An Effective Solution to Minimize The Dc Component In Grid Connected Pv Inverters

A. Kusumanjali[1] *Dr.Samalla Krishna*[2] *Mr.S.Srikanth*[3]

[1]*M. Tech Student Deptt of of Electrical & Electronics Engg. Tudi Ram Reddy Institute of Technology&Sciences, Hydearabad.* ***kusuma202@gmail.com***

[2] *Professors, & Principal. Tudi Ram Reddy Institute of Technology&Sciences, Hydearabad.* ***Krishna.oume@gmail.com***

[3] *Assistant Professor, Department of Electrical & Electronics Engg. Tudi Ram Reddy Institute of Technology & Sciences, Hydearabad.* ***Ssrikanth674@gmail.com***

ABSTRACT

The main aim of project is dc component is a special issue in transformer less grid-connected photovoltaic (PV) inverter systems and may cause problems regarding system operation and safety. 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.. 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 proposed method has been validated on a 10-kVA experimental prototype, where the dc current has been effectively attenuated to be within 0.5% of the rated current. The total harmonic distortion and the second-order harmonic have also been reduced as well as the dc-link voltage ripple. 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 or 60 Hz) transformer is bulky, heavy, and expensive and its power loss brings down the overall system efficiency.

Index terms: Grid connected PV inverter, PIR controller, virtual capacitor, harmonics

I.INTRODUCTION

There are several issues associated with transformerless structures, such as dc component in the inverter output (grid) current, ground leakage current (due to common-mode voltage and parasitic capacitance), and the voltage-level mismatch between the solar panel (inverter) and grid. 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. The dc component can have negative impacts on the power system in the following ways: 1) The dc component can affect the operating point of the transformers in the power system. The transformer cores are driven into unidirectional saturation with consequent larger excitation current. The service lifetime of the transformer is reduced as a result with further increased hysteresis and eddy current losses and noise. 2) The dc component can circulate between inverter phase legs as well as among inverters in a paralleled configuration. The dc component circulation affects the even current and loss distribution among paralleled inverters. 3) The dc component injected to the grid can affect the normal operation of the loads connected to the grid, for example, causing torque ripple and extra loss in ac motors. 4) The corrosion of grounding wire in substations is intensified due to the dc component. There are several sources leading to the dc components in grid-connected inverters:

1) asymmetry in the switching behavior of power semiconductor devices,

2) imparity in gate driver circuits,

3) device turn-on and turn-off delays,

4) nonidentical device voltage drops (on-state resistance, saturation voltage, etc.), and

5) sampling biases from the ac current and ac voltage sensors, etc.

Minimization of the dc component in transformerless PV inverters has been extensively investigated in literatures. Several solutions have been developed which can be grouped
into two categories: passive methods and active methods. For example, coupling transformers and blocking capacitors are inserted on the inverter ac side to minimize the dc component. The main disadvantage of this kind of passive methods is the increased cost, weight, and physical size of the system as well as extra power loss. There are other methods by using alternative or special inverter topologies such as two-level or three-level half-bridge configurations, which are not extendable to other inverter topologies. Regarding active methods, auto calibrating techniques for dc-link sensors in two-level and three-level single-phase inverters were proposed which are effective to minimize the dc component caused by sampling biases of the ac current sensors. However, these methods are not suitable for the dc component caused by other sources, e.g., asymmetry in switching behavior and an extra dc-link current sensor is required. The authors use different methods to extract the dc component from the output current, and add feedback compensation to minimize it, which are only used in single-phase systems. To the authors' knowledge, at the time of writing, only the technique in is for three-phase systems, which detects and uses the line-frequency voltage ripple on the dc-link to build an indirect feedback loop to compensate the dc component of the output current. However, since the dc components are not measured and feedback directly, the method cannot guarantee that the dc component in each phase is minimized effectively.

