

# POWER QUALITY IMPROVEMENT OF PV POWER GENERATION SYSTEMS USING HYBRID FILTER

Farhad Shahnia

*farhadshahnia@yahoo.com*

*Electrical and Computer Engineering Faculty, University of Tabriz, Tabriz, Iran*

Seyed Hossein Hosseini

*hosseini@tabrizu.ac.ir*

*Key words: PV, distributed generation, power quality, hybrid filter, harmonics*

## ABSTRACT

A hybrid filter constructed of a shunt active filter and distributed passive filters used for power quality improvement in PV power generating systems is presented. The distribution system consists of a photovoltaic power generation system and several dynamic nonlinear loads. The power quality problems of dispersed generation low voltage systems are introduced and the necessity of using hybrid filters instead of active or passive filters alone for power quality improvement are discussed. The simulation is done with PSCAD/EMTDC software for a distribution system with four dynamic nonlinear loads and a PV system that the DC output voltage of the PV is inverted to AC through an inverter which is hysteresis band controlled, making the system to behave as an active filter. The distribution system is simulated without any filters, with usage of just passive filters or the PV connected active filter and the hybrid filter structure, introduced in the paper. Studying and comparing the waveforms, frequency spectrums, harmonic contents and THD of system current with different filter structures mentioned, proves the effectiveness of power quality improvement by the applied hybrid filter.

## I. INTRODUCTION

In two last decades, there has been a considerable interest in installation of dispersed generation systems such as wind turbines or photovoltaic cells in medium or low voltage distribution systems. Recent advances in technology including higher efficiency power production and the possibility of effectively exploiting renewable and cogeneration are the principle factors which motivate the use of small distributed generation units in the power distribution systems. Because of installation of wind turbines and PV's, low power quality issues such as harmonics, voltage flicker and fluctuation is imposed to the distribution system [1-3]. The circumstance becomes more serious because of harmonics and high THD of the current waveform of nonlinear and dynamic loads in the distribution system. Therefore, it is necessary to use effective power quality improvement facilities for improving the power quality of the distribution system and reducing the current. Usage of passive or active filters can be a successful procedure in limitation or removal of

harmonics and improving THD of the system current. But because of dynamic loads, using passive filters alone cannot compensate the harmonics greatly also it might cause resonances in the system so they cannot be effective regardless of their low costs. Using active filters alone with the ability for removing system current harmonics of dynamic loads can increase the costs of the project for high rating of active filters. Therefore, usage of hybrid filters would be the best solution for power quality improvement because the problems of using passive or active filters alone will not be any problem in such a structure, also the advantages of both of these filters can be gained together [4-6].

In this paper, power quality problems of dispersed generation low voltage systems are introduced and the necessity of using hybrid filters instead of active or passive filters alone are discussed. A hybrid filter constructed of distributed passive filters and a PV connected shunt active filter used for power quality improvement in PV based dispersed generation systems is presented and the parameters of the passive filters and the control system of the active filter are discussed. A distribution system with dynamic nonlinear loads and PV system as dispersed generation unit is simulated with PSCAD/EMTDC software [7]. The simulation is done for the distribution system without any filters, with usage of just PV connected shunt active filter or passive filters and the hybrid filter structure introduced in the paper. Studying and comparing the waveforms of the system current in time and frequency domains, harmonic contents and THD with different filter structures mentioned, proves the effective power quality improvement of the distribution system by the applied hybrid filter [8-12].

## II. POWER QUALITY PROBLEMS OF PV BASED DISTRIBUTION SYSTEM

Technical studies of dispersed generation systems prove low power quality issues of these systems such as voltage fluctuation and flicker or high harmonic contents of the system current.

In the case of installation of DG units to distribution systems, voltage fluctuation is remarkable especially at

the connection points resulting of DG units' switchings or sudden fluctuations in their output power. Therefore, load flow analysis of these systems should consider the voltage fluctuations not to exceed the standards for preventing power instruments and costumers from damage. According to the standards of the distribution systems, voltage fluctuation of LV systems should be less than 10%.

