Using PV in Distribution Network to Supply Local Loads and Power Quality Enhancement

Seyed Hossein Hosseini[1], Mitra Sarhangzadeh[1], Mohammad B. B. Sharifian[2], Farzad sedaghati[2]

[1]Islamic Azad University, Tabriz Branch, Tabriz, Iran
hosseini@tabrizu.ac.ir, sarhangzadehm@tabrizu.ac.ir
[2]University of Tabriz, Tabriz, Iran
sharifian@tabrizu.ac.ir, farzad.sedaghati@gmail.com

Abstract

The grid-connected photovoltaic (PV) power generation system is expected to be more widespread in distribution systems due to increasing fossil-fuel cost. This paper presents a control system that combines photovoltaic (PV) grid connected generation and power quality managements with two system configurations. The system can not only realize photovoltaic generation, but also suppress current harmonics and compensate reactive Power.

1. Introduction

Recently, the use of distributed generation systems (DGS) is rapidly increasing due to technology improvements in small generators, power electronics, and energy storage devices. Efficient clean fossil-fuels technologies such as micro-turbines, fuel cells, and environmental-friendly renewable energy technologies such as biomass, solar/photovoltaic arrays, small wind turbines and hydro turbines, are growingly used for new distributed generation systems. Solar/photovoltaic systems to transform sunlight into electricity are also a good renewable technology for DGS because sunlight is an abundant resource around the world and solar electric systems are clean, quiet and easy to use, and first of all no fuel other than sunlight is needed. Furthermore, they are durable, reliable, and easy to maintain because they do not hold any moving parts. Solar cells, also known as photovoltaic (PV) cells, use special materials called semiconductors that produce electricity when exposed to light. Nowadays the solar energy has become one of the most promising renewable energy due to its inexhaustible and environmental advantages. Grid-connected PV generation is one of the major development trends of photovoltaic applications. Meanwhile, with the development of the power electronics industrialization process, a large number of nonlinear loads have appeared. Harmonics and reactive current from nonlinear load induce that the power quality problems become more and more serious. PV grid-connected generation operates during the day and has to stop at night. This affects the stabilization of power system and the utilization of equipment. Therefore, in order to increase the utilization, the PV system can be designed to also provide the function of power quality managements. In this paper we will use PV to supply local loads and also to compensate reactive power and current harmonics. Then This paper combines PV grid-connected generation device and shunt active power filter. The unified system can supply active power as well as current harmonics and reactive power compensation when sunshine is available. At weak irradiation, it has the all function of shunt active [1].

2. Solar Cell Model

Solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor. In the dark, the I-V output characteristic of a solar cell has an exponential characteristic similar to that of a diode. When exposed to light, photons with energy greater than the band gap energy of the semiconductor are absorbed and create an electron-hole pair. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. Thus the simplest equivalent circuit of a solar cell that is shown in Fig.1 is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell. The diode determines the I-V characteristics of the cell [2].

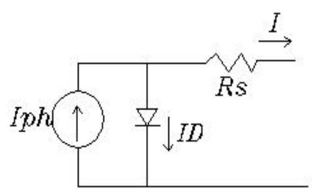

Fig. 1. Circuit model of PV cell

The diode is the most important element of the circuit for the correct working of the PV cell model. Its presence indeed determines the exponential course of the current curve. Right on this curve the working point of the circuit model of the PV cell can be found. The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation:

$$V = \frac{AKT_c}{e}\ln\left(\frac{I_{ph} + I_D - I}{I_D}\right) - RsI \quad (1)$$

Where:
e : electron charge
K : Boltzmann constant
I : cell output current
I_{ph} : photocurrent
I_D : reverse saturation current of diode
R_S : series resistance of cell

T_C : reference cell operating temperature
V : cell output voltage

The variable temperature affects the cell output voltage and cell photocurrent. These effects are represented in the model by the temperature coefficients C_{TV} and C_{TI} for cell output voltage and cell photocurrent as:

$$C_{TV} = 1 + \beta_T (T_c - T_x)$$
$$C_{TI} = 1 + \frac{\gamma_T}{S_c}(T_c - T_x) \quad (2)$$