II. OPERATION OF PROPOSED SYSTEM

A typical three-phase transformerless PV inverter system is shown in Fig. The PV array is connected to the grid via a threephase 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

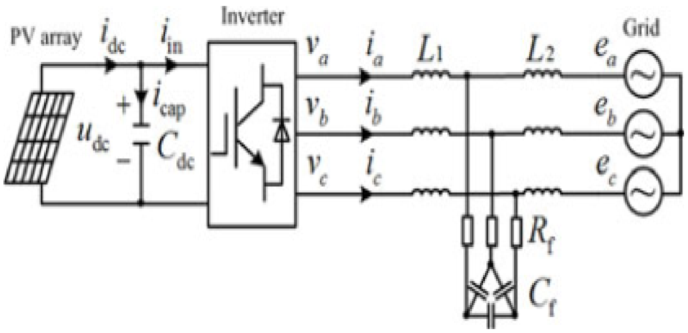

Fig. 1. Transformerless three-phase PV inverter system.

In order to analyze the impact of dc components on the threephase 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 concerned, *F* can be defined as an electrical variable (e.g., for ac-side voltage and current) and is expressed as in (1) in each coordinate (three-phase stationary (*abc*), two-phase stationary (*αβ*), and two-phase rotational (*dq*))

$$\begin{cases} F_a = F_{a0} + F_{a1} \\ F_b = F_{b0} + F_{b1} \\ F_c = F_{c0} + F_{c1} \end{cases}, \begin{cases} F_\alpha = F_{\alpha 0} + F_{\alpha 1} \\ F_\beta = F_{\beta 0} + F_{\beta 1} \end{cases}, \begin{cases} F_d = F_{d0} + F_{d1} \\ F_q = F_{q0} + F_{q1} \end{cases} \tag{1}$$

where the subscript 0 denotes the dc component and the subscript 1 denotes the line-frequency component. Note that the zero component in conventional coordinate transformation is not taken into account due to the three-wire system. If there are dc components in the *abc* coordinate, they will also exist in the form of dc or line-frequency components in *αβ* and *dq* coordinates, respectively. In a three-phase three-wire system, there is no current flowing through the neutral point and hence

$$\begin{cases} F_{a0} + F_{b0} + F_{c0} = 0 \\ F_{a1} + F_{b1} + F_{c1} = 0. \end{cases} \tag{2}$$

With (1) and (2), the coordinate transformations of the dc components from *abc* coordinate to *αβ* and *dq* coordinate can be expressed as

$$\begin{bmatrix} F_{\alpha 0} \\ F_{\beta 0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} F_{a0} \\ F_{b0} \\ F_{c0} \end{bmatrix} = \begin{bmatrix} F_{a0} \\ \frac{\sqrt{3}}{3} F_{b0} - \frac{\sqrt{3}}{3} F_{c0} \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} F_{d1} \\ F_{q1} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} F_{a0} \\ F_{b0} \\ F_{c0} \end{bmatrix} = \begin{bmatrix} F_{a0}\cos\theta + \frac{\sqrt{3}}{3}(F_{b0} - F_{c0})\sin\theta \\ \frac{\sqrt{3}}{3}(F_{b0} - F_{c0})\cos\theta - F_{a0}\sin\theta \end{bmatrix} \tag{4}$$

where θ is the angle between the dq coordinate and abc coordinate, for example, the grid angle in a grid-voltage oriented vector control. As seen in (3) and (4), by the coordinate transformation, $Fa0$, $Fb0$, and $Fc0$ (dc components) in the stationary abc frame can be transformed into $F\alpha 0$ and $F\beta 0$ in the stationary $\alpha\beta$ frame and then $Fd1$ and $Fq1$ (line-frequency) in dq frame. Therefore, the voltage and current in the control loop of each frame will contain both dc and line-frequency components. The synthesized vector ***F*** of dc components can be decomposed in the frames shown in Fig, where F is a stationary vector. Since the dq frame rotates anticlockwise, the dc component in the synchronous dq frame appears in the form of a negative-sequence line-frequency component. According to the instantaneous power theory [26], [27], the system active power pac and reactive power qac can be expressed in (5) and (6) in the dq frame, where the mark "·" and the mark "×" are the inner and outer product of vectors, respectively

$$p_{\mathrm{ac}} = \frac{3}{2} \begin{bmatrix} \boldsymbol{U}_d \\ \boldsymbol{U}_q \end{bmatrix}^{\mathrm{T}} \cdot \begin{bmatrix} \boldsymbol{I}_d \\ \boldsymbol{I}_q \end{bmatrix} = \frac{3}{2} \begin{bmatrix} u_{d0} + u_{d1} \\ u_{q0} + u_{q1} \end{bmatrix}^{\mathrm{T}} \cdot \begin{bmatrix} i_{d0} + i_{d1} \\ i_{q0} + i_{q1} \end{bmatrix}$$

