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RESEARCH ARTICLE

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RIPPLE MINIMIZATION IN GRID CONNECTED PHOTOVOLTAIC INVERTERS BASED ON PIR CONTROLLER

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ABSTRACT

This paper presents about the minimization of ripple content in grid connected photovoltaic inverters. Elimination of ripple reduces the loss and improves the overall efficiency of the system. Ripple also causes line frequency ripple, dc link voltage ripple and second order harmonics in ac current. This project proposes an effective solution to minimize the ripple content in the three phase ac current by designing a PIR (Proportional Integral Resonant) controller which is used to regulate the dc & line frequency component in the current loop to provide precise control of dc current on ac side. It also reduces the total harmonic distortion (4.3%, 3.3%and 3.8%) to (2.7%, 2.6% and 2.8%). and second order harmonic in the system.

Keywords: Ripple content, PIR controller, grid connected PV inverters.

I. INTRODUCTION

The line transformer is always included in the grid connected photovoltaic system which takes place between the power converter and the grid. The transformer provides a galvanic isolation between the grid and PV systems which guarantees that no injection of dc current takes place in the grid [1]. With the transformerless structures there are several problems, such as ripple component in the inverter output (grid) current, ground leakage current and the voltage-level mismatch between the DC side(inverter) and AC side(grid)[2]. Among the above problems, the ripple content affects 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 (IEEE Standard 1547-2003) [3], [4].Therefore, this paper will investigate effective solutions to minimize the ripple content in a PV system. Ripple minimization in transformerless PV inverters has been elaborately discussed in literature [5].Based on this many solutions have been developed which can be categorized into two methods: passive methods and active methods. For example, inverter ac side is connected with the coupling transformer and blocking capacitor to minimize the ripple content. The major drawback of this type of passive method leads to extra power loss and also increases the cost, weight and size of the system. Other methods include the use of various inverter topologies such as half- bridge (two levels and three levels) configuration [1, 8]. In active method, the ripple content caused by the sampling biases is minimized by using auto calibrating technique for dc-link sensors in two-level and three-level singlephase inverters which were proposed in [6] and [7]. But, these methods are not suitable for the ripple, caused by other sources, e.g., asymmetry in switching behavior and an extra dc-link current sensor is required. The ripple minimization method of single-phase PV inverter differs from that of three-phase PV inverter. Ripple exist in each phases and flow between phases in case of three- phase PV inverter. Ripple minimization is the most challenging for all the three phases at the same time because of their couplings. In single phase PV system the ripple content is minimized by using virtual capacitor [9]. It replaces the physical capacitor which could block the dc component on the ac side with a novel control strategy. A proportional-integral- resonant (PIR) controller is also designed to provide a precise control for both dc and line-frequency signals [10]. Note that though the dc component minimization method can be implemented in each phase, e.g., by a per-phase PI controller, this paper specifically investigates how to implement that in a synchronous rotational frame (d, q frame) where existing three phase PV inverter control system are normally based, e.g., with a dual closed-loop control. Therefore, the proposed ripple minimization method can be relatively easily added to the existing three- phase systems.

II. IMPACT OF THE RIPPLE ON PV SYSTEMS

A typical three-phase transformerless PV inverter system is shown in Fig. 1.The PV panel is connected to the grid through the three phase inverter and LCL filter. In LCL filter the capacitors are configured on both star and delta connection. Here delta connection are extensively used to reduce the number of required capacitor, reduced short circuit current and also the cost when compared to star connection. 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 [10]. The influences of ripple on PV system are illustrated in fig.2

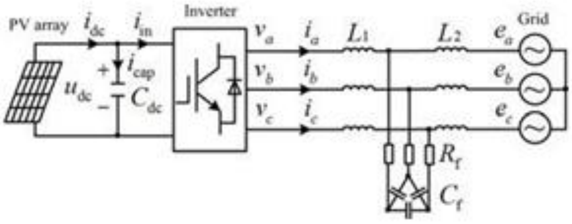


Fig.1 Transformerless three-phase PV inverter system.