Where, β_T = 0.004 and γT = 0.06 for the cell used and T_c=25°C is the ambient temperature during the cell testing and the T_X is the temperature of environment. The change in the operating temperature and in the photocurrent due to variation in the solar irradiation level can be expressed via two constants, C_{SV} and C_{SI}, which are the correction factors for changes in cell output voltage V and photocurrent I_{ph}, respectively:

$$C_{SV} = 1 + \beta_T \alpha_S (S_x - S_c)$$
$$C_{SI} = 1 + \frac{1}{S_c}(S_x - S_c) \quad (3)$$

Where, S_C is the reference solar irradiation level during the cell testing to obtain the modified cell model. S_x is the new level of the solar irradiation. The constant αs=0.2 represents the slope of the change in the cell operating temperature due to a change in the solar irradiation level. Using correction factors C_{TV}, C_{TI}, C_{SV} and C_{SI}, the new values of the cell output voltage (V) and photocurrent (I) are obtained for the new temperature T_x and solar irradiation S_x as follows:

$$V = C_{TV} C_{SV} V$$
$$I = C_{SV} C_{TV} I \quad (4)$$

If we have Ns cells in series and N_P cells in parallel for photovoltaic panel then the current and voltage of panel will be as following:

$$V = N_S V$$
$$I = N_P I \quad (5)$$

In this paper we use the temperature and irradiation variety curve with time as shown in Fig. 2 and Fig. 3.

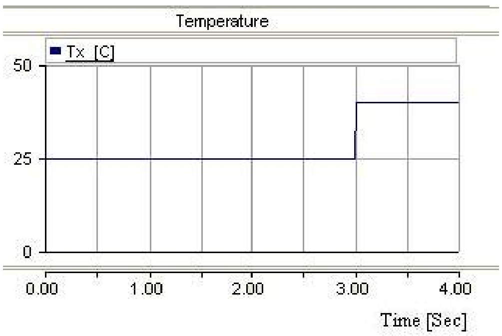

Fig. 2. Temperature variety curve.

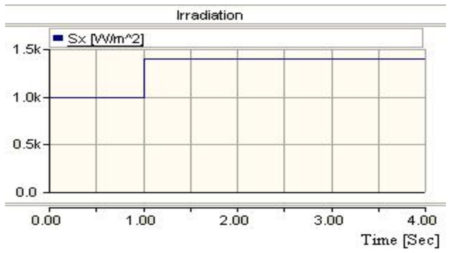

Fig. 3. Irradiation variety curve.

As the power supplied by the solar array depends on the insulation, temperature and array voltage, an important consideration in the design of efficient solar array systems is to track maximum power point (MPP) correctly. The purpose of the MPPT (Maximum Power Point tracking) is to move the array operating voltage close to the MPP under changing atmospheric conditions. Many methods for tracking maximum power point had been proposed. Two algorithms often used to achieve the MPPT are the perturbation and observation (P&O) method and the incremental conductance method. In this paper we use P&O method [2].

3. System Configuration

Since the increase in the occurrence of nonlinear loads in the power system, Active filters have been used extensively. Compensation of the undesired harmonics generated by offending loads and reactive power are the main aim of Active filters. In recent years Active filters have been widely studied and several methods to control them have been proposed. In harmonic filtering the Active filter current reference generation plays an important role: if the reference is poor, a good filtering result cannot be achieved. Active filters are inverters driven to compensate for both fundamental reactive power and harmonic distortion [3-5]. Their operation principle is based on the injection in the network of a compensating current which provides the fundamental reactive component as well as the harmonic currents due to distorting load operation. Thus, a reference waveform for the current to be injected in the ac network should be provided by the control unit, so that the inverter is required to produce a current as close as possible to the reference one. The proposed system consists of non linear load with a rectifier, Active filter that senses load currents to determine the reference compensation currents and also a PV panel to feed local loads (Fig.6 for first configuration). To reduce the low-order harmonic content of the Active filter output, hysteresis current control is applied. If a nonlinear load is applied, then the load current will have a fundamental component and harmonic components, which can be represented as equation 6 for phase a:

$$i_a(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} I_{an} Sin(n\omega t - \varphi_n) = i_{af} + i_{an} =$$
$$I_{a1} Sin(\omega t - \varphi_1) + \sum_{n=3,5,\ldots}^{\infty} I_{an} Sin(n\omega t - \varphi_n) \quad (6)$$