Another problem of dispersed distribution systems is an increase in the fault level of the distribution system. This is caused when a short circuit fault is occurred in the system because DG units still feed the fault although the power system feeders are disconnected.

The most important power quality problem of dispersed generation systems is the existence of high contents of harmonics and interharmonics in the system current waveform. For limiting the harmonics level of the system less than the standards, it is required to limit maximum output power of DG units in the system or use effective power quality improvement or harmonic removal facilities in the power system to be able to gain more power form DG unites. In this paper, an effective solution for this problem is proposed and presented.

### III. FILTER STRUCTURE

#### PASSIVE FILTERS

Passive filters as classic methods for power quality improvement of distribution systems consist of series LC tuned for removing a specific harmonic or blocking a bandwich of severe harmonics of nonlinear loads current. These filters have low impedances for the tuned frequencies such as 5<sup>th</sup> and 7<sup>th</sup> and for these frequencies, the lower impedance of the filter in comparison with system impedance, the better filtering characteristics of passive filter. Low cost is a great benefit of these filters but because of their LC constant parameters, they cannot be efficient power quality improvement facilities for dynamic nonlinear loads. Another problem of installation of passive filters is probable resonances between the impedance of passive filter and the system resulting in increasing the harmonics and lower power quality of the distribution system.

#### ACTIVE FILTERS

Active filters as modern applications of power electronics inverters are used to fulfill the necessity of compensating the harmonics of power systems for dynamic conditions such as switching on and off loads and PV units. Shunt active filters are used at the main bus of distribution systems for reducing the amount of current harmonics of the system being inserted to HV network. These filters are controlled as current sources for producing non sinusoidal currents according to non sinusoidal current of loads or system for removing the harmonics and making the current of the distribution system sinusoidal. High ratings of theses filters lead to an increase in the costs.

### HYBRID FILTERS

Hybrid filters constructed of active and passive filters with different structures are used for removing the disadvantages of passive filters such as probability of resonances and non dynamic responses and also high costs of active filters, while using both the advantages of both of them with lower costs. Different structures of hybrid filters can be utilized in power systems such as shunt passive filter and series active power filter with nonlinear loads, shunt active and passive filter with nonlinear load, series active and passive filter parallel with nonlinear load, etc. shown in Fig. 1.

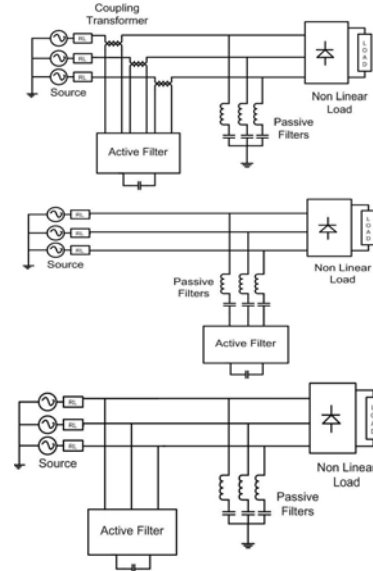


Fig. 1: Different structures of hybrid filters in power systems.

### IV. STUDY CASE AND SIMULATION RESULTS

Fig. 2 shows a 0.4 kV, 60 Hz power distribution system with a PV connected to the main bus through an inverter behaving as a shunt active filter and four dynamic nonlinear loads with distributed passive filters connected to their main buses, simulated with PSCAD/EMTDC.

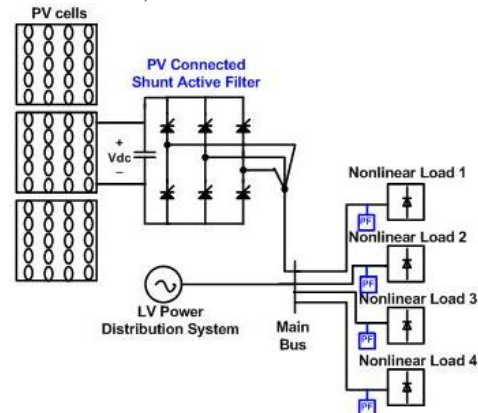


Fig. 2. Simulated power distribution system with PV units and hybrid filter structure.