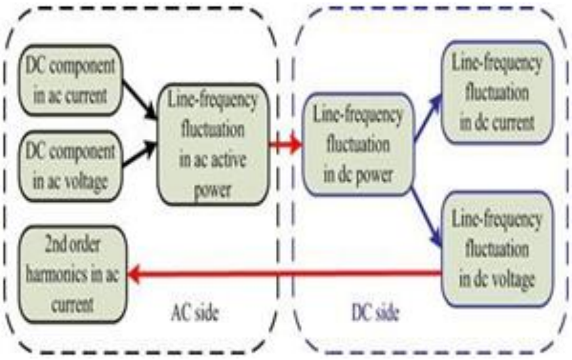


Fig. 2. Influences of ripple on PV systems.

The impacts of dc component on three phase grid connected PV system can be analyzed by adding dc component to the system model in addition to the fundamental frequency components. From the instantaneous power theory [13, 14] the active power (pac) and the reactive power qac can be expressed as

$$p_{ac}=\frac{3}{2}\left(\underbrace{u_{d0}i_{do}+u_{q0}i_{qo}}_{DC\,component}+\underbrace{u_{d0}i_{d1}+u_{d1}i_{do}+u_{q0}i_{q1}+u_{q1}i_{q0}}_{Line-frequency\,fluctuation}+\underbrace{u_{d1}i_{d1}+u_{q1}i_{q1}}_{2nd\,fluctuation}\right)$$

$$q_{ac}=\frac{3}{2}\left(\underbrace{u_{q0}i_{d0}-u_{d0}i_{q0}}_{DC\,component}+\underbrace{u_{q0}i_{d1}+u_{q1}i_{d0}-u_{d0}i_{q1}-u_{d1}i_{q0}}_{Line-frequency\,fluctuation}+\underbrace{u_{q1}i_{d1}-u_{d1}i_{q1}}_{2nd\,fluctuation}\right)$$

From the above equations it is clear that both the active and the reactive power contains dc component, fundamental frequency and second order fluctuation. For PV applications in vector control technique when the power factor is unity, then uq0 =0 and iq0 =0. Hence the above equations becomes,

$$p_{ac}=\frac{3}{2}\left(\underbrace{u_{d0}i_{do}}_{DC\,component}+\underbrace{u_{d0}i_{d1}+u_{d1}i_{do}}_{Line-frequency\,fluctuation}\right)$$

$$q_{ac}=\frac{3}{2}\left(\underbrace{u_{d0}i_{d0}-u_{d0}i_{q1}}_{Line-frequency\,fluctuation}\right)$$

Vol.4., Issue.2., 2016 (Mar-Apr)

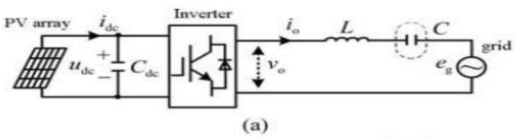
It is clear from the above equations that when we consider dc component in the ac voltage and ac current, line frequency occurs in both active power and reactive power. The reactive power does not affect the dc side of the inverter because it circulates only across the ac side inverter(inverter phase legs).Therefore effective solution to minimize the ripple content is very important in photovoltaic system.

III. PROPOSED STRATEGY

A. Single Phase Grid Connected PV Inverters with Virtual Capacitor

We can minimize the ripple content by adding the series capacitor C on the ac side of the inverter in fig 3(a). But the value of the capacitor becomes very large in order to suppress the capacitive reactance at other frequencies. This increases the size of the system and cost of the system. This affects the system dynamic performance and decreases the transmission of the system. This problem can be overcome by replacing the physical capacitor by software based model called as virtual capacitor. The single phase inverter with the current control loop diagram with a blocking capacitor is showed in the fig 3(b). From the fig 3(c) the blocking capacitor C is replaced by an integral and feedback block called as virtual capacitor which can be implemented by software-based method and prevents the use of large capacitor to block the dc component on ac side.

Based on the virtual capacitor concept in singlephase system, the three-phase system with the blocking capacitors in different frame and examine the suitability of applying virtual capacitor concept to three-phase systems in each frame. For deriving a mathematical model the damped LCL filter is used as shown in fig.4.



