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Extraction and Reduction of DC Component in Three Phase PV Inverter System

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Abstract: The DC component is a special issue in transformer less three phase photovoltaic (PV) inverter system and may cause problems regarding system operation and safety. The DC component can cause line frequency fluctuation and second order harmonics in the AC current. This paper has proposed a software based approach to minimize DC component in three phase AC currents. DC component extraction is done by double time integral of current.

Keywords**: DC component, Three phase Photovoltaic (PV) Inverter, Transformer less**

I. INTRODUCTION

Photovoltaic (PV) systems often include a power electronic interface between the solar panel and the load. The galvanic isolation between the load and the PV systems is guaranteed by the transformers.IEEE standard 1547-2003 has defined the limit for dc component in the load side ac currents, e.g. below 0.5% of the rated current.[1] The transformer used satisfies the safety standards and also ensures that no direct current (dc) is injected to the load. The low-frequency (50 or 60Hz) transformer is bulky, heavy and expensive and its power loss brings down the overall system efficiency. High frequency transformer has more than one power stages and increases the system complexity. Thus to eliminate the transformer and achieve cost, size and weight reduction as well as efficiency improvement, the research and interest on transformer less power conversion is growing.[3]

The transformer less approach has many issues, such as dc component in the inverter output current, ground leakage current (due to common-mode voltage and parasitic capacitance) and the voltage level mismatch between the solar panel (inverter) and load . Among them, the dc component can affect the normal system operation and cause safety concerns. DC component present in the output of the inverter can cause core saturation of distribution transformers, anomalous meter readings, cable corrosion etc [4]. Thus this paper will investigate effective solution to minimize the DC component in PV systems.

The dc component can have negative impacts on the power system in the following ways:[2]

The operating point of the transformers in the power system can be affected by the DC component. This drives the transformer core into unidirectional saturation with consequent larger excitation current. This results in increase of hysteresis and eddy current loss which reduces the service lifetime of transformer.

There is a possibility of Dc component circulation inbetween the inverter phase legs as well as among inverters in a paralleled configuration.This circulation may affect the even current and loss distribution among the paralleled inverters.

3. The Corrosion of grounding wire in substation is intensified due to the DC component.

There are many sources leading to the dc components in load connected inverters:[4]

1) Asymmetry in the switching behaviour of power semiconductor devices,
2) Imparity in gate driver circuits,
3) Device turn-on and turn-off delays,
4) Non-identical device voltage drops (on-state resistance, saturation voltage, etc.),
5) Sampling biases from the ac current and ac voltage sensors, etc.

The paper is structured as follows: The Block Diagram of the system proposed to minimize the DC component is given and explained in section II, the different methods to minimize the DC component is explained in the section III, the methods to extract DC component is explained in the

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section IV , the methods for minimization of DC component in ttansformerless three phase system is explained in a detailed manner in section V. The simulation diagram and the results of the open loop circuit is explained in section VI.

II. Proposed Method

The typical block diagram of the system proposed to minimize the DC component is shown in Fig.1.

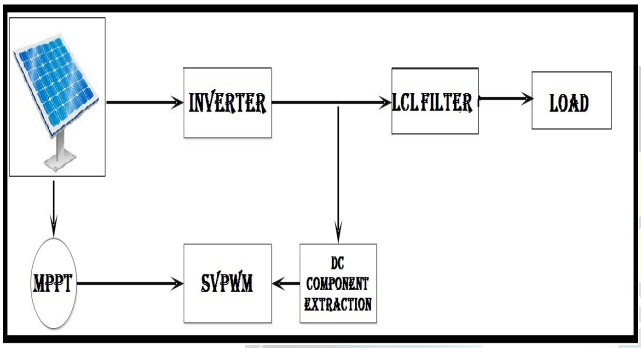

Fig.1.Block Diagram of Photo Voltaic Inverter System

A. *Modelling Of PV Panel*

A PV panel consists of solar cells connected in series and parallel. A single solar cell can be modelled using a diode, two resistors and a current source.[7]

Table I
PV Panel Specification

Parameter	Values	Units
Short Circuit Current (Isc)	4.75	A
Open Circuit Voltage(Voc)	10	V
Irradiance used for measurements(Iro)	1000	W/m^2
Quality Factor (N)	1.6	
Series Resistance(Rs)	5.1e-3	Ω
No. Of Cells	72	nos
Connection Type : Series		

B. *Inverter*

The Inverter used here is a three phase two level voltage source inverter. Here MOSFET switches are used which are connected with a diode in a parallel combination with a series RC snubber circuit. The Space Vector Pulse Width Modulation (SVPWM) technique is used to give gate pulse for the MOSFET switches. 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 The circuit diagram of a two level inverter is shown in Fig.2.[6][2]

