Performance Evaluation of PV Integrated DSTATCOM Based on Complex Variable Filter

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***Abstract*—Extraction of fundamental active component of load current is the key for any distribution static compensator (DSTATCOM). In this study, a control technique based upon complex variable filter and second order generalized integrator (SOGI) has been used for single phase photovoltaic integrated distribution static compensator (PV-DSTATCOM). Active component of load current is extracted with the help of a filter and it is used to control the pulses of DSTATCOM. A two stage system consisting of a full bridge boost converter in cascade with an inverter is taken to model a DSTATCOM. Power is drawn maximally from the PV panel. Dynamic conditions like step load change and linear irradiation change have been employed to study the performance of the system for this control strategy.**

***Keywords*—Power quality, PV-DSTATCOM, SOGI, CC-CVF, MPPT.**

I. Introduction

Modern day equipments like computers, printers, motor soft start modules and telecommunication equipments etc. invariably need switch mode power supply (SMPS) which demand non-linear current from the grid. As the penetration of these devices increases, the burden of non-linear current, which can disturb the normal functioning of the equipments connected to the grid, on the grid also increases. Harmonic current limits which can be injected by an equipment has been summarized in various standards in [1]. So special devices like distribution static compensator (DSTATCOM) are needed which can supply the non-linear current demand of the load locally, thereby reducing the distortions in the grid and effectively improving the power quality.

Integration of renewable energy sources with the existing grid reduces the active power demand from the grid when power is available from the renewable source. So single phase inverters are becoming a popular choice for roof-top applications. Single phase grid connected full bridge inverters are usually designed for 3 kW to 5 kW power level because of limited space and investment reasons. It is able to feed surplus power to the grid and thereby reducing the consumer's bill. But if the power from PV panel is not available, it remains idle. Some additional features like reactive power compensation and harmonic compensation can be added so that even if sufficient power is not available from PV panel, it should not remain unutilised. This will improve the utilization factor of the system. Thus renewable energy based DSTATCOM is a good option not only in terms of improving power quality but also in active power generation. The functioning of DSTATCOM depends mainly upon the extraction scheme to estimate the reference current signal [2]. The better the extracted component of fundamental current would be, the better the power quality would be.

In the literature, various control schemes have been reported to extract the fundamental component of signal from the polluted voltage signal. Instantaneous reactive power theory (IRP), adaline based control and synchronous reference frame theory (SRF) and second order generalized integrator (SOGI) based control are some of the techniques used to control DSTATCOM [3]. Three phases are required for using SRF-PLL. For less polluted grid, SRF-PLL correctly estimates the fundamental component. PLL adds some distortion if the point of common coupling (PCC) of inverter is corrupted with noise or harmonics [4]–[6]. Leaky least mean square (LMS) adaptive filter has been implemented to extract the active and reactive components of load currents in a three phase system in [7]. In [8], back propogation algorithm has been used to extract the weighted value of active and reactive power of load in a three phase system. But this algorithm needs more time for training. In [9], adaptive notch filter technique has been used to estimate the fundamental signal from the polluted signal. Various schemes for frequency locked loop applications such as second order generalized integrator (SOGI) [10] and reduced order generalized integrator [11] have been developed. If lower order harmonics are present in the signal, SOGI can not accurately extract the fundamental component from the signal without compromising the dynamic performance. Complex coefficient complex variable filter (CC-CVF) has been reported to extract the fundamental component of signal in [12].

In this paper, SOGI and CC-CVF are combined to extract the benefits of both the schemes to control PV-DSTATCOM. Fundamental component of load current is extracted with the help of this combined filter (SOGI-CVF) while the grid fundamental voltage is extracted with SOGI algorithm only. PV-DSTATCOM is modelled by a two staged inverter. Input is directly clubbed to the PV-DSTATCOM. A fix value of dc-link reference voltage is used which is obtained depending upon the peak value of maximum grid voltage. Gate pulses for the first stage are generated by Maximum power point tracking (MPPT) algorithm while gate pulses for the second stage are derived by the hysteresis controller. Performance of the system is measured by testing it under a) changing load condition b) changing irradiation conditions. In the end, comparison between the two techniques, SOGI based control and SOGI-CVF based control has been done.

II. PV-DSTATCOM AND SYSTEM CONFIGURATION

The system consists of two stages a) full bridge dc-dc boost converter followed by b) full bridge inverter. Input is provided by PV array. A blocking diode has been used to block the reverse current flowing into the PV array. The complete system is shown in Fig 1. Full bridge dc-dc stage is realized with four power switches S_1, S_2, S_3 and S_4, input boost inductor L_{boost} and an isolation transformer T_x to provide isolation and a diode rectifier.

