International Journal of Pure and Applied Mathematics
Volume 114 No. 9 2017, 389-398
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue

Shunt Active Power Filter connected to MPPT based photo voltaic Array for PQ enhancement

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Abstract

Due to increase of Non linear loads, maintaining Power Quality (PQ) became an important issue to Utility. Shunt Active Power Filters is one of the best Harmonics compensating devices. Day to day the demand of electrical energy is increasing leads to the more power generation. To generate pollution free energy the utilities are triggering on Renewable Energy. Solar Energy is best suitable source of energy to convert in to electrical energy. With the application of MPPT in PV array system helps to produce maximum energy under the variable conditions like environmental temperature and solar radiation. This Paper presents the operation of Shunt active power Filter along with MPPT based solar array system. During Day time the generated electrical power from solar array is connected to load through the SAPF and in night times the distribution system acts as utility to the load. In both cases the non-linear source current is compensated by SAPF and source current becomes harmonics free. Simulation and Hardware results are presented.

Key words: Power Quality, Harmonics, SAPF, PV array, MPPT,

1 Introduction

The Non linear loads like Switched mode power supplies, Electrical motor drives, electronic ballasts and battery chargers draws non linear current from source rather than sinusoidal. These Non linear loads raising power quality related problems. The basic property of Non linear load is to absorb harmonic currents from the source and consumes reactive power. The purpose of Shunt Active power Filter(SAPF) connecting at PCC is to make source current sinusoidal or fundamental by injecting compensating current into the line [1-3]. The Utilities are more concentrating on clean energy generation. A renewable energy source generates pollution free clean energy. Solar power generation is one of the best clean and reliable sources of renewable energy. The sun rays falling on Photo Voltaic (PV) cell excites the electrons in solar cells leads to generation of Electrical Energy [4-5]. The generated DC power temperature varies time to time, the Power output from PV cell also varies time to time [6]. To get the maximum power from PV array under variable conditions Maximum Power Point Tracking (MPPT) algorithms are proposed. Most of the researchers used Perturb and Observe (P&O) algorithm because of its simplicity. In this method the maximum power point is decided by changing current or voltage the photo voltaic array [7-8].

Recently researchers are more concentrating on connection of PV array to distribution system via Shunt Active Power Filter. In this system the power generated in PV array supplies the real reactive power. This paper presents the analysis of combined operation of a PV array and Shunt Active Power Filter system for simultaneous harmonic compensation and real power injection. Perturb and Observe algorithm is used for MPPT in PV array. PI Controller-Based predictive Algorithm is used as control methodology for SAPF. Simulations are performed using MATLAB® Simulink.

2 Shunt Active Power Filter

Fig.1. shows the proposed distribution system. A Diode rectifier with RL load acts as Non linear load which connected to Source through the source impedance Zs. The SAPF is connected in shunt with the system. The PV system is connected across the capacitor of SAPF. The controller is modeled to generate the triggering pulses to switches of voltage source converter (VSI). The VSI is always used to act as an active power filter to compensate the nonlinear load harmonics and reactive power and also as inverter to convert DC power generated in PV array in to AC power to supply the Load.

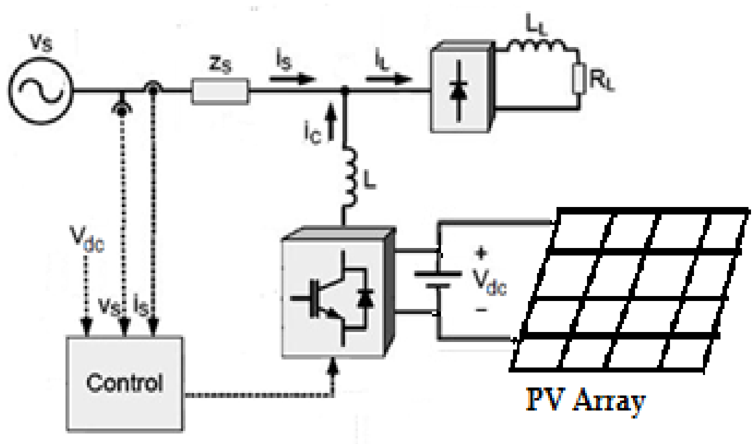


Fig. 1 Circuit diagram of proposed system

The performance parameters are smoothing and decoupling element (L_c), energy storage element dimension (C_{dc}), the methods used to extract compensation reference currents (i_{sa}^*, i_{sb}^*, i_{sc}^*) and control technique used to regulate the compensation currents (i_{ca}, i_{cb}, i_{cc}) and the DC voltage (V_{dc}). The SAPF injects the desired compensation current in to the distribution system at PCC such that Source current is sinusoidal.