Where ω is the frequency of network, I_{an} is amplitude of load current and Φ_n is phase angle of fundamental load current in nth harmonic. i_{af} is fundamental component and i_{an} is the harmonic components of the load current. The fundamental current can be divided into two currents, the fundamental active current i_{afa} and the fundament reactive current i_{afr}:

$$i_{afa} = I_{a1} Sin(\omega t) Cos\varphi_1 \quad (7)$$

$$i_{afr} = I_{a1} Cos(\omega t) Sin\varphi_1 \quad (8)$$

The objective of Active filter is to cancel the harmonics and to compensate reactive power, therefore the reference current of Active filter is equal the fundamental active current:

$$i_s^* = i_{afa} = i_a - (i_{an} + i_{afr}) \quad (9)$$

Multiplying both sides of i_{af} by sin (ωt) gives:

$$i_a(\omega t) Sin(\omega t) = \frac{I_{a1}}{2} Cos\varphi_1 - \frac{I_{a1}}{2} Cos(2\omega t - \varphi_1) \quad (10)$$
$$\sum_{n=3,5,...}^{\infty} I_{an} Sin(n\omega t - \varphi_n)$$

The expression shows the presence of a dc component and the ac. A low pass filter, of which the cut-off frequency is relatively low to prevent the high frequency component from being in the output, filters out these last ones. The peak value of the reference current has been estimated by regulating the DC side capacitor voltage of the PWM converter. In this paper we use two system configurations with PV panel connected to active filter and block diagram of their controller to feed local loads and improvement of power quality problems will be shown. The load currents and PCC voltage for both of configurations are shown in figures 4, 5.

Fig. 4. Three phase load currents

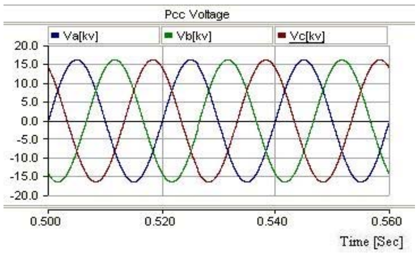

Fig. 5. Voltage of PCC

3.1. First system configuration

As is shown in Fig.6, in this configuration we use a PV panel with 25000 cells in series and 7500 cells in parallel with each other connected directly to a dc/ac converter to feed local loads and also for improvement of power quality problems. Table1, Fig. 7 shows the PV panel outputs, I-V and P-V curves of this panel in different temperatures and irradiations. [3- 5]

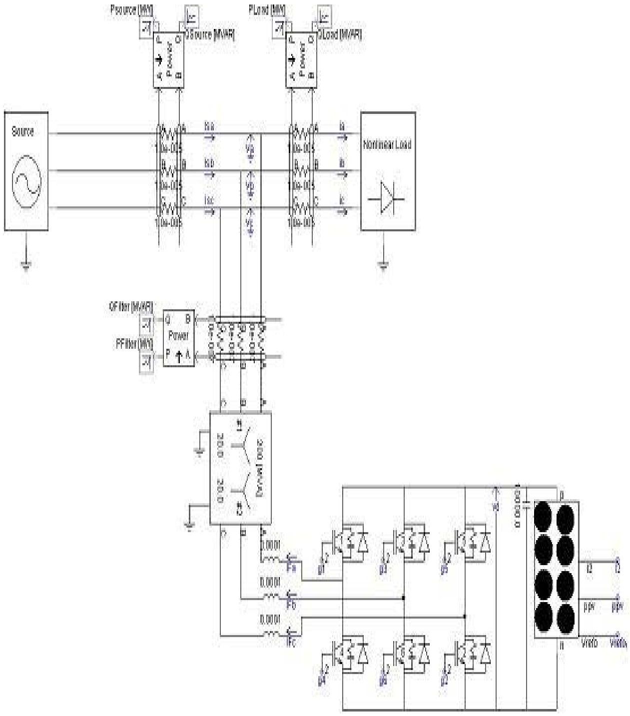

Fig. 6. First system configuration:
Connecting PV panel directly to active filter (dc/ac converter).