Full bridge inverter stage, used to invert the dc voltage obtained from the dc-dc stage, is realized using similar structure as that in dc-dc converter. These two stages are interconnected via dc link capacitor (C_{dc}). Non linear load is connected at the point of common coupling (PCC) with the help of two inductors namely L_{L1} andL_{L1}. Non-linear load draws non-linear current from the grid but the DSTATCOM system compensates grid current such that it draws only sinusoidal current from the grid while harmonic currents are drawn from the DSTATCOM. A full bridge rectifier with R-L load is deployed as a non-linear load. Almost square wave shape current is drawn by the non-linear load as the inductor connected at the output is of higher value. Maximum power point tracking (MPPT) algorithm is used to draw maximum power from the PV array.

III. CONTROL STRUCTURE OF PV-DSTATCOM

Both the stages are controlled separately. To control dc-dc stage, PV voltage (V_{pv}) and current (I_{pv}) is sensed and by the MPPT controller, duty ratio (D) for dc-dc converter is generated which is used for generating the gate pulses for the dc-dc converter. Inverter is controlled with hysteresis control. A reference current (i_g^*) is needed for the inverter control. To have faster control, reference current should have all the information regarding the PV current (I_{PV}), loss component of current (I_{loss}) and active component of fundamental load current (I_{FLa}). If any of the current information is not there, the hysteresis control would take longer time to respond.

Overall control scheme has been shown in Fig. 2. Fundamental component of load current (I_{FLa}) is calculate by SOGI-CVF. PV current component (I_{PV}) is found out using eq. 1. Loss component (I_{loss}) is decided by feeding a reference dc bus voltage ($V_{dc}{}^*$) and dc bus voltage (V_{dc}) to a PI loop. The reference current (i_g^*) is calculated by using these three components. Hysteresis controller is used to get the gate pulses for inverter. DC-DC stage works in open loop. Its gate pulses are derived by MPPT algorithm. Value of reference dc bus voltage is chosen based upon maximum grid voltage.

The three components of magnitude of reference current ($I_g{}^*$) are calculated as follows:

A. PV current components (I_{pvg})

With the input and output power balance, the PV current component (I_{pvg}) is obtained by PV voltage V_{pv}, PV current I_{pv} and grid voltage V_g by eq. 1

$$I_{pvg} = 2\frac{V_{pv}I_{pv}}{V_g} \tag{1}$$

B. Loss components (I_{loss})

There would be a loss component in the magnitude of reference current ($I_g{}^*$) due to the dc-link capacitor. This loss component is calculated with a PI controller as shown in Fig. 2. Dc-link voltage (V_{dc}) and a reference voltage (V_{dc}^*) are passed to a PI controller whose output gives the loss component(I_{loss}) of the magnitude of reference current.

C. Active components of Fundamental Load current(I_{FLa})

Amplitude of fundamental load current (I_{FLa}) is calculated by SOGI-CVF whose structure is shown in Fig. 3. This block is a series combination of SOGI and Complex variable filter (CVF). SOGI filters out harmonic components present in the load current and provides quadrature and in-phase components for CVF. These in-phase and quadrature components may contain lower order harmonics. The Complex variable filter further attenuates lower order harmonics and dc-offset present in the output signal of SOGI and gives quadrature and in-phase component of load current. If lower order harmonics are present in the load current, SOGI alone can not effectively filter out the harmonics. It has to compromise between its accuracy and speed to extract the fundamental component of signal.

Load current (i_L^*) is sensed and fed to the SOGI-CVF block which outputs the amplitude of fundamental load current (I_{FLa}). To calculate amplitude of active component of fundamental load current, grid voltage in-phase and quadrature components are also needed. These are estimated with the help of SOGI. After obtaining in-phase and quadrature phase grid voltage template and in-phase and quadrature phase component of fundamental of load current, amplitude of active component of fundamental of load current is calculated as in eq. 2.

$$\begin{aligned} I_{FLa} &= I_{FL}\cos(\phi_{i_L} - \phi_{v_s}) \\ &= (I_{FL}\cos\phi_{i_L})\cos\phi_{v_s} + (I_{FL}\sin\phi_{i_L})\sin\phi_{v_s} \end{aligned} \tag{2}$$

These three components are added (with proper sign) to obtain the amplitude of reference current (I_g^*). Reference current (i_g^*) is obtained by multiplying amplitude of reference current (I_g^*) with the grid voltage envelope ($\sin(\phi_{v_s})$, estimated by the SOGI algorithm. With the application of reference current (i_g^*) and sensed grid current (i_g) to the hysteresis controller, gate pulses for the inverter are derived.

