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Reduction in harmonic and Compensation of Reactive power in Photovoltaic fed circuit

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Abstract

This research suggests an enhanced hybrid DSTATCOM for reactive and harmonic power adjustment that is fuelled by solar energy. A series-connected capacitor at the front end of the voltage source inverter and an LCL passive filter is used to connect the solar system to the grid. The series capacitor contributes to lowering the DC link voltage, which lowers the DSTATCOM and solar system ratings. The system's non-linearity is taken into account while modeling and controlling the system. The fuzzy logic controller is used to maintain the DC link voltage and regulate the solar system's power flow. Sliding approach controller is used to create switching pulses for the inverter to achieve a robust arrangement. The behavior of the controllers for DC bus voltage and current control is examined using Simulink.

1. Introduction

The demand to supply ratio of energy has drastically decreased due to heavy population growth and high demand electrical energy by the consumers. This is the important reason where the conventional energy sources throughout the world continue to deplete. Rapid advancement in technologies has forced the era to depend on the renewable energy sources to the grid as conventional power sources are losing their capability and sustainability to fulfil the demand to supply ratio [1]. Out of different renewable sources, the photovoltaic (PV) source becomes the eye candy for power researchers due to its abundant availability, low running cost, and along with that it has the advantage of connecting it in series to get the required dc voltage level. Through solar inverters the PV systems are generally integrated to grid. The grid connected PV system either fulfils the load active power demand or injects power to the

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grid. This operation of solar system can be continued till the solar radiation is sufficient for the PV system to generate active power. So during insufficient solar radiation the solar inverter remains unused [2], [3]. Considering this issue for increased utilization and efficiency, the solar invertersare also utilized to solve power quality issues caused by non-linear load [4], [5].

Power quality Issues arise due to the presence of harmonics caused by the non-linear load which affects the performance in terms of voltage distortion, harmonics and power factor. Use of the conventional ways to solve the issues related to the power quality by implementation of the passive filters, creates problems likeresonance, fixed compensation, heavy weightand large space requirement which make the system operation more complex and faulty [6-7]. Considering the issues related to the conventional filters researchers introduced power quality improvement devices like distribution static compensators (DSTATCOMs) having capability to provide the compensation for changing harmonics,reactive power, and unbalanced source currents [8-9]. Now these DSTACOMs are integrating with solar system (named as PV-DSTATCOMs) for combined operation of integration to grid and power quality enhancement [10-14].

The PV-DSTACOMs are integrated to grid through voltage source inverters and passive filters like L or LCL switching harmonic minimizing filter. A large drop across the inductance of conventional Lswitching harmonic minimizing filterforces for higher dc link voltage and as well as increased VSI weight, cost and power rating. To avoid the limitations of traditional L filter, hybrid LCL filters are proposed in [13]. Different control techniques are applied to enhance the compensator performance [15-24]. In [10] a new hybrid topology for DSTATCOM is proposed, in which a capacitor in connected in series with LCL filter at the front end of voltage source inverter to overcome the problems LCL filter and a damping resistor is connected in series with shunt capacitor of LCL filter to avoid resonance damping. The author had shown that with proposed topology the power rating of DSTATCOM had been reduced without affecting the compensation capability of the compensator.

In this paper, a new PV-DSTATCOM topology is proposed which operates at lower power rating. With the proposed topology comparatively smaller photovoltaic source can also be integrated to grid without boost converter.

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For current control the performance of the system is observed and compared with two different controller named as modified instantaneous $i_d - i_q$ theory and sliding mode control (SMC). Similarly for dc bus voltage control two techniques are applied, one is proportional plus integral (PI) controller and the other one is Fuzzy logic controller. The efficacy of the proposed topology is verified through both simulation and experimental results.

The paper is organized as follows. Section 2 presents the brief discussion about proposed topology and its effect on real power flow from solar system. It also discuss the non-linear modelling of PV-DSTATCOM. simulation results and discussions.

