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A MICC Algorithm for Power Quality Improvement Using PV-DSTATCOM

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***Abstract* - A modified indirect control algorithm is presented in this paper to improve the operation of photovoltaic fed distributed static compensator. This new algorithm overcomes the limitations of direct current control algorithm under non-ideal supply voltage conditions such asswitching notches in source current after compensation, distortions in the reference source current and poor harmonic elimination. The design and performance testing of the presented system has been carried out in MATLAB/Simulink software. Furthermore, the efficacy and robustness of the presented system are validated through experiment.**
***Keywords:* Power Quality, Indirect Current Control, LCLC Filter, Reactive Power, Harmonic Elimination**

I. INTRODUCTION

In distribution sector, due to high power loss, reliability issues and challenges in coming to the provincial territories, the conventional power system structures are now being integrated with micro-sources. Out of distinctive sort of micro-sources, photovoltaic (PV) cell only has the facility to connect it in series to provide necessary dc voltage [1]. So, the photovoltaic sources are widely integrated to the grid through a PV-inverter, which is power electronics based equipment.

Because of the progression in power electronics, the number and sorts of nonlinear burden have been massively increased on distribution system. That leads to the flow of distorted current from the source and increased requirement of reactive power compensation. This has propelled the utilities and clients of electric energy to implement harmonic compensators for enhanced effectiveness of the electronic gadgets. Because of the weaknesses like expansive size, substantial weight and resonance with system impedance, the passive harmonic compensators are gradually replaced by distributed static compensators (DSTATCOMs).

Different topologies of distributed static compensators for interfacing with distribution system are proposed in [2]-[4].As the photovoltaic sources are now being integrated with distribution system, the power researchers thought of the idea to combine it with DSTATCOM (PV-DSTATCOM) to reduce the requirement of a greater number of inverter and for improved utilization of solar inverter [5-8].

For continuous and effective compensation, a suitable control algorithm is required. So different control algorithms are applied for PV-DSTACOM in [9-11]. The reference current generation algorithm used are instantaneous reactive power theory (IRPT), unit template technique, power balance theory, IcosΦ control algorithm, Synchronous reference frame (SRF) theory, Instantaneous symmetrical component theory (ISCT), dc link energy balance theorem etc. Among these aforementioned control techniques, IRPT scheme is mostly used for its simple, robust and ease of implementation characteristics. The IRPT scheme includes two approach such as direct current control (DCC) and indirect current control (ICC). The ICC approach doesn't give satisfactory performance when supply voltage contains some distortion [12].

In this paper, a modified indirect control algorithm has been implemented to improve the system performance under distorted supply voltage condition. The new LCLC type passive interfacing filter has been used to integrate solar system into grid. The exchange of active and reactive power between solar system and grid will be increased with LCLC type passive interfacing filter. For better understanding the advantage of modified indirect current control techniques the performance of the system has been compared with ICC based PV-DSTATCOM. The hardware model is developed in lab and experiments have been carried out to verify the practical viability and effectiveness of the presented system.

The rest of the paper is organized in five major sections; Section II briefly describes the model considered for simulation and experimental studies. The controller applied is discussed in section III. In segment IV the result analysis has been done for both simulation and hardware and finally section V concludes the paper.

II. LCLC-TYPE PV-DSTATCOM

The schematic diagram of the implemented LCLC-type PV-DSTATCOM is shown in Fig. 1. The PV array is connected to grid through a three-phase voltage source inverter followed by LCL passive filter and series capacitor. In Fig. 1, the inverter side resistance and inductance are represented by R_i&L_i, grid side resistance and inductance is represented by R_g, L_g, shunt.