III.DC COMPONENT MINIMIZATION STRATEGY BASED ON DC COMPONENT FEED-FORWARD AND PIR CONTROLLER

In the control strategy shown in Fig, an accurate dc component measurement and extraction is the key to implement the virtual capacitor concept and achieve the overall dc component minimization. As mentioned, the dc component needs to be minimized within 0.5% of the rated output current (e.g., IEEE Standard1547-2003). Compared with the ac component, the dc component is very small and an accurate dc component extraction is challenging.

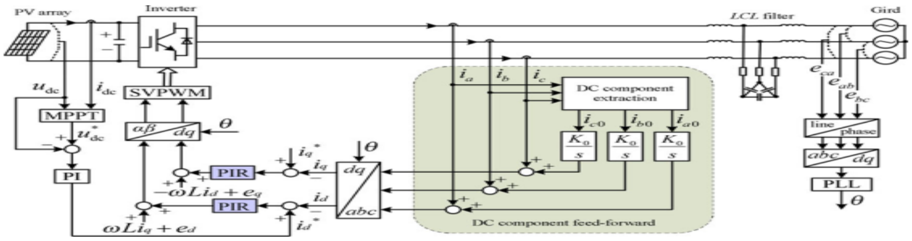

Fig 2.DC component minimization strategy based on dc component feed-forward and PIR controllers.

In PV inverters, the Hall-effect current sensors are widely used to measure the ac-side currents (including both ac and dc components) due to their smaller size, isolated output, and wide bandwidth (e.g., from dc to several hundred kilohertz). In this paper, an integral method based on the sliding window iteration algorithm is used to accurately extract the dc component from the ac-side currents. Taking the ac-side Phase A current *ia*, for example, *ia* can be expressed as in (18) if considering both the dc component and other ac components of different frequencies (e.g., harmonics)