Outline of PV fed hybrid DSTATCOM

The photovoltaic fed hybrid distribution static compensator (PV-DSTATCOM) considered for studying purpose is shown in Fig. 1(A). The implemented system consists of a photovoltaic array, three phase solar inverter, a non-linear load (means three phase bridge rectifier with ohmic-inductive load) and the distribution grid. The solar inverter is integrated to grid through an LCL filter and series capacitor. The system transfers the active power from PV array when solar radiation is available and also satisfies the compensating capability of DSTATCOM. Rest of time, the implemented system behaves as a conventional DSTATCOM. As shown in Fig. 1(a), R_1 and $L_1$are inverter side resistance and inductance respectively; R_2 and L_2 represents the load side resistance and inductance respectively; C_f is the LCL filter capacitance connected in shunt with all three phases; a damping resistor is connected in series with the capacitor (C_f) for passive damping of the total system represented as R_d; the series capacitor inserted in series at the front end of LCL filter is represented as C_{se}; Source impedance is represented as R_s, L_s; voltage across the dc link capacitor (C_{dc}) and the source voltage are represented as V_{pv}, and V_s respectively; V_{pa}, V_{pb}, V_{pc} represents voltage at the point of common coupling (PCC) for phase a, b, and c respectively; load currents for all phases and source current are represented as i_{la}, i_{lb}, i_{lc}, and i_s respectively. The system parameters are given in Table 1.

The dynamic model of the presented system under synchronous reference frame can be expressed as follows:

$$\frac{di_{1j}}{dt} = \frac{D_j V_{pv}}{L_1} - \frac{R_d}{L_1} i_{1j} + \frac{R_d}{L_1} i_{2j} - \frac{V_{cfj}}{L_1} \pm \omega i_{1j'} \quad (1)$$

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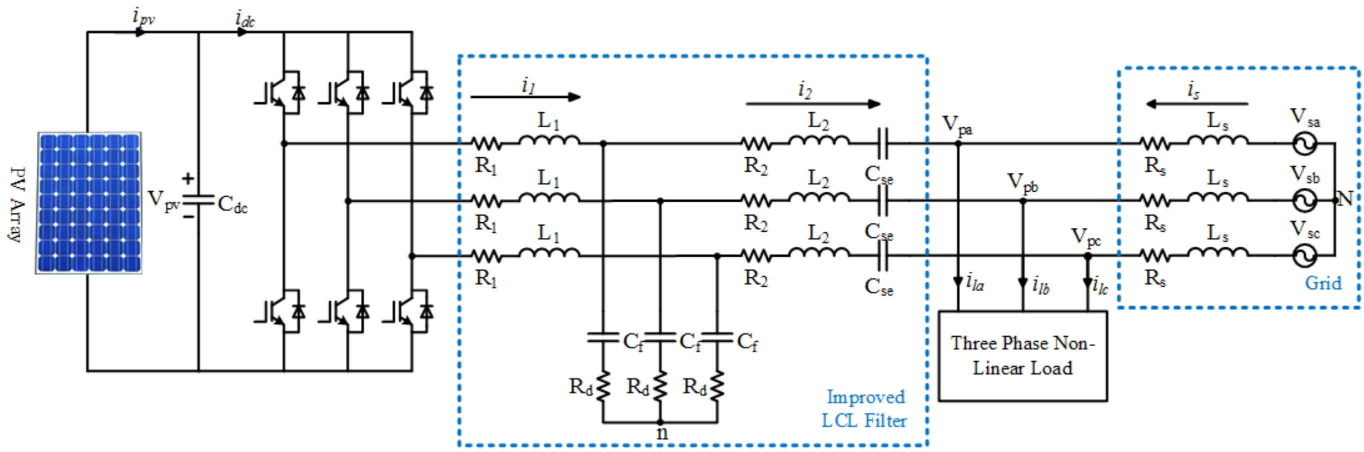
$$\frac{di_{2j}}{dt} = \frac{R_d}{L_2} i_{1j} - \frac{R_d}{L_2} i_{2j} - \frac{V_{sej}}{L_2} - \frac{V_{sj}}{L_2} + \frac{V_{cfj}}{L_2} \pm \omega i_{2j'} \tag{2}$$

$$\frac{dV_{pv}}{dt} = \frac{1}{C_{dc}} i_{pv} - \frac{1}{C_{dc}} \left[D_d i_{1d} + D_q i_{1q} \right] \tag{3}$$