IV. RESULTS AND DISCUSSION

A two staged PV-DSTATCOM with SOGI-CVF filter has been simulated in MATLAB/Simulink environment and its working performance has been analysed. Solar panel model

Fig. 4. Irradiation (G) is varied from 1000 W/m^2 to 600 W/m^2 in 0.04 sec at time instance 2.0 sec.

The results of the harmonic analysis have been depicted in Fig. 5.The harmonic analysis of grid current (i_g) and load current (i_L) at 1000 W/m^2 solar irradiation is depicted in Fig. 5. Total harmonic distortion (THD) of grid current is found out to be 1.59 % while THD of load current is 31.00 %.

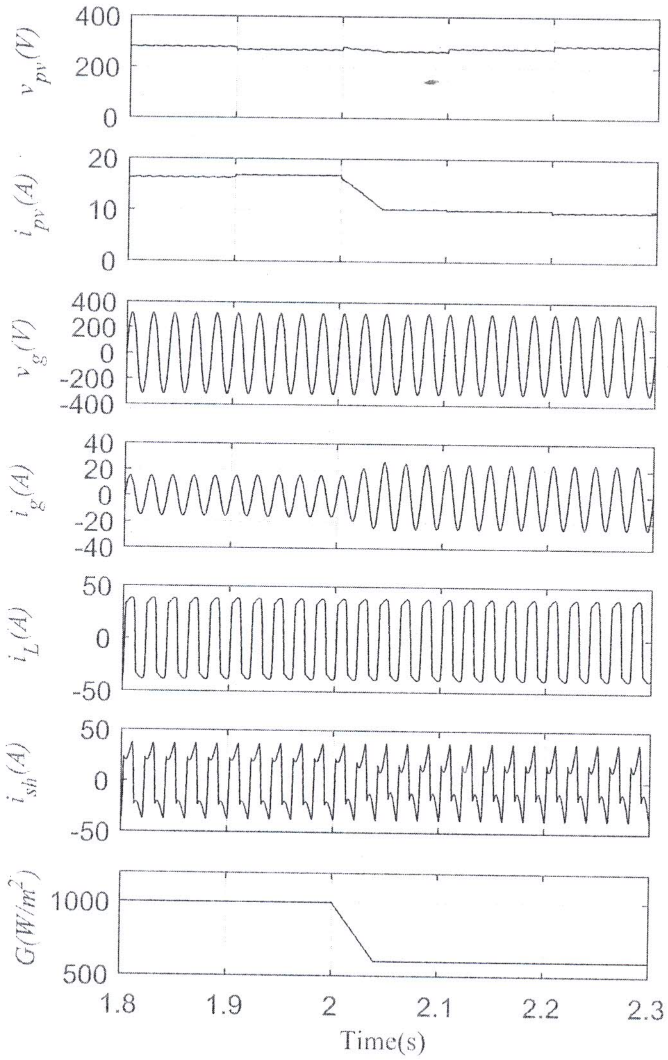
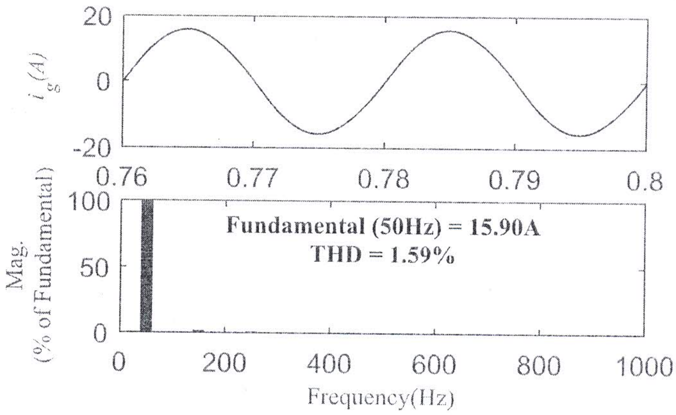
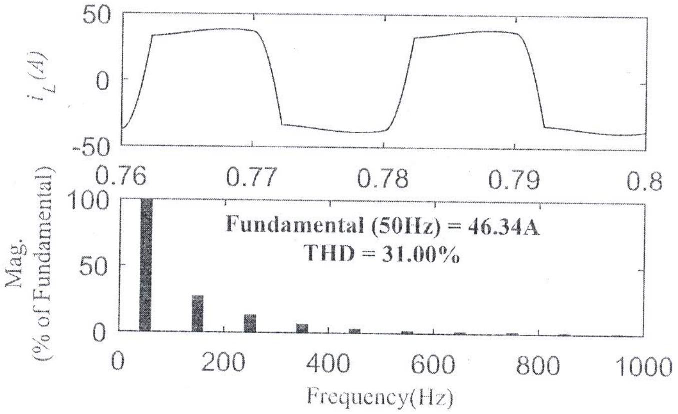


Fig. 4. System simulation under dynamic irradiation conditions.