III.SIMULATION RESULTS

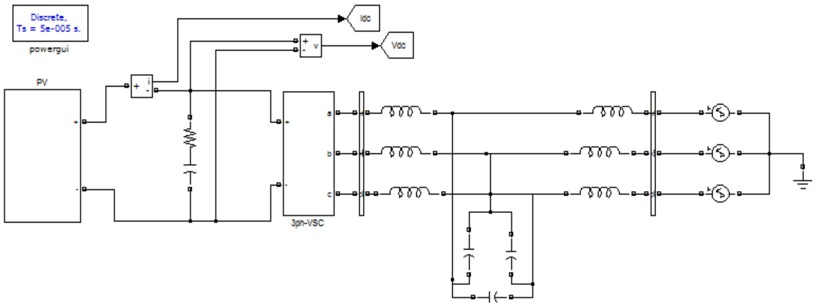

Fig 3. MATLAB/SIMULATION Circuit diagram of proposed system

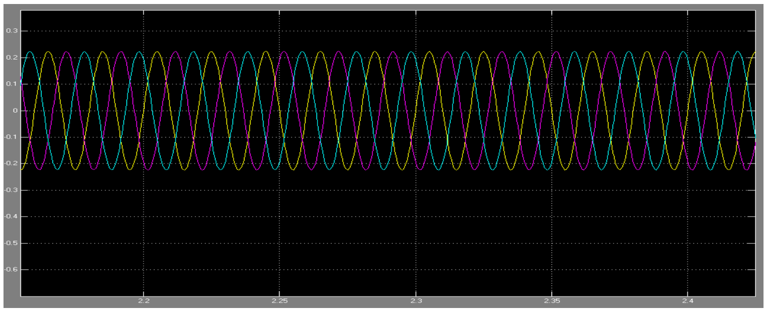

Fig 4. Three-phase grid-side currents in the grid-connected PV inverters

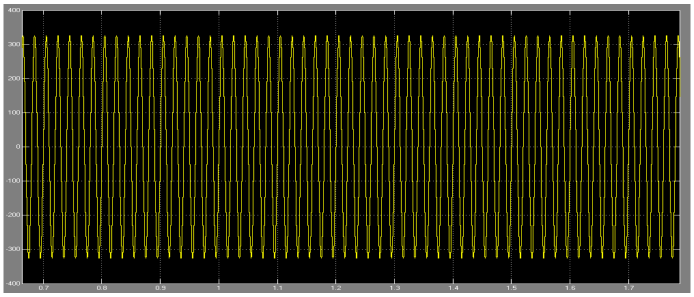

Fig 5. single phase voltage

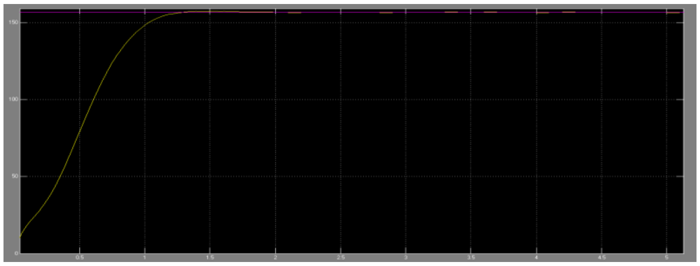

Fig 6. DC link voltage simulation and theretical

IV.CONCLUSION

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 softwarebased "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 has been reduced below 0.5% and the dc-link voltage ripple has been attenuated as well. The proposed method can be well adopted in the existing PV systems for dc component minimization by adding software programs for dc-component extraction, dc-component feedforward term as well as the resonant controller in the current control loops.

REFERENCES

[1] R. Gonzalez, E. Gubia, J. Lopez, and L. Marroyo, "Transformerless singlephase multilevel-based photovoltaic inverter," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2694–2702, Jul. 2008.

[2] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of singlephase grid-connected inverters for photovoltaic modules," IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005.

[3] E. Koutroulis and F. Blaabjerg, "Design optimization of transformerless grid-connected PV inverters including reliability," IEEE Trans. Power Electron., vol. 28, no. 1, pp. 325–335, Jan. 2013.

[4] B. Gu, J. Dominic, J. Lai, C. Chen, T. LaBella, and B. Chen, "High reliability and efficiency single-phase transformerless inverter for gridconnected photovoltaic systems," IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2235–2245, May 2013.

[5] S. V. Araujo, P. Zacharias, and R. Mallwitz, "Highly efficient single-phase transformerless inverters for grid-connected photovoltaic systems," IEEE Trans. Ind. Electron., vol. 57, no. 9, pp. 3188–3128, Sep. 2010.

[6] O. Lopez, F. D. Freijedo, A. G. Yepes, P. Fernandez-Comesaa, J. Malvar, R. Teodorescu, and J. Doval-Gandoy, "Eliminating ground current in a transformerless photovoltaic application," IEEE Trans. Energy Convers., vol. 25, no. 1, pp. 140–147, Mar. 2010.

[7] V. Salas, E. Ol´ ıas, M. Alonso, and F. Chenlo, "Overview of the legislation of DC injection in the network for low voltage small grid-connected PV systems in Spain and other countries," Renewable Sustainable Energy Rev., vol. 12, no. 2, pp. 575–583, Feb. 2008.

[8] B. Wang, X. Guo, H. Wu, Q. Mei, and W. Wu, "Real-time DC injection measurement technique for transformerless PV systems," in Proc. IEEE 2nd Int. Symp. Power Electron. Distrib. Generation Syst., Hefei, China, Jun. 2010, pp. 980–983.