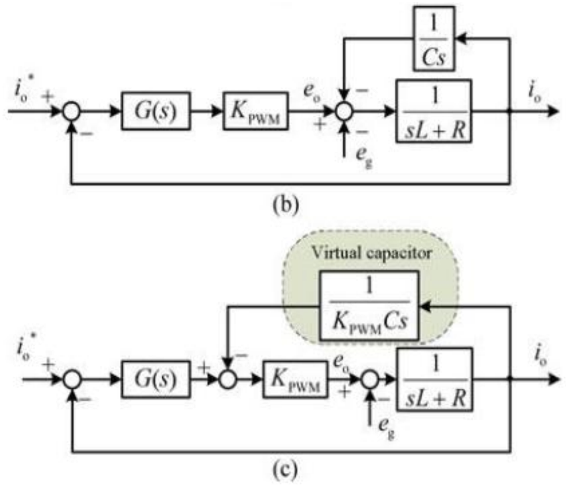


Fig.3.(a) circuit diagram of a single-phase grid-connected PV inverter with the blocking capacitor, (b) current control loop diagram, and (c) equivalent transformation of the current control loop with virtual capacitor concept.

B. Ripple Minimization in Three-Phase PV Inverters with Feed Forward and PIR Controllers

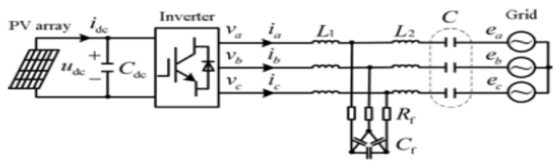


Fig.4. Circuit diagram of a three-phase grid-connected PV inverter with blocking capacitors.

The PI(proportional-integral) controller is normally adopted in the standard three-phase inverter current loop in the d-q frame in order to regulate the d-axis and q-axis currents. The PI controller in d-q frame is equivalent to a proportional-resonant (PR) controller in the stationary a-b-c frame [11], given the resonant frequency of the R controller is selected as the line frequency (rotational frequency).The PR controller is similar to P(proportional) controller if only the ripple content is taken into account. In standard dual closed- loop control system (i.e.) in synchronous frame, the system is transferred into mixed abc-dq frame. The reference current, grid voltage and corresponding parameters in a-b-c frame are converted into d and q parameters in d-q frame. Thus the virtual capacitor is implemented in the stationary a-b-c frame.

With this approach, only an additional R controller needs to be added to the conventional PI controller

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(Mar-Apr)

and also the feed forward term which represents the virtual capacitor has been implemented in the current feedback path. The new control structure based on the dc component feed forward (in the feedback path of the inverter-side current [11])and PIR controllers for dc component minimization is shown in Fig.5[12].As we know that the dc component in the ac-side currents will appears as the inner current control loop with direct axis and quadrature axis current (e.g., id , iq) in the form of a negative-sequence line-frequency current which can be controlled by using R(resonant) controller.

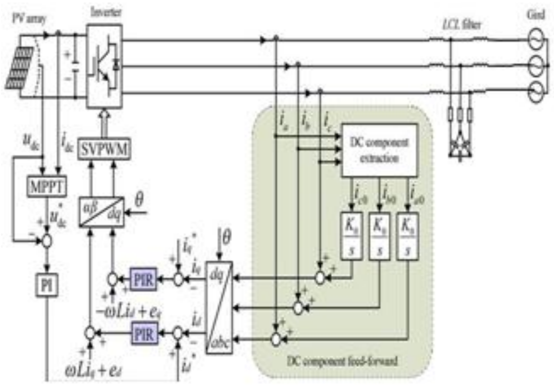

Fig.5 .DC component minimization strategy based on dc component feed-forward and PIR controllers.

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, as shown in the dashed rectangle in Fig.5.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).In Fig. 5, k0 is the integral gain of the dc component and k0 = 1/C. The larger the value of k0 is, the smaller the virtual capacitor is, and the faster the integrator responses. However, smaller virtual capacitor will lead to larger fluctuations in the steady-state errors. On the other hand, smaller k0 means larger virtual capacitor and slower integral responses. The steady- state errors become smaller and a stable operation of the PV systems is achieved. Since the dc minimization does not need a very fast response, a relatively small value of k0 (large virtual capacitor) is suggested in this paper.

IV. RESULTS

The results implemented from above analysis can reduce the ripple in ac side of the inverter (grid). The results obtained from above method can reduce the total harmonic distortion THD value from (4.3%, 3.3%and 3.8%) to (2.7%, 2.6% and 2.8%). These results can show the effectiveness of implementing the feed-forward control and PIR controller on the three phase grid connected transformerless photovoltaic system. The output of three phase grid current in grid connected photovoltaic inverter with dc component minimization is illustrated in fig.6.