The parameters of the PV cell model in PSCAD/EMTDC library used for the simulation case are shown in Table 1.

Table 1. Parameters of PV cells

Number of modules connected in series	20
Number of module string in parallel	20
Number of cells connected in series	36
Number of cell strings in parallel	2
Reference radiation	1000
Reference cell temperature	25
Effective cell area	0.01 m <sup>2</sup>
Series resistance	0.01 ohm
Shunt resistance	1000 ohm
Diode ideality factor	1.5
Band gap energy	1.103 eV
Saturation current at reference temperature	1E-9 A
Spectral average responsibility	0.005 A/W
Temperature coefficient of photo current	0.0017

Consuming the PV system with the parameters in Table 1 and for a reference radiation of 1000 and ambient temperature of 35<sup>0</sup> centigrade degrees, the output voltage of the PV system is approximately 0.5 kV DC. A DC-AC inverter and an appropriately selected transformer are needed to transform the DC output voltage of the PV system to 0.4 kV AC of the distribution system while producing the sufficient insulation for the PV system. The most important fact in using PV systems for power distribution networks is that the PV cells can only generate power in a specific period of the 24 hours a day, as shown in Fig. 3. So, the active power filter for power quality improvement of the distribution system can be utilized in this period only. This facts does not affect the basis of the proposed method because we can assume, at night times, lower power is needed which can be obtained from the distribution system but at day times, with the increase in the power consumption, the PV can generate the required power besides improving the power quality of the distribution system by acting as a shunt active filter.

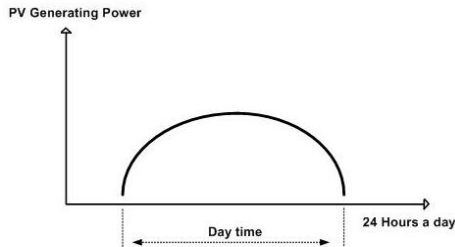


Fig. 3. PV cell operating time in 24 hour period.

The nonlinear loads structure in the distribution system is constructed of thyristor controlled RL loads in series with low RL loads as shown in Fig. 4. The parameters of the nonlinear loads including the magnitude of resistances and reactances, thyristors firing degree, THD% and 5<sup>th</sup> and 7<sup>th</sup> harmonic levels of nonlinear load bus are shown in

Tables 3 and 4 respectively. Their steady state waveforms in time domain are also shown in Fig. 5.

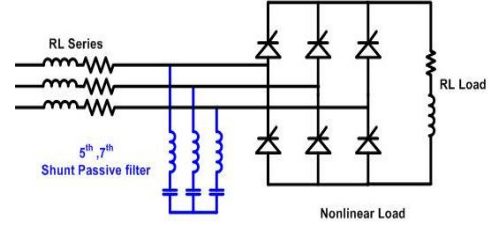


Fig. 4. Structure of Nonlinear Loads

Table 3. Parameters of nonlinear loads

Load No.	R <sub>Load</sub> Ω	L <sub>Load</sub> mH	Thyr. deg	R <sub>series</sub> Ω	L <sub>series</sub> mH
1	3	150	85	0.265	0.635
2	1	300	75	0.525	1.3
3	0.8	700	65	0.35	2
4	5	400	55	0.3	10

Table 4. THD and harmonic contents of system current at the buses of nonlinear loads

Load No.	THD%	h <sub>5</sub>	h <sub>7</sub>	h <sub>11</sub>	h <sub>13</sub>
1	24.45	0.192	0.126	0.072	0.050
2	20.58	0.169	0.105	0.043	0.027
3	24.76	0.187	0.127	0.076	0.062
4	10.43	0.094	0.038	0.013	0.018