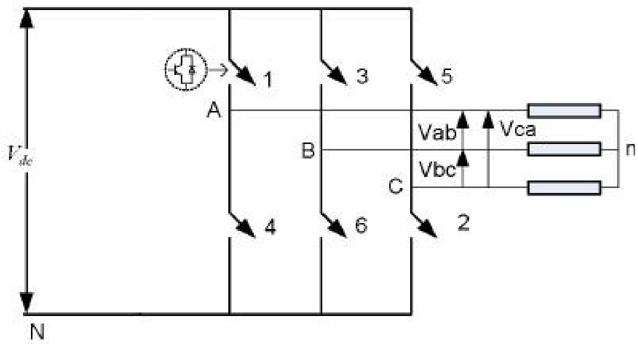

Fig.2. Circuit diagram of a Two-Level Inverter

C. *LCL filter*

The output of the inverter will have harmonics in it which will result in several issues. Thus a LCL filter is designed to avoid the harmonics present in the output of the inverter. The second important use of LCL filter is that it provides isolation between the inverter and the load and also it prevents the injection of Dc current harmonics. 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.[2][7]

D. *Maximum power point tracking*

Since the output from the PV panel is not same at all the time, to get a constant output from the power converters Maximum Power Point Tracking (MPPT) is used. The MPPT gives the signal which is compared with the reference signal and then given to PI controller which provides the pulse to the power converters. There are many algorithms

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available in MPPT. The most commonly used algorithms are Perturb and Observe type and Incremental Conductance type. [8]

E. Space Vector Pulse Width Modulation

Space vector modulation (SVM) is one of the preferred real-time modulation techniques and is widely used for voltage source inverters. The concept of space vectors is derived from the rotating field of AC machine which is used for modulating the inverter output voltage. In this modulation technique the three phase quantities can be transformed to their equivalent 2-phase quantity either in synchronously rotating frame or stationary frame. From this 2-phase component the reference vector magnitude can be found and used for modulating the inverter output.

III. Methods to Minimize DC Component

This section deals with many methods to minimize the Dc component. There are several methods available to minimize the Dc Component. They are classified into two groups: A) Passive Methods B) Active Methods.[5]

A) Passive Methods

In this method the passive components such as coupling transformers and capacitors are used to prevent the DC component. The Coupling transformers and Capacitors are inserted on the inverter AC side to minimize the DC component. The disadvantage of this method 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.

B) Active Methods

Auto-calibrating techniques for dc-link sensors in 2-level and 3-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 behaviour and an extra dc-link current sensor is required.

The dc component minimization methods of single-phase PV inverters differ from that of three-phase PV inverters. In three-phase PV inverters, dc component may exist in each phase and flow between phases. It's more challenging to minimize the dc component for all the three phases at the same time due to their couplings.

The 'virtual capacitor' concept was proposed to minimize the dc component in single-phase PV inverters. It replaces the physical capacitor which could block the dc component on the ac side with a novel control strategy. Based on that, this paper further analyses the difference and challenges of using this method for three-phase inverter systems and extends the control strategy to three-phase PV inverters by integrating the extracted dc component and adding it in the current feedback path. A proportional-integral-resonant (PIR) controller is also designed to provide a precise control for both dc and line-frequency signals.

IV. Methods to Extract DC Component

Several methods can be used to measure the dc component.

1) Shunt resistors
2) Voltage transformers
3) Mutual coupled inductors
4) Integral methods, etc.

Among them, only the integral methods do not need extra hardware. However, the performance of the conventional integral method based on fundamental-period integral degrades under line-frequency variations. In this paper, a new integral method based on the sliding window iteration algorithm and double time integral is presented. This method is effective in the extraction of the dc component even for currents with frequency fluctuations and harmonics.[2]

V. Effects of DC Component over Power System

A typical three phase transformer less PV inverter system is shown in Fig.3.

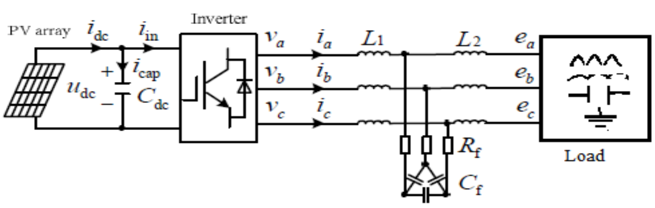

Fig.3.Three phase transformer less PV Inverter system

In order to analyze the impact of dc components on the three-phase PV systems, the dc components have been added

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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 (*a-b-c*), two-phase stationary (*α-β*), and two-phase rotational (*d-q*)).