[9] W. Li, L. Liu, T. Zheng, G. Huang, and S. Hui, "Research on effects of transformer DC Bias on negative sequence protection," in Proc. Int. Conf. Adv. Power Syst. Automat. Protection, Beijing, China, Oct. 2011, pp. 1458–1463.
[10] A. Ahfock and A. J. Hewitt, "DC magnetisation of transformers," IEE Proc.-Electr Power Appl., vol. 153, no. 4, pp. 601–607, Jul. 2006.
[11] M. A. S. Masoum and P. S. Moses, "Impact of balanced and unbalanced direct current bias on harmonic distortion generated by asymmetric threephase three-leg transformers," IET Electr. Power Appl., vol. 4, no. 7, pp. 507–515, Jul. 2010.
[12] F. Berba, D. Atkinson, and M. Armstrong, "A review of minimization of output DC current component methods in single-phase grid-connected inverters PV applications," in Proc. 2nd Int. Symp. Environ. Friendly Energies Appl., Tyne, U.K., Jun. 2012, pp. 296–301.
[13] M. Armstrong, D. J. Atkinson, C. M. Johnson, and T. D. Abeyasekera, "Auto-calibrating DC link current sensing technique for transformerless, grid connected, H-bridge inverter systems," IEEE Trans. Power Electron., vol. 21, no. 5, pp. 1385–1393, Sep. 2006.
[14] F. Berba, D. Atkinson, and M. Armstrong, "Minimization of DC current component in transformerless Grid-connected PV inverter application," in Proc. 10th Int. Conf. Environ.Elect. Eng., Rome, Italy, May 2011, pp. 1–4.
[15] Y. Shi, B. Liu, and S. Duan, "Eliminating DC current injection in currenttransformer-sensed STATCOMs," IEEE Trans. Power Electron., vol. 28, no. 8, pp. 3760–3767, Aug. 2013.
[16] G. Buticchi, E. Lorenzani, and A. Fratta, "A new proposal to eliminate the DC current component at the point of common coupling for grid connected systems," in Proc. IEEE 36th Ann. Conf. Ind. Electron. Soc., Glendale, USA, Nov. 2010, pp. 3244–3249.
[17] T.-F. Wu, H.-S. Nien, H.-M. Hsieh, and C.-L. Shen, "PV power injection and active power filtering with amplitude-clamping and amplitudescaling algorithms," IEEE Trans. Ind. Appl., vol. 43, no. 3, pp. 731–741, May/Jun. 2007.
[18] W. M. Blewitt, D. J. Atkinson, J. Kelly, and R. A. Lakin, "Approach to low-cost prevention of DC injection in transformerless grid connected inverters," IET Power Electron., vol. 3, no. 1, pp. 111–119, Jan. 2010.
[19] R. Sharma, "Removal of DC offset current from transformerless PV inverters connected to utility," in Proc. 40th Int. Universities Power Eng. Conf., Cork, Ireland, Sep. 2005, pp. 1230–1234.
[20] L. Bowtell and A. Ahfock, "Direct current offset controller for transformerless single-phase photovoltaic grid-connected inverters," IET Renew. Power Gener., vol. 4, no. 5, pp. 428–437, May 2010.

AUTHOR’S PROFILE

DR. SAMALLA KRISHNA so far has successfully guided many post graduate students in the fields of Signal and Image Processing, Neural Networks and Pattern Recognition while several other students are being supervised by him in a wide variety of other fields like DSP, Medical Image Processing and Object Recognition in addition to this he supervised many electrical and other disciplinary engineering students .He served as an academic supervisor to more than 300 Bachelor Degree dissertations towards the award of Undergraduate Degree ,and He has published more than 35 research papers in reputed International Journals. He shared his research experience more than many podiums like conferences, workshops, seminars and symposia. And currently he is working as a professor in TUDI Group of institutions, Hyderabad. He has 12 years of experience in the teaching and research field. His many research articles are cited by scholars and research institutions.

MR. S.SRIKANTH is a Post Graduated from the field of Electrical Engineering. He has 3 years of teaching experiences for Graduate and Post Graduate engineering courses. He has published her research work many International Journals and conferences. He guided several engineering students for their academic projects.

A. Kusumanjali *PG Student of Electrical , Tudi Ram Reddy Institute of Technology& Sciences, Telangana, India. She did bachelor degree from Auroras Engineering college,Bhongir, Telangana, India*