Table1. The PV panel outputs in different temprature and irradiation with Ns=25000, Np=7500

T(deg)	G (kw/m^2)	Isc [kA]	Voc [kV]	Vpmax [kV]	Ipmax [kA]	Pmax [MW]
25	1000	7.5	34.75	26.72	6.54	174.93
25	1400	10.5	35.86	27.57	9.16	252.74
40	1400	10.5	33.71	25.92	9.17	237.79

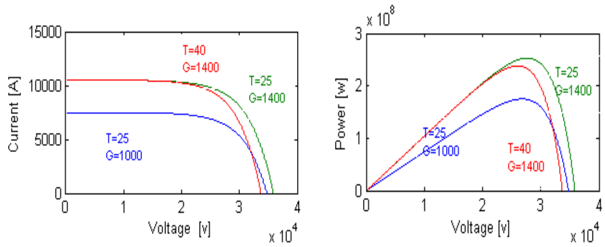

Fig. 7. I-V and P-V curve of a photovoltaic panel for different temprature and irradiation.

Block diagram of this configuration presented in Fig.8, shows that the PV current at maximum power is injected to the controller (ii) and voltage of DC bus is controlled with PI controller to reach the voltage at maximum power point (V_{refo}).

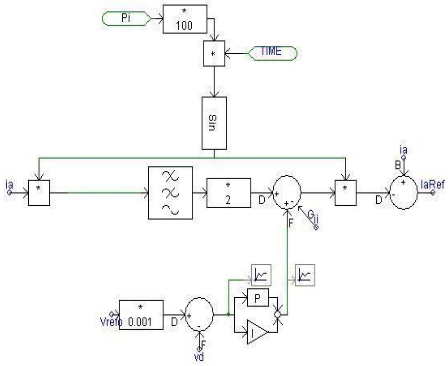

Fig. 8. Block diagram of control circuit for first configuration.

Fig.9 shows that with this controller, voltage of DC bus will be equal to voltage of PV panel and reference voltage.

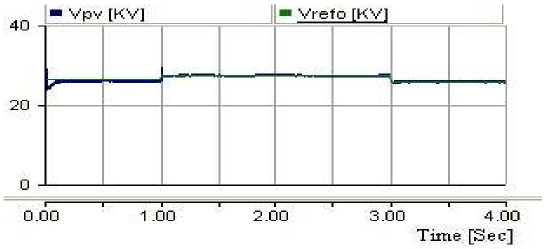

Fig. 9. Photovoltaic panel and reference voltages

Fig.10 presents currents of Load (I_a) and source (I_{sa}) and the injected current of Active filter (I_{Fa}) and reference current of active filter (I_a-Ref) for phase A. The source current is sinusoidal with active filter and also load reactive power have been compensated (Fig.11) and only active power have been flowed at source side. Fig.12 shows that load active power is equal to sum of source power and PV power injected to network.

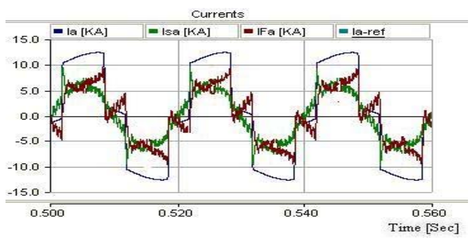

Fig. 10. The current of Load and source and Active filter for phase A.

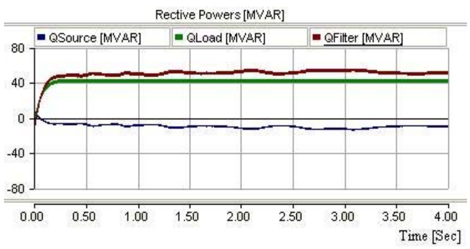

Fig. 11. Reactive power of load (QLoad) and source (QSoursce), Active filter (QFilter) sides.