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

where, the subscript 0 denotes the dc component and the 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 *a-b-c* coordinate, they will also exist in the form of dc or line-frequency components in *α-β* and *d-q* coordinates, respectively.

In a three-phase three-wire system, there is no current flowing through the neutral point and hence

$$F_{a0} + F_{b0} + F_{c0} = 0$$
$$F_{a1} + F_{b1} + F_{c1} = 0$$

with (1) and (2), the coordinate transformations of the dc components from *a-b-c* coordinate to *α-β* and *d-q* coordinate can be expressed as

$$\begin{pmatrix} F\alpha 0 \\ F\beta 0 \end{pmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} Fa0 \\ Fb0 \\ Fc0 \end{bmatrix}$$

$$= \begin{bmatrix} Fa0 \\ -\frac{\sqrt{3}}{3}Fb0 - \frac{\sqrt{3}}{3}\ Fc0 \end{bmatrix}$$

$$\begin{pmatrix} Fd1 \\ Fq1 \end{pmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} Fa0 \\ Fb0 \\ Fc0 \end{bmatrix}$$

$$= \begin{bmatrix} Fa0\cos\theta + \frac{\sqrt{3}}{3}(Fb0 - Fc0)\sin\theta \\ Fa0\cos\theta + \frac{\sqrt{3}}{3}(Fb0 - Fc0)\sin\theta \end{bmatrix} \qquad (4)$$

(1)

where, θ is the angle between the *d-q* coordinate and *a-b-c* coordinate, for example, the grid angle in a grid-voltage oriented vector control.

As seen in (3) and (4), by the coordinate transformation, Fa0, *Fb*0 and *Fc*0 (dc components) in the stationary *a-b-c* frame can be transformed into *Fα*0 and *Fβ*0 in the stationary *α-β* frame and then *Fd*1 and *Fq*1 (line-frequency) in *d-q* 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. 4, where ***F*** is a stationary vector. Since the *d-q* frame rotates anti-clockwise, the dc component in the synchronous *d-q* frame appears in the form of a negative-sequence line-frequency component.

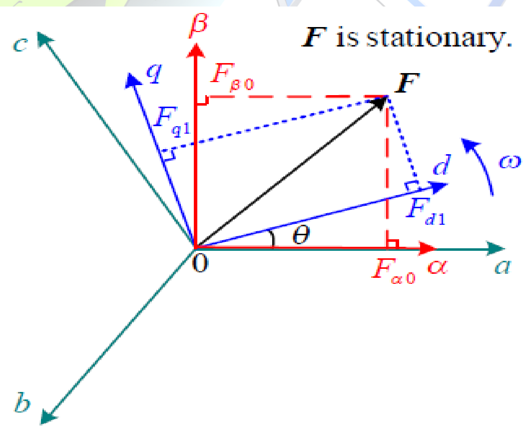

Fig.4. Coordinate Transformation of DC Components

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The line-frequency fluctuations will appear in both active power p_{ac} and reactive power q_{ac} 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 power, e.g. causing voltage ripple in the dc-link, which in return will generate a 2nd 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 in Fig. 5.

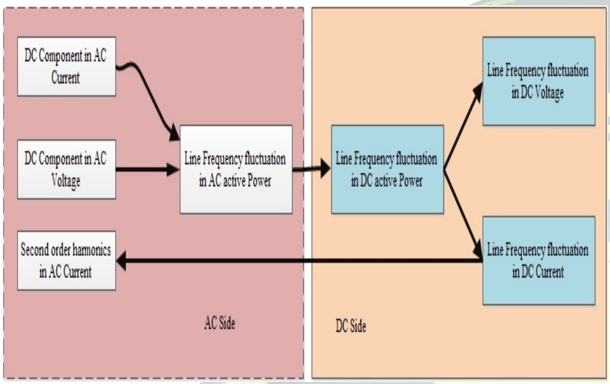

Fig.5. Influences of DC Component on Power System

VI. Minimization of DC Component in 3 Phase System

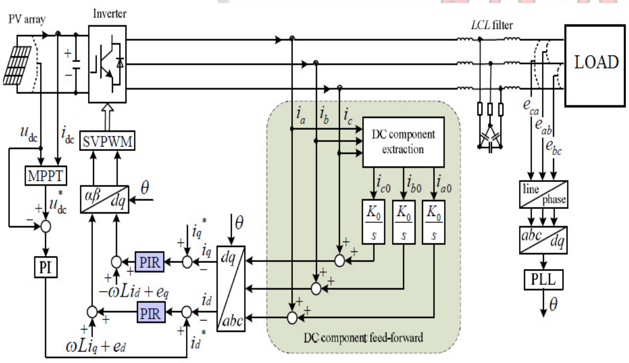

Fig.6. DC Component Minimization Strategy

The new control structure based on the dc component feed-forward (in the feedback path of the inverter-side current and PIR controllers for dc component minimization is shown in Fig. 6. As derived in Section IV, the dc component in the ac-side currents will appear in the inner current control loop (e.g. id, iq) in the form of a negative-sequence line-frequency current. 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. 6. In the outer voltage loop, a PI controller is used to enable the dc
link voltage $u$dc to track the reference voltage u^* dc , thus achieving maximum power point tracking (MPPT).