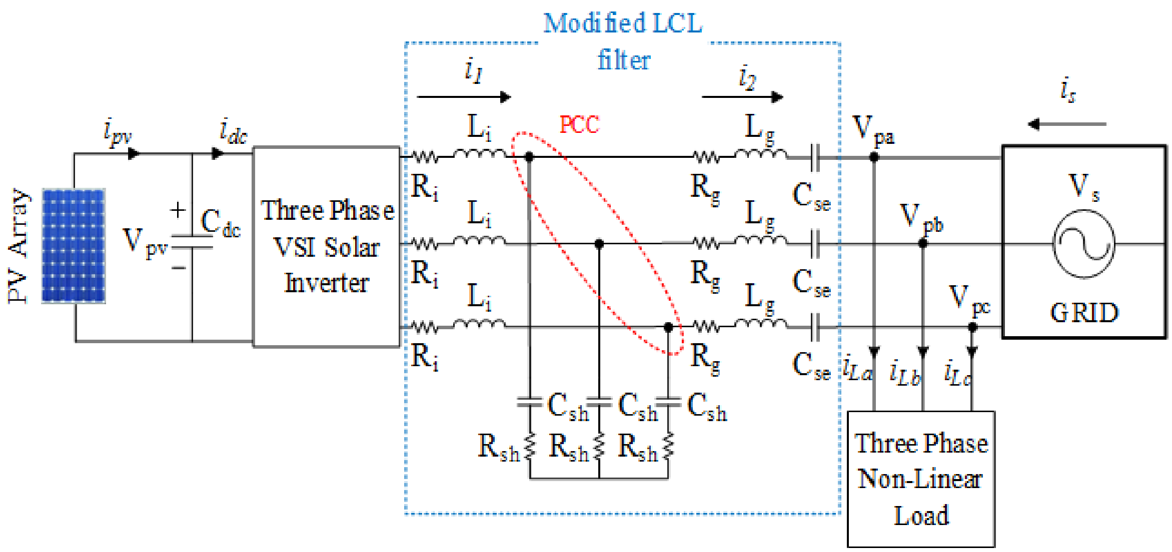


Fig. 1 Schematic diagram of LCLC-type PV-DSTATCOM

capacitor is represented by C_{sh}, and series capacitor is represented by C_{se}. A resistor (R_{sh}) is connected in series with shunt capacitor to reduce the damping. With the implemented PV-DSTATCOM, both active power flow from solar system to load and power quality problems can be taken care of when sufficient solar radiation is available (i.e. in day time). But during insufficient solar radiation the same solar inverter will only take care of power quality problems. The enhanced capability of the system for active and reactive power exchange can be observed from the following equations [13]:

$$Re\left[I_f^1\right] = \frac{R_f\left(V_{inv}^1 - V_p^1\right)}{\left(X_{f12} - X_{se}^1\right)^2} \quad (1)$$

$$Im\left[I_{f,1}\right] = -\frac{V_{inv,1} - V_{t,1}}{X_{f12} - X_{se,1}} \quad (2)$$

III. REFRENCE CURRENT GENERATION

The main aim of generating the reference source current is to supply a compensating current to the utility, so that the harmonic component on the grid side get cancelled and the reactive power consumed by the load can be compensated. For generating the reference current, in this paper indirect current control has been used. For better understanding the direct current control techniques has been discussed and the block diagram of the ICC is shown in Fig. 2. In modified ICC, first the instantaneous active and reactive power has been calculated in $\alpha - \beta$ domain. To remove any distortion present in instantaneous active power due to distortion in source voltage a low pass filter has been used to extract the dc component. Then this is used further for calculation of reference source current. The orthogonal coordinates of supply voltages and load currents can be calculated as follows

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (4)$$

The calculated instantaneous real power and reactive power by using orthogonal system coordinates of currents are as follows

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (5)$$

The instantaneous real power is then passed through a low pass filter which is designed to eliminate high frequency components and passes only low frequency signals. The fluctuating component of active power and mostly the reactive power we want to compensate for the power quality improvement. Sothe dc component of instantaneous real power ($\bar{p}$) has been considered for further calculation and the distortion free reference source current is synthesized as follows:

$$i_{s\alpha}^* = \frac{V_{s\alpha}}{V_{s\alpha}^2 + V_{s\beta}^2} \bar{p} \quad (6)$$

$$i_{s\beta}^* = \frac{V_{s\beta}}{V_{s\alpha}^2 + V_{s\beta}^2} \bar{p} \quad (7)$$

The computed distortions free orthogonal reference source currents are further converted into a-b-ccoordinates.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} \quad (8)$$

These a-b-c coordinates of reference currents are compared with actual source current and the error has been given to hysteresis band current controller for generation of switching sequence for solar inverter. The block diagram for ICC controller is shown in Fig. 3. The switching sequence generation is presented in Fig. 4.

