current Component Methods In Single-Phase Grid-Connected Inverters Pv Applications,"

Nowadays, it is a general trend to increase the Distribution Generator (DG) based on renewable energy such as photovoltaic (PV) system. This generator can affect the grid by causing a number of problems due to injection of DC current into the grid. If this DC current is not properly prevented, result problems in distribution network such as increased corrosion in underground equipment and transformer saturation. This paper reviews the minimization methods which employ to minimize the output DC current component in single-phase grid inverters photovoltaic applications. These methods are categorized into four classifications. The basic approach is to make use of an isolating transformer to prevent the DC current. Another technique is to use a half-bridge inverter which has the capability of blocking the DC current flow to the AC side. It is also possible to use a DC blocking capacitor in the inverter output. A more recent method is to use current sensing and control techniques to monitor and calibrate the DC link current sensors.

E. Eliminating DC Current Injection in Current Transformer-Sensed STATCOMs

Grid-connected power electronics converters/ inverters usually have certain amount of dc component at their ac terminal.They are likely to inject unwanted direct current into the power grid, unless a line-frequency transformer is employed. This study investigates this dc injection problem for static synchronous compensator (STATCOM) and connects the dc injection with current transformer (CT), ac current sensing element widely used in high-voltage converters. By introducing CT's model into the STATCOM's model, this study found that using CT for current feedback control can cause large dc injection, if no extra means is taken. Expressions of the dc injection for different

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A. Simulation Diagram

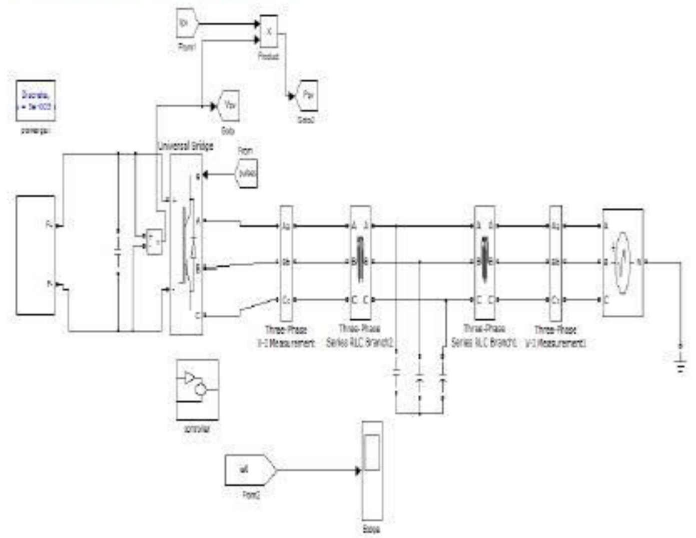

Fig.7. DC component minimization strategy based on dc component feed-forward and PIR controllers.

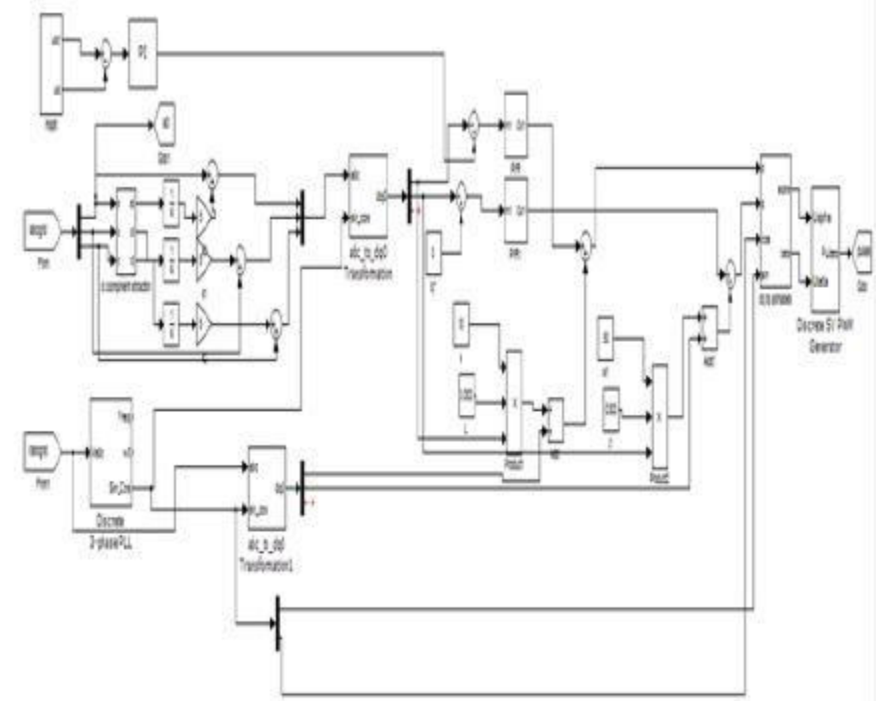

Fig.8. Subsystem of DC component minimization strategy based on dc component feed-forward and PIR controllers

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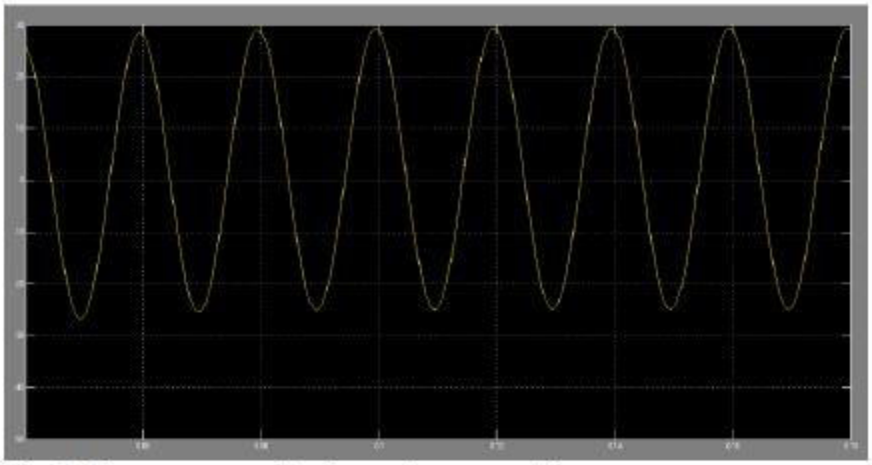

Fig.9.The measured phase A current ia.

V. CONCLUSION

This paper has presented an effective method to minimize the dc component in a three-phase transformer less grid-connected PV system. The dc component can introduce line-frequency power ripple in the system and further cause dc-link voltage ripple and second-order harmonics in the ac currents. A software based "virtual capacitor" approach has been implemented to minimize the dc component via a feed-forward of the dc component. The dc component can be accurately obtained using the sliding window iteration and double time integral even under frequency variation and harmonic conditions. A PIR controller has been designed to enable the precise regulation of both the dc and line-frequency components in the d-q frame. Experimental results have validated the proposed method, where the dc component

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