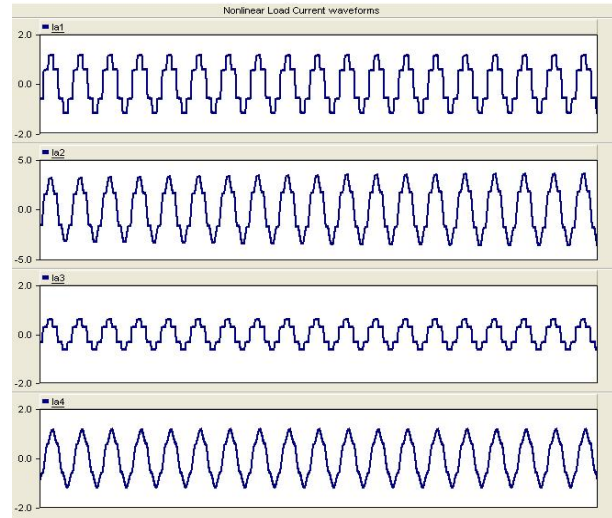


Fig. 5. Steady state waveforms of nonlinear loads in time domain.

For reducing the harmonic contents of the distribution system because of nonlinear loads, several passive filters are designed and used in the buses of nonlinear loads for removing or restricting the most severe harmonics such as 5<sup>th</sup> or 7<sup>th</sup>. The parameters of the selected passive filters for the buses of nonlinear loads are shown in Table 5.

Table 5. Parameters of the Designed Passive Filters

Passive Filter	L (mH)	C (uf)
5 <sup>th</sup>	28	10
7 <sup>th</sup>	14.4	100

The PV system is connected to the main bus of the low voltage distribution system through an inverter which is hysteresis band controlled, acting as a shunt active filter for the distribution system at the PV power generating periods of the day. The active filter is used for harmonic reduction and reactive power compensation. The control system is a  $pq$  theory based system. Equations 1 and 2 show the  $\alpha\beta$  components of the voltage and current of the system.

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 120^\circ) & \cos(\theta - 240^\circ) \\ \sin\theta & \sin(\theta - 120^\circ) & \sin(\theta - 240^\circ) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 120^\circ) & \cos(\theta - 240^\circ) \\ \sin\theta & \sin(\theta - 120^\circ) & \sin(\theta - 240^\circ) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2)$$

Then, the instantaneous active and reactive power can be executed from Equations 3 and 4 after being passed through a high pass filter.

$$P_{inst.} = V_\alpha \cdot I_\alpha + V_\beta \cdot I_\beta \quad (3)$$

$$Q_{inst.} = V_\alpha \cdot I_\beta - V_\beta \cdot I_\alpha \quad (4)$$

The reference currents in  $\alpha\beta$  mode are also calculated from Equations 5 and 6, which are transformed to  $abc$  mode through Eq. 7.

$$I_{Re f-\alpha} = \frac{V_\alpha \cdot P_{inst.} - V_\beta \cdot Q_{inst.}}{V_\alpha^2 + V_\beta^2} \quad (5)$$

$$I_{Re f-\beta} = \frac{V_\alpha \cdot Q_{inst.} + V_\beta \cdot P_{inst.}}{V_\alpha^2 + V_\beta^2} \quad (6)$$

$$\begin{bmatrix} I_{Re f-a} \\ I_{Re f-b} \\ I_{Re f-c} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 120^\circ) & \sin(\theta - 120^\circ) & 1 \\ \cos(\theta - 240^\circ) & \sin(\theta - 240^\circ) & 1 \end{bmatrix} \begin{bmatrix} I_{Re f-\alpha} \\ I_{Re f-\beta} \\ I_{Re f-0} \end{bmatrix} \quad (7)$$

The difference between  $abc$  reference currents and the current flowing through the active filter to the power system is the error input for the switchings of the inverter. The block diagram of the control system for controlling the PV connected active filter is shown in Fig. 6.