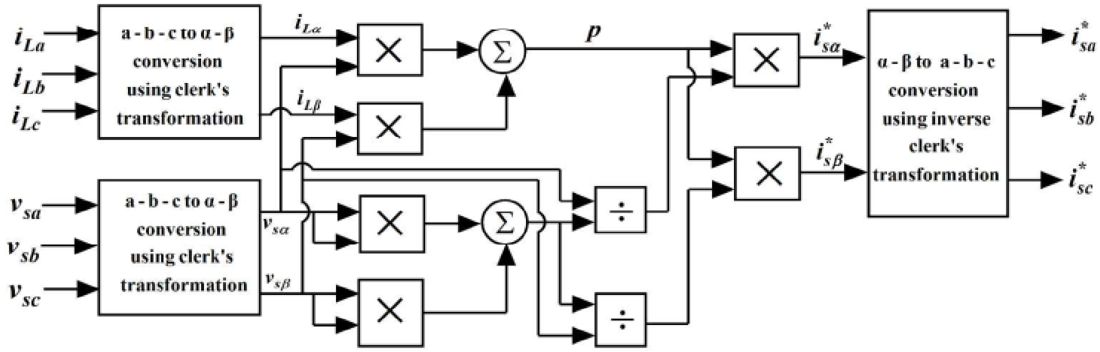


Fig. 2 Block diagram for ICC algorithm

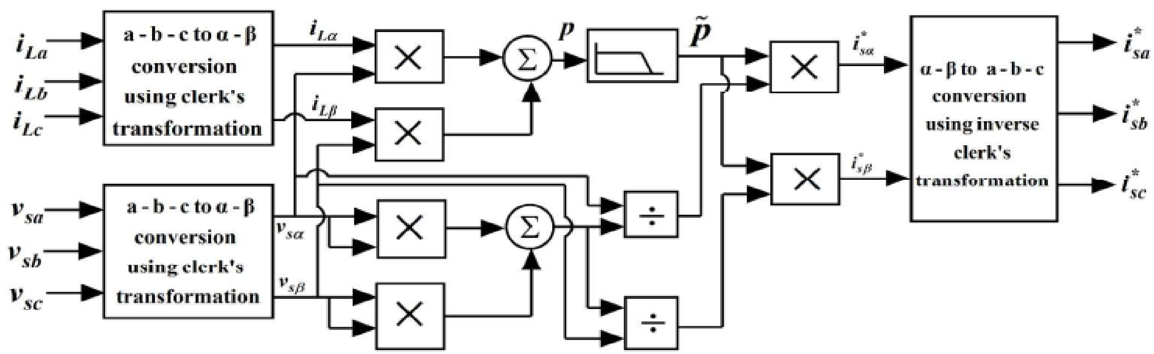


Fig. 3 Block diagram of modified ICC algorithm

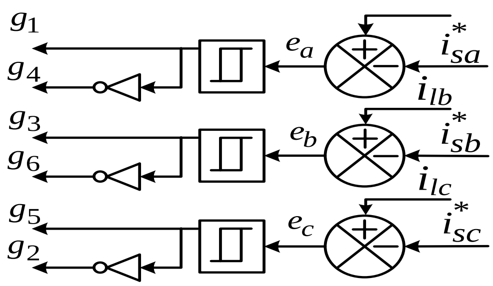


Fig. 4 Generation of switching sequence for solar inverter

IV. RESULT ANALYSIS

In order to investigate the performance of implemented system with ICC a bridge uncontrolled rectifier with ohmic-inductive load is considered. The design parameters for the implemented system have been given in Table I and solar panel details has been given in Table II.