The source current and source voltage of the system are represented in Eq. (1) and Eq. (2).

$$v_s(t) = V_m \sin \omega t \qquad (1)$$

$$i_s(t) = i_L(t) - i_c(t) \qquad (2)$$

As the load is Non linear, Load current has fundamental component and harmonic component. Mathematically represented as in Eq. (3)

$$i_L(t) = I_1 \sin(\omega t + \varphi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varphi_n) \qquad (3)$$

Load power can be represented as

$$p_L(t) = v_s(t) * i_L(t) \qquad (4)$$

Substitute Eq. (1) and Eq. (3) in Eq. (4), then

$$+V_m sin\omega t * \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varphi_n) \quad (5)$$

From Eq. (5) it is clear that load current has three components. They are Active Power ($p_f(t)$), Reactive Power ($p_r(t)$) and Harmonic Power($p_h(t)$).

$$p_L(t) = p_f(t) + p_r(t) + p_h(t) \quad (6)$$

The active power drawn by the load is

$$p_f(t) = V_m I_1 sin^2\omega t * \cos\varphi_1 \quad (7)$$

But $p_f(t) = v_s(t) * i_s(t)$

$$i_s(t) = p_f(t)/v_s(t) = I_1 \cos\varphi_1 \, sin\, \omega t = I_{sm} \sin\omega t \quad (8)$$

The compensating current is calculated by using Eq.(9)

$$i_c(t) = i_L(t) - i_s(t) \quad (9)$$

Where $i_s(t)$ is the fundamental component of the load current $i_L(t)$

The source currents, after compensation, can be given as

$$i_{sa}^* = I_{sm} \sin\omega t$$
$$i_{sb}^* = I_{sm} \sin(\omega t - 120)$$
$$i_{sc}^* = I_{sm} \sin(\omega t + 120) \quad (10)$$

Where i_{sm} is the amplitude of the desired source current, while the phase angle is obtained from the source voltages. I_{sm} can be calculated by controlling the dc-side capacitor voltage.

3 MPPT based PV array System

The basic principle behind the conversion of light energy into electrical energy is Photovoltaic effect. As PV cell is a semiconductor device, the electron is emitted due to energy of photon is more than the PV cell band width. This moment in electrons causes current flow. PV cell is a forward biased device. PV modules are arranged in parallel and series combination to get desired energy.

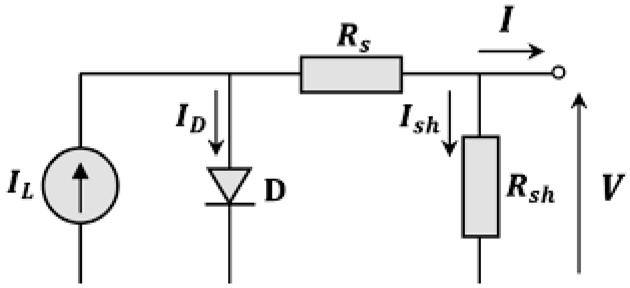
3.1 PV Modeling

Single Diode model based PV cell block diagram is shown in Fig.1. It consists a DC current source (I_L) in anti parallel with a Diode. The value of current source is decided depends on the solar irradiation and atmospheric temperature. To represent internal power loss a Series Resistance (R_s) is connected. To represent leakage current a shunt resistance (R_{sh}) is connected.

The Current produced by solar cell can be obtained by applying Kirchhoff laws in Fig.1.

$$I_{pv} = I_{ph} - I_o\left[exp\left(\frac{(V_{pv}+I_{pv}R_s)}{\propto KT/q}\right)\right] - \left(\frac{V_{pv}+I_{pv}R_s}{R_{sh}}\right) \quad (11)$$

Where, I_{pv} is photo-current generated by the solar irradiation to PN junction cell. I_o is diode saturation current . q is coulomb constant ($1.602x10^{-19}$). K is Boltzmann's constant ($1.381X10^{-23}$ J/K). T is temperature in ^oK. $\propto$ is PN junction ideality factor of diode(in general value 1).