In Fig.6, $K0$ 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.

VII. Simulation Circuits and Results

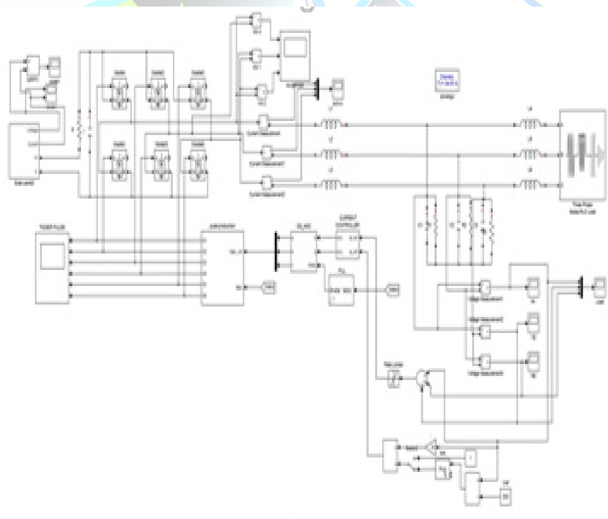

Fig.7. Simulation Circuit

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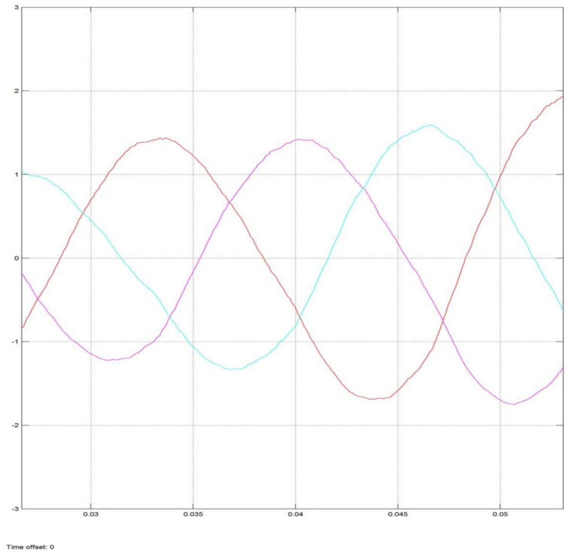

Fig.8. Simulation result of Currents Ia,Ib,Ic

Fig.9. Pulses Given to the MOSFETS

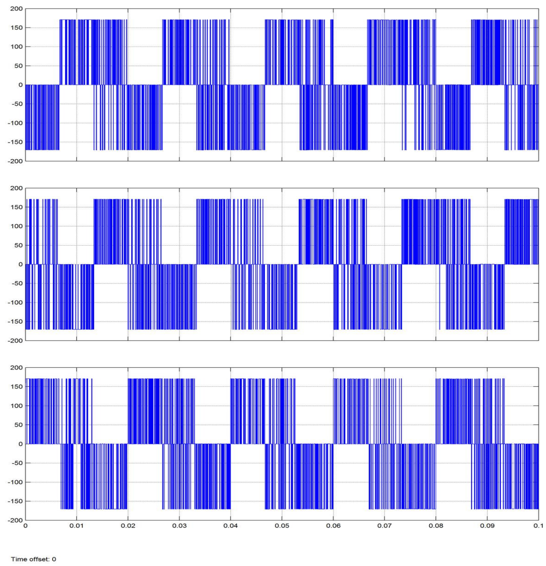

Fig.10. Simulation Result of Voltages Va,Vb,Vc

The circuit is simulated in MATLAB/SIMULINK and it is shown in Fig.7.The current output, Voltages Output and the Pulse output are shown in the Fig.8,9,10.

VIII. CONCLUSION

Thus this paper gives an effective solution to minimize the DC component in the transformer less three phase Photovoltaic Inverter systems. The integral method used to extract the DC component and the minimization technique used with the help of PIR controllers was very effective and thus reduced the DC component thus fulfilling the IEEE standards. Researches are further made on this topic for the better extraction and reduction technique.

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