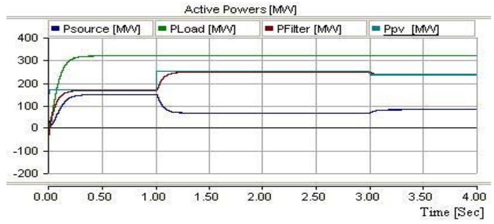

Fig. 12. Active power of load (QLoad) and source (QSoursce) and Active filter (QFilter), PV (Ppv) sides.

3.2. Second system configuration

As is shown in Fig.13, in this configuration we use a PV panel with 37000 cells in series and 5100 cells in parallel with each other connected to a dc/ac converter with a boost dc/dc converter to feed local loads and also for improvement of power quality problems. Table2, Fig. 14 shows the PV panel outputs, I-V and P-V curves of this panel in different temperatures and irradiations [3- 5] .

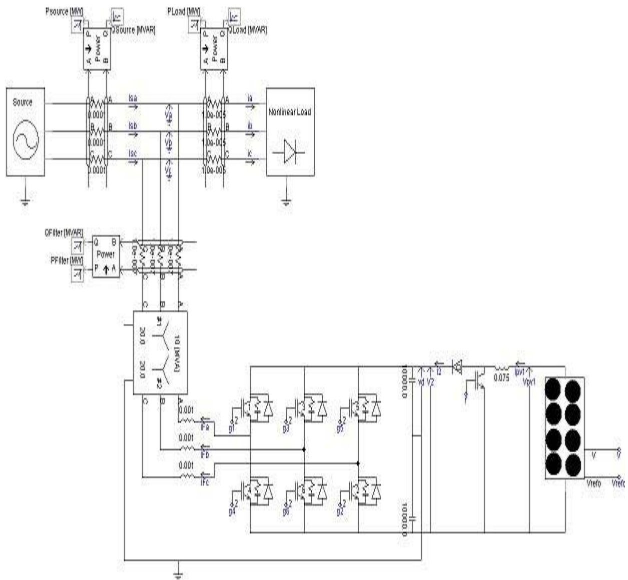

Fig. 13. System configuration second:
Connecting PV panel to active filter (dc/ac converter) with a boost dc/dc converter

Table 2. The PV panel outputs in different temprature and irradiation with Ns=37000, Np=5100

T(deg)	G (kw/m^2)	Isc [kA]	Voc [kV]	Vpmax [kV]	Ipmax [kA]	Pmax [MW]
25	1000	5.1	51.43	39.72	4.4	173.7
25	1400	7.14	53.07	40.53	6.19	250.97
40	1400	7.146	49.89	38.10	6.19	236.12

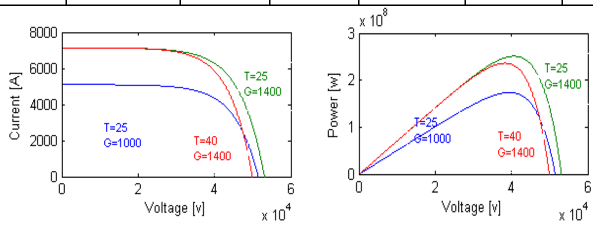

Fig. 14. I-V and P-V curve of a photovoltaic panel for different temprature and irradiation.

Block diagram of this configuration that is presented in Fig.15 shows that the PV current at maximum power is injected to the controller (ii) and voltage of DC bus is controlled with PI controller and also boost dc/dc converter to reach 27 kv. The boost dc/dc converter is used to set output voltage of PV panel to maximum power point.

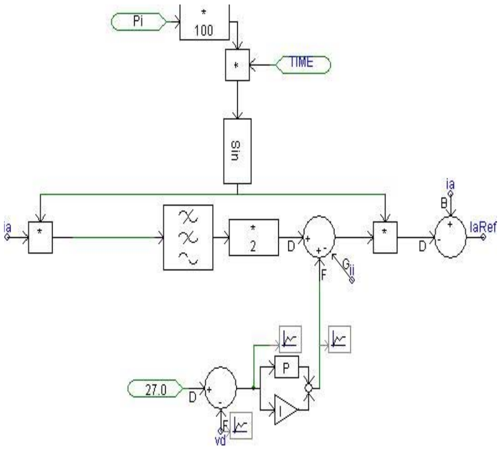

Fig. 15. Block diagram of control circuit for second configuration.