TABLE I DESIGN PARAMETERS OF IMPLEMENTED SYSTEM

Parameters	Value
Grid Voltage	VS = 230 V rms/phase
Frequency	f = 50Hz
DC bus capacitor	Cpv = 3000μF
Grid side inductance	Lg = 2.5mH
Inverter side inductance	Li = 3mH
Shunt passive capacitor	Csh = 10μF
Series passive capacitor	Cse = 55μF
Nonlinear Load	Rdc= 25Ω, Ldc= 50mH

TABLE II SOLAR PANEL SPECIFICATION

System Parameters	Values	System Parameters	Values
Rated maximum power (P_{max})	200.143W	Series resistance (R_s)	0.221Ω
Short circuit current (I_{sc})	8.21A	Shunt resistance (R_{sh})	415.405Ω
Open circuit voltage (V_{oc})	32.9V	S.C current coefficient (K_i)	0.0032A/K
Diode Ideality constant (a)	1.3	O.C voltage coefficient (K_v)	-0.1230V/K
Number of PV array in series	15	Number of PV array in parallel	5

A. Simulation Results

The PV-DSTATCOM is operated under a balanced but ideal source voltage. The source current is non-sinusoidal and heavily contaminated with harmonics when the compensator is not switched on, which can be clearly observed from Fig. 5. But after compensation the source current is sinusoidal and THD is less 5% (IEEE 519 standard) for both ICC and modified ICC. In Fig. 6 the THD analysis for source current before and after compensation has been presented as a bar diagram. Again, the PV-DSTATCOM has been operated under distorted voltage supply. As shown in Fig. 7, for distorted voltage ICC algorithm is not being able to track the reference adequately. But with modified ICC the source current is sinusoidal and harmonic elimination is more. To check the robustness of the implemented system with modified ICC, a linear load is connected to nonlinear load. The linear load is nothing, but three resistors connected in parallel whose values are 10Ω. From the results shown in Fig. 8, it is observed that after compensation the harmonics from source current are eliminated for all type of loading conditions. Also modified ICC scheme is being able to reduce the reactive power burden on the system to a negligible amount. To rate the effectiveness of controller's total harmonic distortion (THD) is considered as performance index and is shown in Fig. 9.

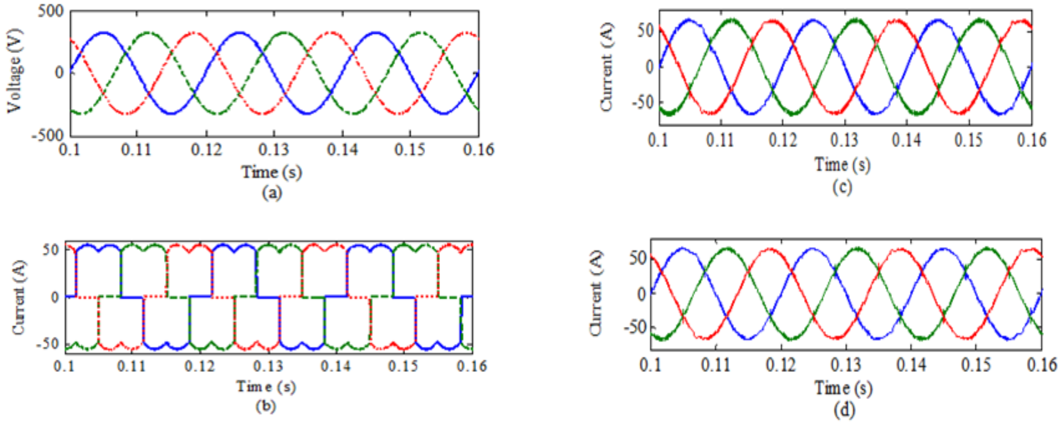
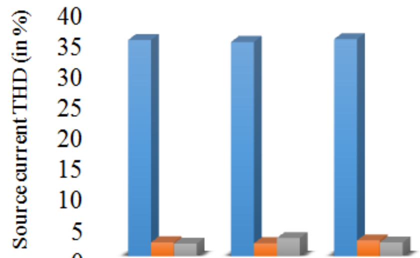


Fig. 5 Simulation results under ideal supply (a) source voltage (b) load current before filtering (c) source current after compensation with ICC (d) source current after filtering with modified ICC



	Phase-a	Phase-b	Phase-c
Without Compensator	35.23	34.92	35.36
ICC	2.27	2.13	2.57
Modified ICC	2.07	2.98	2.26