The waveforms of the distribution system current at the main bus without any filters, with usage of passive filter at nonlinear load 1, nonlinear load 2 and both of them, with usage of just shunt active filter and the hybrid filter structure introduced in the paper in the system structure in

time and frequency domains are shown respectively in Figures 7a and 7b. %THD, 5<sup>th</sup> and 7<sup>th</sup> harmonic contents of the system current are also measured as shown in Table 6.

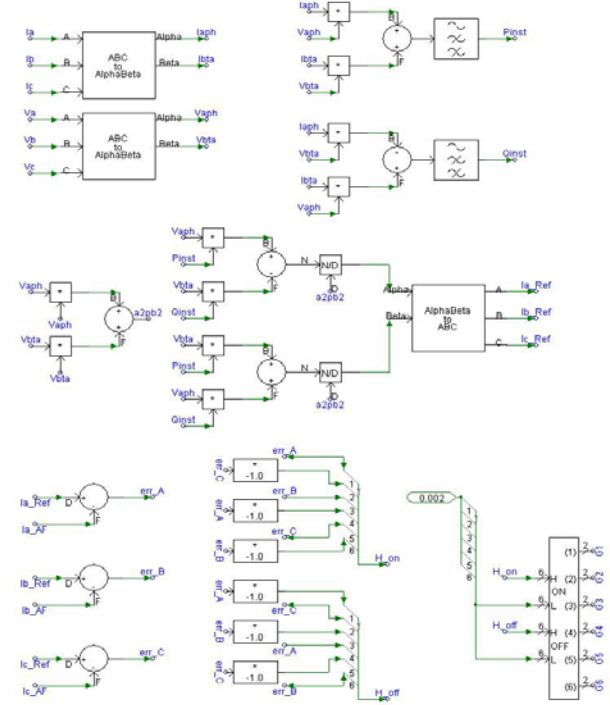


Fig. 6. Control block diagram of shunt active filter.

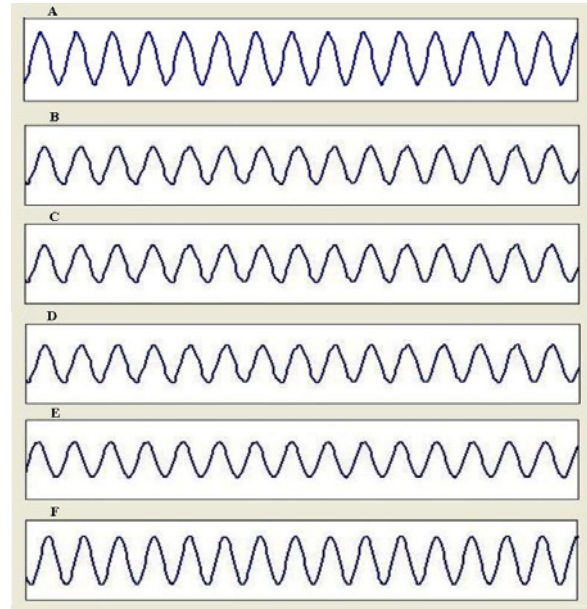


Fig. 7a. System current waveforms in time domain for the system A) without any filters, B) just passive filter at load 1, C) just passive filter at load 2, D) just passive filters at loads 1&2, E) just PV-shunt active filter, F) the hybrid filter structure introduced in the paper.

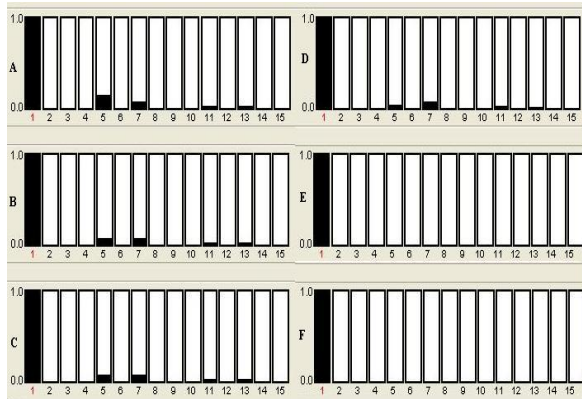


Fig. 7b. System current waveforms in frequency domain for the system A) without any filters, B) just passive filter at load 1, C) just passive filter at load 2, D) just passive filters at loads 1&2, E) just PV-shunt active filter, F) the hybrid filter structure introduced in the paper.