Fig.16 shows that with this controller, output voltage of PV panel will be equal to reference voltage.

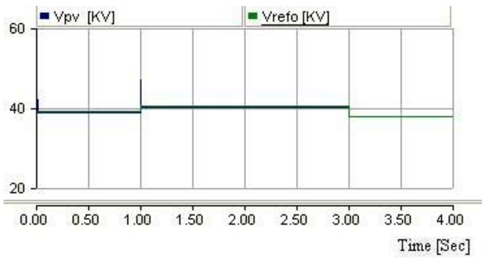

Fig. 16. Photovoltaic panel and reference voltages

Fig.17 presents currents of Load (I_a) and source (I_{sa}) and the injected current of Active filter (I_{Fa}) and reference current of active filter (I_a-Ref) for phase A. The source current is sinusoidal with Active filter and also load reactive power have been compensated (Fig.18) and only active power have been flowed at source side. Fig.19 shows that Load active power is equal to sum of source power and PV power injected to network.

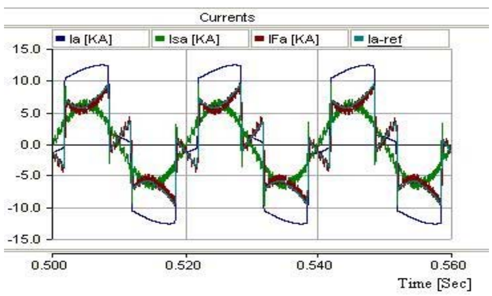

Fig. 17. The current of Load and source and Active filter for phase A.

Fig. 18. Reactive power of load (QLoad), source (QSoursce) and Active filter (QFilter) sides.

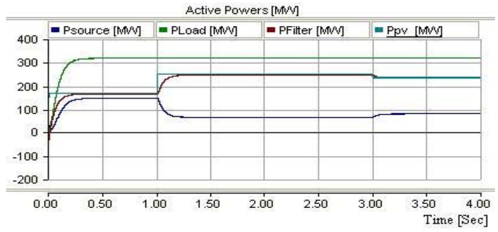

Fig. 19. Active power of load (QLoad), source (QSoursce), Active filter (QFilter) and PV (Ppv) sides.

4. Conclusion

In this paper, we use a PV panel that is connected to an active filter to transfer the PV power to the ac local loads and improve power quality problems like current harmonics cancelation and reactive power compensation. We use two configurations to connect PV panel to the network. In first configuration the output voltage of PV panel is equal with DC bus voltage in maximum power point of it, and then the PV panel is connected directly to active filter. In second configuration due to low voltage of PV panel, it is connected to active filter with a boost DC/DC converter. Simulation results with PSCAD/EMTDC software show that the PV system can be used to provide the function of power quality managements and also to transfer its power to the ac local loads.

5. References

[1] Oystein Ulleberg, "Stand-Alone power systems for the future: design, operation & control of solar-hydrogen energy systems", PHD dissertation, Department of Thermalnergy and Hydropower Norwegian university of Science and Technology, Trondheim, December 1998.

[2] M. Buresch, Photovoltaic Energy Systems Design and Installation, McGraw-Hill, New York, 1983.

[3] Rong-Jong Wai, Wen-Hung Wang, "Grid-connected photovoltaic generation system", *Circuits and Systems I: Regular Papers, IEEE Transactions on Publication*, Volume: 55, Issue: 3, On page(s): 953-964, April 2008.

[4] Tey,L.H; So,P.L; Chu,Y.C, "Improvement of power quality using adaptive shunt active filter", *Power Delivery, IEEE Transactions on* Volume 20, Issue 2, Part 2, April 2005 Page(s):1558 – 1568.

[5] Zue, A.O, Chandra, A, "Grid Connected Photovoltaic Interface with VAR Compensation and Active Filtering Functions", *Power Electronics, Drives and Energy Systems, 2006. PEDES '06. International Conference on Publication* Date: 12-15 Dec. 2006 On page(s): 1-6.