Fig. 6 Total harmonic distortion of source current

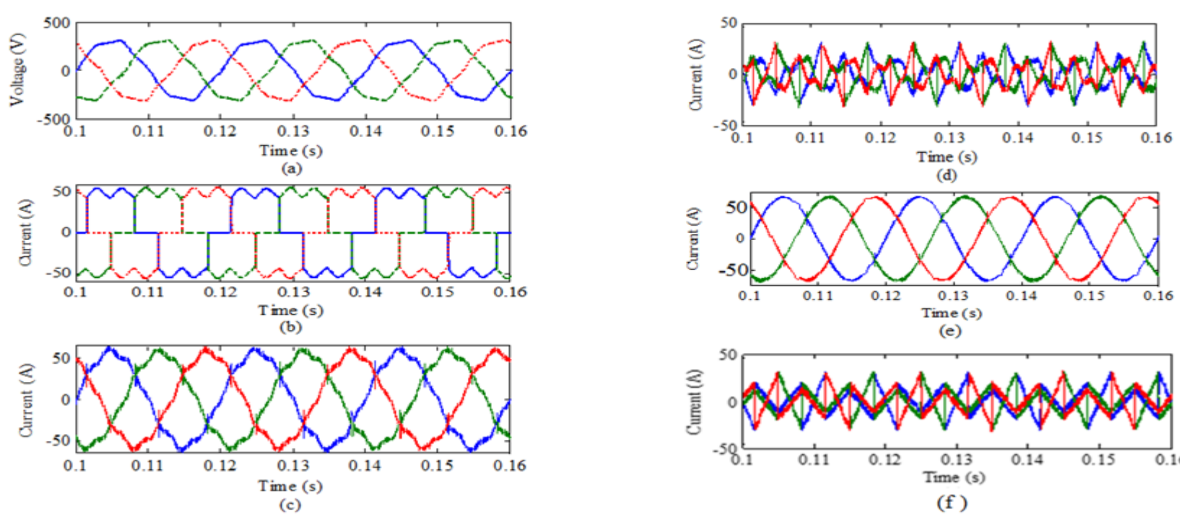


Fig. 7 Simulation results under distorted supply (a) source voltage (b) load current before filtering (c) source current after compensation with ICC (d) filter current for ICC (e) source current after filtering with modified ICC (f) filter current for modified ICC

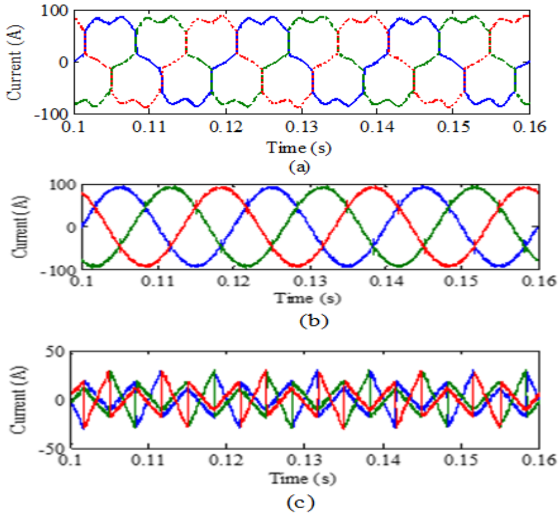
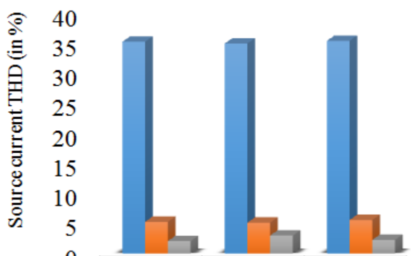


Fig. 8 Simulation results under distorted supply and linear plus nonlinear loadwith modified ICC (a) load current before filtering (b) source current after compensation (c) filter current



	Phase-a	Phase-b	Phase-c
Without Compensator	35.23	34.92	35.36
ICC	5.27	5.13	5.57
Modified ICC	2.07	2.98	2.26

Fig. 9 Total harmonic distortion of source current for linear plus nonlinear load

V. CONCLUSION

This paper implemented a modified ICC for LCLC type PV-DSTATCOM. The LCLC type passive interface filter decreases line impedance thereby increasing the power transfer (both active and reactive) between PV-DSTATCOM and grid. From simulation results it is observed the modified ICC algorithm performs better than ICC algorithm under distorted voltage condition. Also, the performance ability of the controller is independent of load.

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