If N_s is series connected PV modules and N_p is parallel connected PV modules then Current produced by solar cell becomes

$$I_{pv} = N_p \left\{ I_{ph} - I_o \left[exp\left(\frac{(V_{pv}+I_{pv}R_s)}{N_s(\propto KT/q)} - 1 \right) \right] - \left(\frac{V_{pv}+I_{pv}R_s}{R_{sh}} \right) \right\} \quad (12)$$

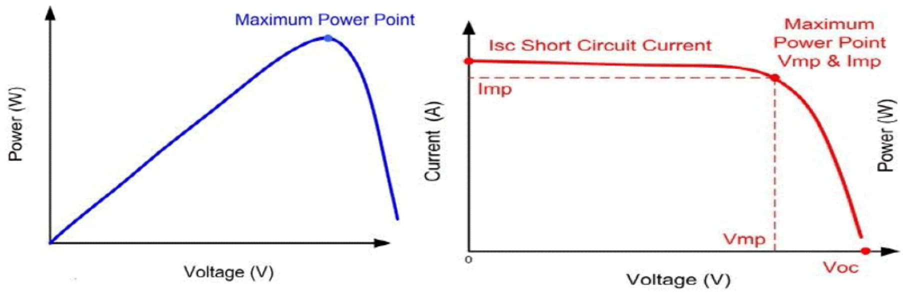


Fig. 3. Characteristics of PV Cell

The I-V curve and power output curve of a solar panel shown in Fig 3. When load is not connected to the PV cell, It produces an open circuit voltage V_{oc} at the terminals. If PV cell is short circuited then short circuit current I_{sc} is produced. In both the open circuit and short circuit cases the power generated by PV cell is zero. When load is connected I-V and P-V curves gives the performance of PV cell. On I-V curve maximum power point is specified at knee of the curve. I-V curve changes with change in load, temperature and radiation and hence maximum point also changes. To get maximum power from solar modules MPPT algorithms are used.

3.2 P&O MPPT Algorithm

The P&O method is simplest method based on the evaluation of PV module power change. In this method the system goes to perturbing and the output power impact is observed. The output voltage and current of PV module is sampled to calculate the output power. In each switching cycle instantaneous voltage is read by the algorithm. When the instantaneous voltage of PV cell is perturbed either the direction, the output power (dP/dV) increases. In this procedure continuous until the operating point reaches the MPP point. The flow chart of P&O method is shown in Fig.4

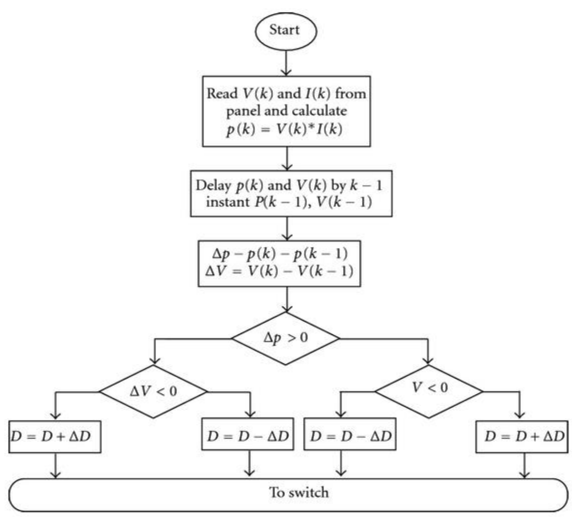


Fig. 4. Flow chart of P&O MPPT Algorithm

this problem can be solved.

4 Result Analysis

The analysis of combined operation of PV array and SAPF has been done in SIMULINK/ MATLAB environment. The system parameters values are; Source voltage are Va=Vb= Vc= =220 V; System frequency f= 50 Hz; Source impedance LS = 0.1µH; Diode rectifier with load of 50Ohm,60mH is considered as Non linear load; Filter impedance Rf =5m , Lf = 150 µH; DC voltage capacitor (Vdc_ref)=800 V ;Cdc=3000 µF .The results are given in the following Figures. Hard ware implementation is given in Fig. .The hard ware results are given in the following Figures.