(a) Grid current and its harmonic analysis



(b) Load current and its harmonic analysis

Fig. 5. Harmonic analysis of grid and load current

The harmonic currents are supported by the PV-DSTATCOM.

B. *Performance under changing load condition*

The load is changed from 50 % to 100 % and the system is simulated. Fig. 6 depicts the system response under step load change. PV array voltage and current (v_{pv} and i_{pv}), grid voltage and current (v_g and i_g), load current (i_L), current provided by PV-DSTATCOM (i_{sh}), and irradiation (G) have been shown in Fig. 6. The load is changed in stepwise manner at time instance 1.0 second. The grid current (i_g) settles in 0.1 seconds. Since the load current has increased, the grid current subsequently increases because the PV-DSTATCOM current can not increase as it is still drawing power at the MPPT point.

C. *SOGI-CVF Performance under distorted grid condition*

SOGI-CVF performance has been evaluated based upon the extracted fundamental signal when the grid is polluted with 3^{rd} and 5^{th} harmonics as depicted in Fig. 7(c). The grid voltage is polluted with 5 % of fundamental for 3^{rd} harmonic and 2 % of fundamental for 5^{th} harmonic. As depicted in Fig.7(c) the THD of extracted fundamental component of load current is 0.44 % while the load current THD is 31.00 %.

D. *SOGI-CVF comparison with SOGI in PV-DSTATCOM system*

The fundamental component is extracted with SOGI algorithm and with SOGI-CVF algorithm. As depicted in Fig. 7, the THD of extracted fundamental signal from the SOGI-CVF is much better than that of from the SOGI algorithm. So the performance of the system would improve when SOGI-CVF algorithm is used.

V. CONCLUSION

A two staged PV-DSTATCOM has been designed. A control technique based upon SOGI-CVF has been used for

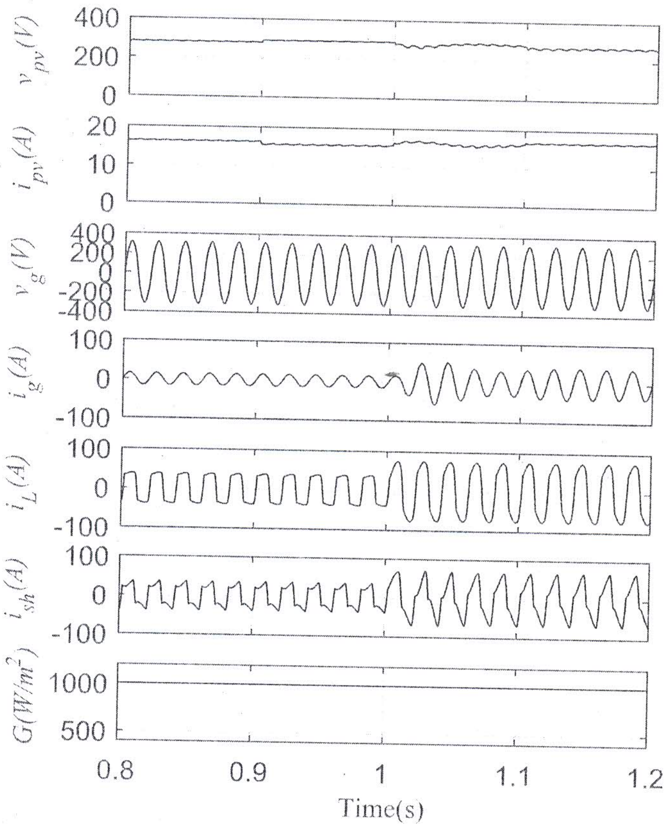


Fig. 6. Simulation results under load change conditions.

controlling PV-DSTATCOM. The complete system has been simulated in MATLAB/Simulink environment. The working performance of the system has been evaluated when the grid is polluted with 3^{rd} and 5^{th} harmonic components. Finally by comparing control technique based upon SOGI-CVF and SOGI, it is argued that SOGI-CVF performs in a better way than SOGI for PV-DSTATCOM.