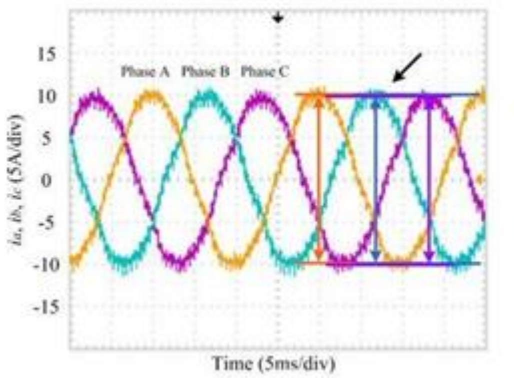

Fig.6. (a) three phase grid current with proposed system with dc component minimization

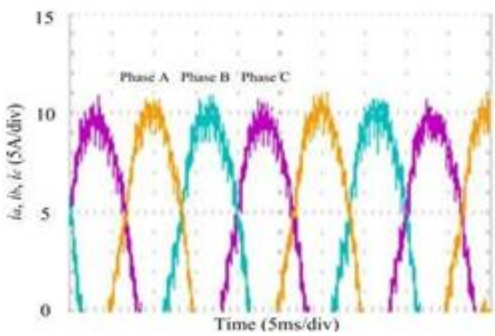

Fig.6 (b).zoom in detail of Fig.6 (a)

The transient response of the dc component with proposed ripple minimization is illustrated in fig.7. The comparison of steady state error of the d-axis and q-axis in standard PI controllers and proposed PIR controllers is illustrated in fig.8 (a) and fig.8 (b).

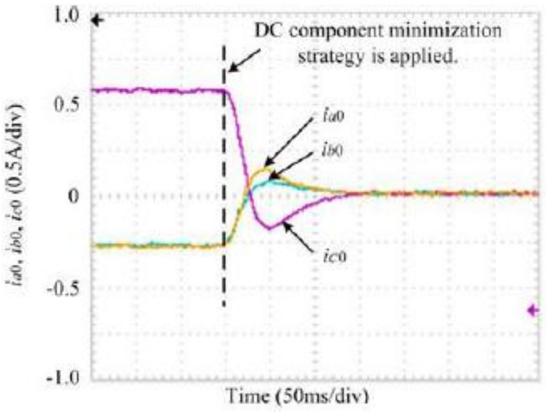

Fig.7(a). Transient response when proposed dc component minimization is applied.

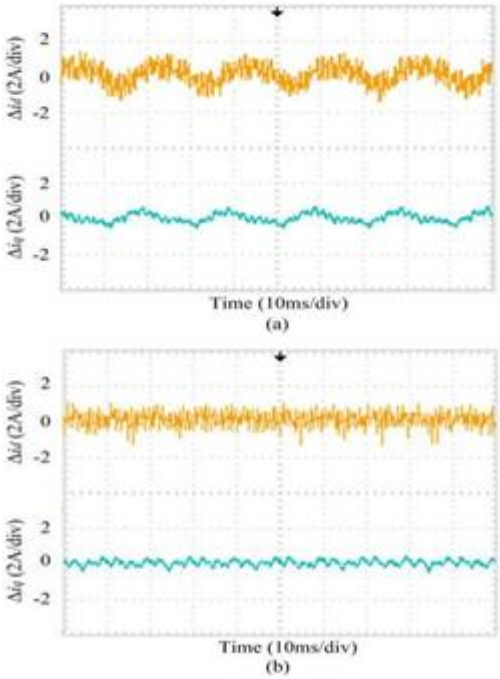

Fig.8. Steady state errors of d-axis and q-axis current with (a) PI controller (b) PIR controller

V. CONCLUSION

This paper proposes an effective solution to minimize the ripple content in three-phase grid connected transformerless photovoltaic system. Elimination of ripple reduces the loss and improves the overall efficiency of the system. Ripple is the major problem in grid connected photovoltaic inverters that affects

the performance of the system. It also causes line frequency ripple, dc link voltage ripple and second order harmonics in ac current. This project proposes an effective solution to minimize the ripple content in the three phase ac current by designing a PIR (Proportional Integral Resonant) controller which is used to regulate the dc & line frequency component in the current loop to provide precise control of dc current on ac side. It also reduces the total harmonic distortion and second order harmonic in the system.

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