$$\frac{dV_{cfj}}{dt} = \pm \omega V_{cfj'} + \frac{1}{C_f} \left[i_{1j} - i_{2j} \right] \tag{4}$$

$$\frac{dV_{sej}}{dt} = \pm \omega V_{sej'} + \frac{1}{C_{se}} i_{2j} \tag{5}$$

where $j = d,q$, $j' = q,d$, i_{1j} and i_{2j} denote d-q axis VSI currents and filter currents respectively, V_{cfj} is the d-q axis voltage across shunt capacitor, V_{sej} represents the voltage across the series capacitor, D_j stands for d-q axis duty ratio functions. By considering the dynamic equation,the average model of the system is shown in Fig. 1(B).



(A)

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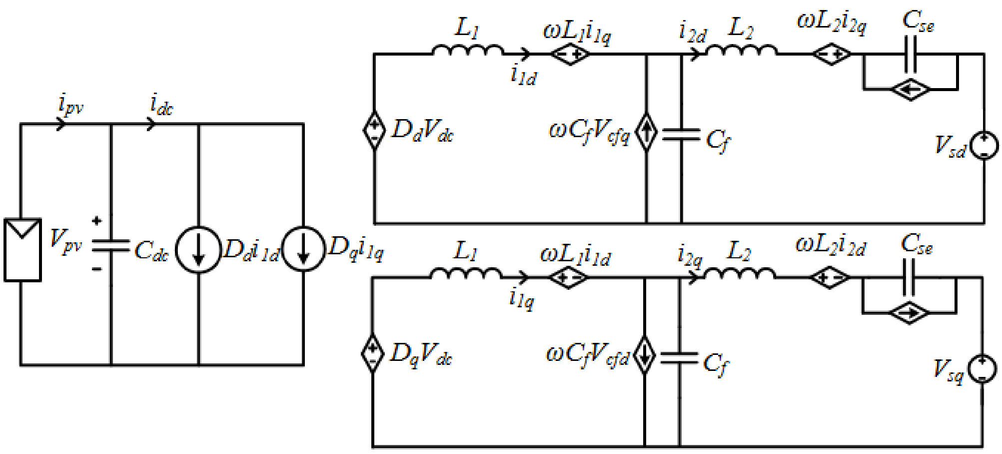

(B)

Fig. 1 (A) Line diagram of PV fed hybrid LCL filter based DSTACOM (B) Average model of implemented system

The reactive power compensation capability of the implemented system without photovoltaic source is discussed and verified in [9]. As the integration of photovoltaic source with the proposed hybrid filter will not affect

Table 1 System parameters

Parameters	Value
Grid Voltage ($\mathbf{V_s}$)	230V rms
System Frequency	50Hz
DC Link Voltage($\mathbf{V_{pv}}$)	165V
DC Link Capacitor ($\mathbf{C_{dc}}$)	3000µF
Non-linear load (3-phase diode bridge rectifier with R-L load) $\mathbf{R_{dc}}, \mathbf{L_{dc}}$	50Ω, 200mH
LCL filter parameters ($\mathbf{L_1}, \mathbf{C}, \mathbf{L_2}, \mathbf{C_{se}}$)	1.3mH, 15µF, 0.4mH, 65µF

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the reactive power compensation capability, so here only the changes in active power flow between grid, PV source and non-linear is discussed. The insertion of series capacitor caused the reduction of dc link voltage. Through a tradeoff process dc link voltage is chosen 165V which found to provide satisfactory compensation. By applying Kirchhoff's voltage law in the system, we get:

$$V_{inv}^{1} - I_f^1 R_f - I_f^1 jX_{f12} - I_f^1 jX_{se}^1 - V_p^1 = 0 \quad (6)$$

where the fundamental voltage available at the VSI side (V_{inv}^1) is $\frac{V_{pv}}{\sqrt{2}}$, $R_f = R_1 + R_2$, $X_{f12} = \omega_1(L_1 + L_2)$, $X_{se1} = 1/\omega_1 C_{se}$, and V_p^1 is the fundamental pcc voltage. From(6), the real part of the fundamental current supplied by the filter can be expressed as:

$$Re\left[I_f^1\right] = \frac{R_f\left(V_{inv}^1 - V_p^1\right)}{\left(X_{f12} - X_{se}^1\right)^2} \quad (7)$$