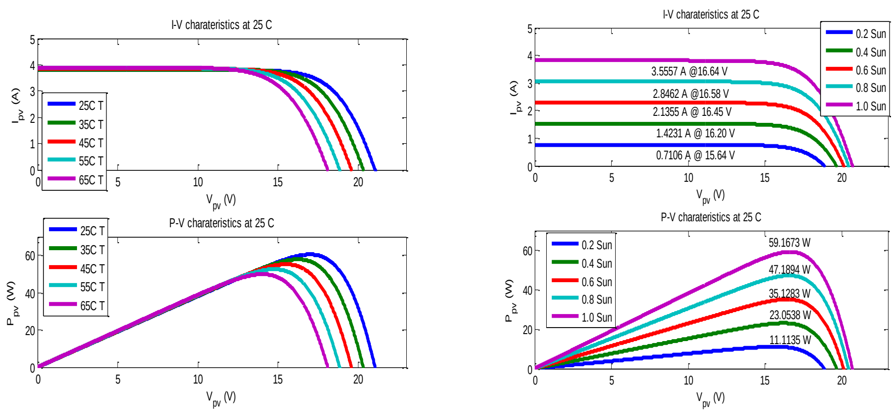


Fig. 5. Characteristics for PV Cell for varying Sun and varying Temperature

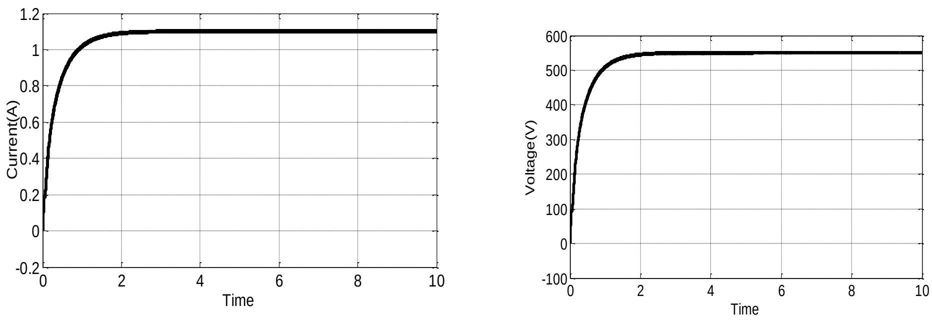


Fig. 6. PV System output Current and output Voltage

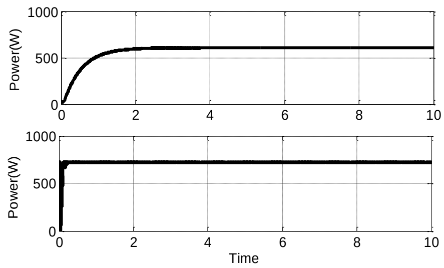


Fig. 7. Output power with and Without MPPT

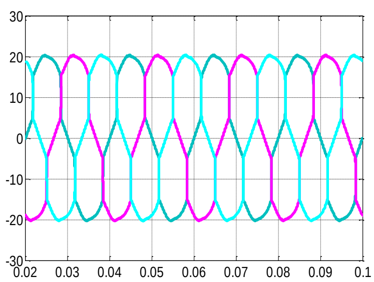


Fig. 8. Load Current

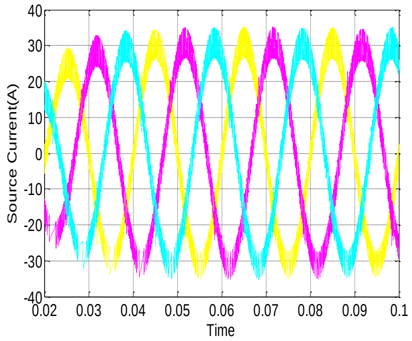


Fig. 9. Source Current

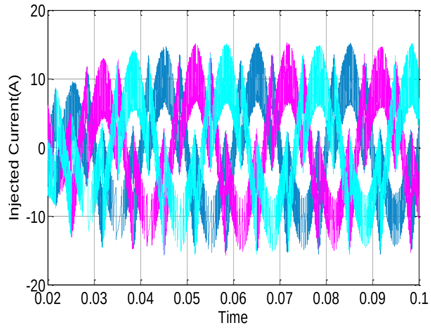


Fig. 10. Current injected by SAPF

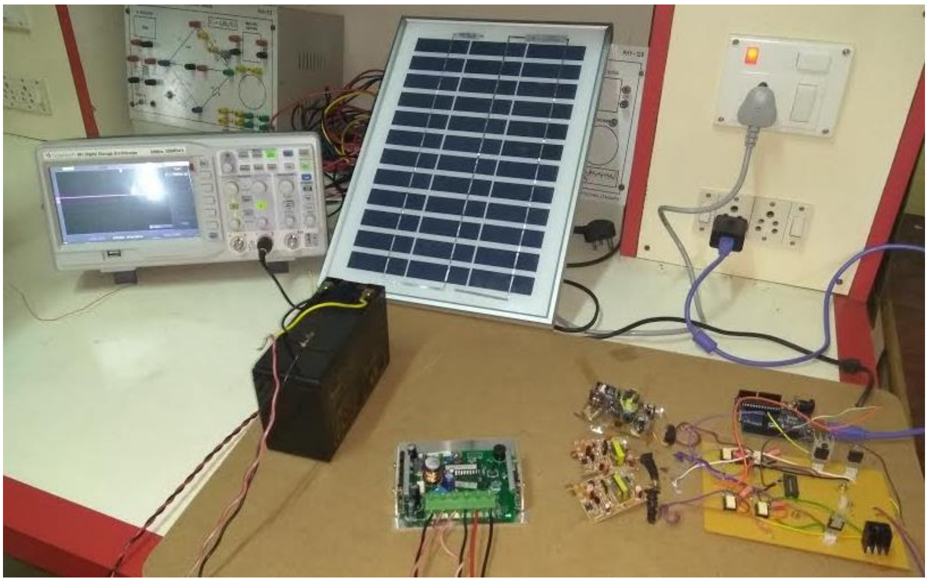


Fig. 11. Hardware implementation of proposed system

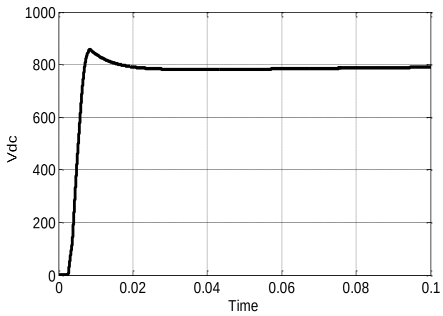


Fig. 12. DC Capacitor voltage

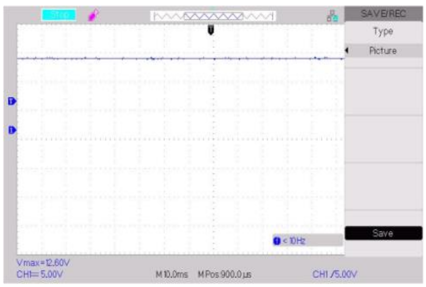
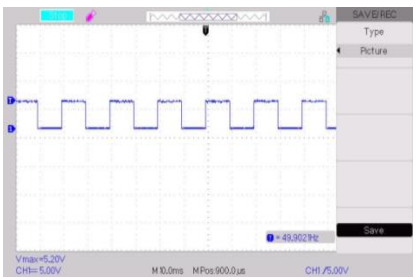


Fig. 13. Solar panel output Voltage



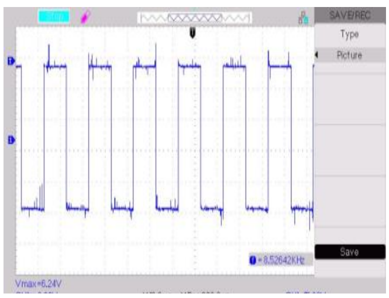


Fig. 14. VSC output Voltage **Fig. 15.** One of the triggering Pulse

The output power of the PV array depends on variation of solar radiation and temperature. Fig.5 shows the characteristics of PV cell for variation of radiation from 0.2 to 1.0Sun and variation in temperature from 25C to 65C. In P-V waveform it can be observed the maximum power point changing with change in radiation and temperature. The Fig. 6 shows the output current and voltage waveforms of PV array. The output power with MPPT and without MPPT is given in Fig.7.