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Appendix

System Parameter: Line voltage: Fundamental $(V_{1,h})$ = 230V (50 Hz-ac), 3^{rd} Harmonic $(V_{3,h})$ = 5 % of $V_{1,h}$, 5^{th} Harmonic $(V_{5,h})$ = 2 % of $V_{1,h}$; Load: Rectifier based on full bridge topology whose output is R-L load: R = 5 Ω, L = 100 mH, DClink voltage = 400V; DC-link Capacitor:5 mF, SOGI-CVF parameters: K_α = 0.2, K_β = 0.1; SOGI for grid voltage: $K1$ = 0.5; PI-controller gains of DC-link controller: K_p = 1, K_i = 10.

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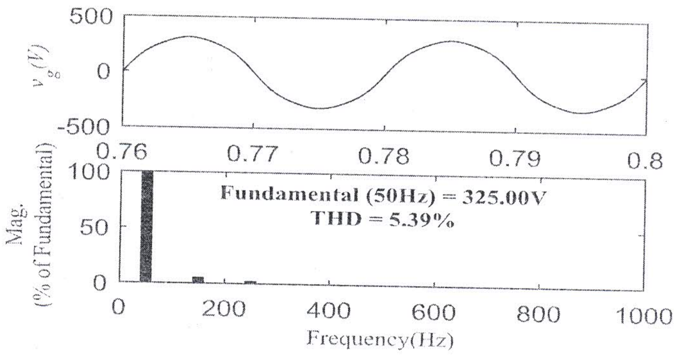
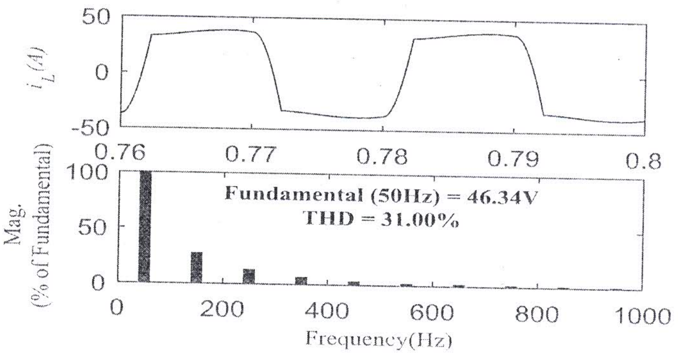
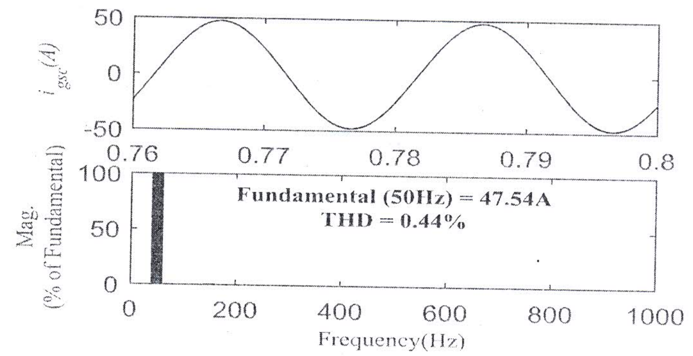


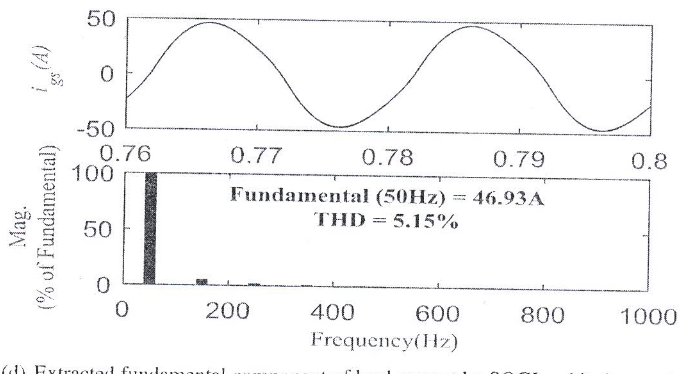
(a) Polluted grid voltage and its harmonic analysis



(b) Load current drawn by the rectifier and its harmonic analysis



(c) Extracted fundamental component of load current by SOGI-CVF and its harmonic analysis



(d) Extracted fundamental component of load current by SOGI and its harmonic analysis

Fig. 7. Comparitive analysis of SOGI-CVF and SOGI under polluted grid conditions

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