From(7), it can be noticed that the impedance of passive filter decreased due to the insertion of series capacitor. Therefore, the same active current can be injected to load through the compensator with reduced dc link voltage and as well as with reduced output voltage of photovoltaic system. When conventional L or LCL filters are used for the interfacing of solar inverter with grid, generally the dc bus voltage required for satisfied operation of compensator is around (650-780)V. When dc bus voltage will be high, the inverter rating will increase as the power rating of the required IGBTs will be high. With increase in rating, the price per unit IGBT will also increase, which will make the inverter costlier as compared the inverter whose dc bus voltage is 165V. Again, if dc link voltage will be high, then low rating PV sources (whose output open circuit voltage is low) will need a boost converter to be integrated with grid. But with the implemented system, the above discussed problems which are responsible for price hike of overall system can be avoided.

2. Simulation results and Discussion

In this section the electric power system of **Error! Reference source not found.** (a) is simulated. The parameters of power system and solar source are shown in Table 1and Table **2**. Initially the system simulated

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under MATLAB/Simulink environment. The system is simulated under two different mains voltage condition. The steady state performance of the system is observed under three different control environments. The efficacy of the controllers is validated by taking total harmonic distortion, steady state error and reactive power compensation as performance index.

Table 2 KC200GT PV array parameters at nominal operating conditions

Parameters	Symbol	Value
Rated maximum power	P_{max}	200.143W
Short circuit current	I_{SC}	8.21A
Open circuit voltage	V_{OC}	32.9
Diode ideality constant	a	1.3
Series resistance	Rs	0.221Ω
Shunt resistance	Rp	415.405Ω
S.C temperature coefficient	Ki	0.0032A/K
Number of PV array in series	--	10
Number of PV array in parallel	--	2

Case-1: Steady state performance of the system with modified $i_d - i_q$ *and PI controller*

Under this section the power system is simulated with ideal and distorted mains voltage condition. The simulation results are shown in Fig. 2 and Fig. 3 for ideal and distorted voltage respectively. FromFig. 2, we can realize that the three phase load currents are highly distorted and non-sinusoidal due to the nonlinear load. After the compensation the source current becomes pure sinusoidal and free of distortions. But from Fig. 3 it is observed that the controller is not being capable to track the reference so proficiently as compared to the ideal mains voltage

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condition. Under ideal source though the controller is achieved the unit power factor requirement but under distorted source the reactive power compensation is not satisfactory. The THD of the source current reduces from 25.56% to 3.24% with ideal voltage source whereas with distorted source it reduces to 3.57% from 32.76% after compensation, which is well under the requirement of IEEE 519 standard.

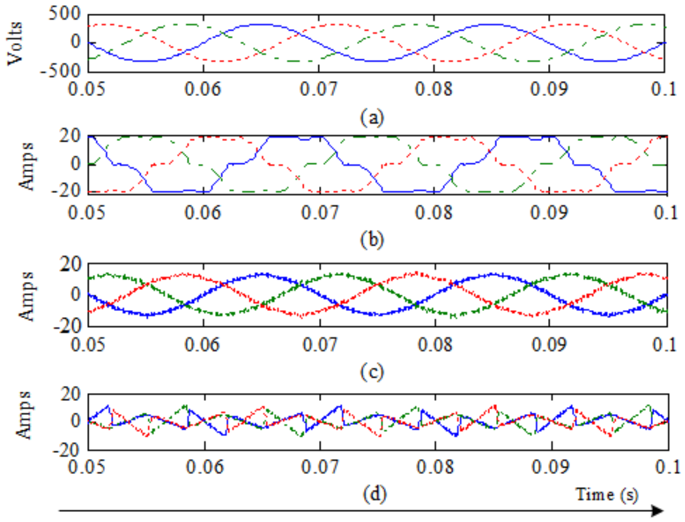

Fig. 2 Steady state performance with *modified* $i_d - i_q$ *and PI controller*(a) ideal source voltage (b) load current before compensation (c) source current after compensation (d) filter current