The distorted current drawn by the Load is shown in Fig. 8. Harmonic free source current is given in Fig.9. The injected current from SAPF is given in Fig.10. The SAPF is successfully injected compensating current and made source current harmonic free. Hard ware implementation of proposed system is given in Fig . 11. The DC capacitor voltage is given in fig.12 Solar panel output voltage and VSC output voltage is given in Fig.13 and Fig 14 Respectively. Fig.15 is the triggering pulse to one switch of VSC.

Table.1. Sending end Active and Reactive Power

Parameter	Sending end		Receiving end	
	SAPF with Solar Array	SAPF without Solar Array	SAPF with Solar Array	SAPF without Solar Array
Active Power(W)	4777	4357	1782	1690
Reactive Power(VA)	8.149	-5.564	-6.177	19.16

Table 2. THD comparisan

Parameter	Without SAPF	With SAPF
THD	16.35%	10.02%

The Active and Reactive power of the system given in Table 1. It can be clearly observed that solar array injecting Active power in to the Line. The THD comparison is given in Table 2. The SAPF reducing the THD of source current from 16.35 % to 10.02% .

5 Conclusion

This paper presents an analysis of combined operation of SAPF and Solar Array and that achieves simultaneously reactive power compensation and harmonic compensation. P&O based MPPT algorithm is used in PV array. Simulation results show that the source current is harmonic free. PV array successfully injected the solar power in to grid. Also, the THD is reduced from 16.35% to 10.02% which confirms the good operation of SAPF which improving the power quality.

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