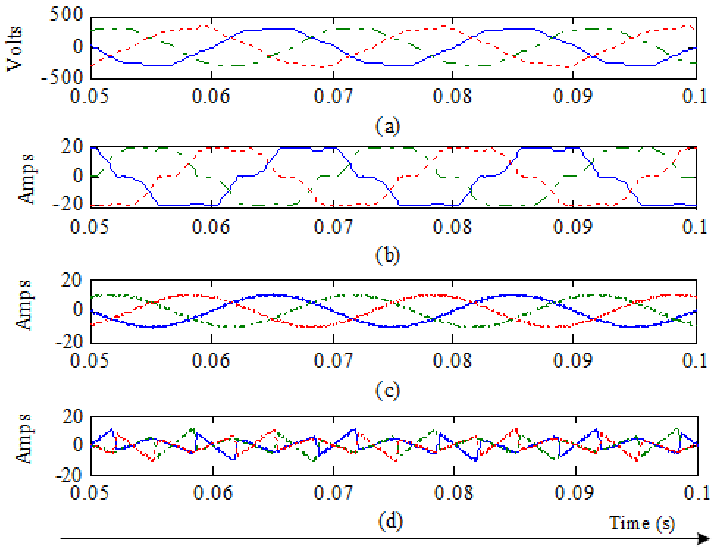

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Fig. 3 Steady state performance with *modified* $i_d - i_q$ *and PI controller*(a) distorted mains voltage (b) load current before compensation (c) source current after compensation (d) filter current

Case-2: Steady state performance of the system with modified $i_d - i_q$*, PI and SMC controller*

Here the performance of the system is observed with non-linear controller named as sliding mode control (SMC). The modified instantaneous $i_d - i_q$ theory and PI controllers are used for reference current generation and dc bus voltage control. For switching pulse generation, the sliding mode controller is implemented. The implementation of SMC control makes the controller robust towards any change in mains voltage or load.From Fig. 4 , it is justified that the performance of the controller is satisfactory for both ideal and as well as distorted voltage source. With the proposed controller the compensator reactive power compensation as well as THD reduction capability reached to satisfactory margin.As the error minimizing capability of the controller increased due to SMC controller the noise in source current after compensation is also reduced. The THD of the source current is reduces to 2.12% for ideal source and distorted mains condition after the compensation.

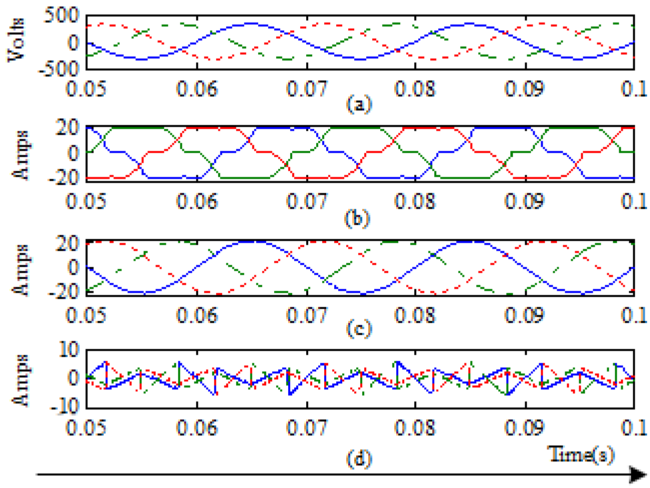

Fig. 4 Steady state performance with *modified* $i_d - i_q$ *PI and SMC controller* (a) ideal mains voltage (b) load current before compensation (c) source current after compensation (d) filter current

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3. Conclusion

In this paper, the modified instantaneous $i_d - i_q$ theory with PI control, SMC based $i_d - i_q$ control and Fuzzy control are surveyed. For current control, linear $i_d - i_q$ as well as nonlinear SMC based control are implemented and the behavior of the compensator was investigated. According to the investigation's findings, SMC control performs better under distorted supply situations than linear control. In a similar manner, fuzzy logic controllers and PI controllers are used to manage the voltage of the DC bus. It was investigated whether a fuzzy controlled inverter could continuously compensate the load's reactive power.

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