Table 6. THD and harmonic contents of the system main bus current

	THD%	$h_5$	$h_7$
Without any filters	15.86	0.1389	0.0725
With 5 <sup>th</sup> and 7 <sup>th</sup> Passive Filters at Load 1	10.76	0.0764	0.0710
With 5 <sup>th</sup> and 7 <sup>th</sup> Passive Filters at Load 2	10.19	0.0715	0.0691
With 5 <sup>th</sup> and 7 <sup>th</sup> Passive Filters at Loads 1 & 2	8.07	0.0337	0.0686
With PV-Shunt Active Filter at Main Bus	0.07	0.0005	0.0004
With Hybrid Power Filter structure (AF+PF 1&2)	0.04	0.0003	0.0001

## V. CONCLUSION

In this paper, a hybrid filter was used for power quality improvement of the low voltage power distribution system. The hybrid filter is constructed of a PV connected shunt active filter at the main bus and distributed passive filters at the buses of nonlinear loads. High harmonic contents of the distribution system because of nonlinear loads and PV units were removed and restricted by the use of the active and passive filters. Studying and comparing the waveforms, frequency spectrums, harmonic contents and THD of the system current without any filters, with PV connected shunt active filter, with passive filters and with the hybrid filter structure introduced in the paper, proves the effectiveness of the proposed structure.

## REFERENCES

- J. Dolezal, P. Santarius, J. Tlustý, V. Valouch, F. Vybiralik, "The effect of dispersed generation on power quality in distribution system", *CIGRE/IEEE PES Int. Symposium on Quality and Security of Electric Power Delivery Systems*, pp. 204-207, October 2003.
- T. Tran-Quoc, C. Andrieu, N. Hadjsaid, "Technical impacts of small distributed generation units on LV networks", *IEEE Power Engineering Society General Meeting*, Vol. 4, July 2003.
- A. Agustoni, M. Brenna, R. Faranda, E. Tironi, C. Pincella, G. Simioli, "Constraints for the interconnection of distributed generation in radial distribution systems", *IEEE 10<sup>th</sup> Int. Conf. on Harmonics and Quality of Power*, Vol. 1, pp. 310-315, October 2002.
- H. Akagi, S. Srianthumrong, Y. Tamai, "Comparisons in circuit configuration and filtering performance between hybrid and pure shunt active filters", *IEEE 38<sup>th</sup> Conf. on Industry Applications*, Vol. 2, pp.1195-1202, Oct. 2003
- D. Rivas, L. Moran, J. Dixon, J.R. Espinoza, "Improving passive filter compensation performance with active techniques", *IEEE Trans. on Industrial Electronics*, Vol. 50, No. 1, pp. 161-170, Feb. 2003.
- L. Chen, A.V. Jouanne, "A comparison and assessment of hybrid filter topologies and control algorithms", *IEEE 32<sup>nd</sup> Conf. on Power Electronics Specialists*, Vol. 2, pp.565-570, June 2001
- Manitoba HVDC Research Center, PSCAD/EMTDC Power System Simulation Software User's Manual, Version 4, 2003.
- Z. Chen, F. Blaabjerg, J. K. Pedersen, "A hybrid compensation system with an active filter and distributed passive filters in power systems with dispersed generation", *IEEE 34<sup>th</sup> Annual Power Electronics Specialist Conf.*, Vol. 2, pp. 767-772, June 2003.
- A.M. El-Tamaly, P.N. Enjeti, H.H. El-Tamaly, "An improved approach to reduce harmonics in the utility interface of wind, photovoltaic and fuel cell power systems", *IEEE 15<sup>th</sup> Annual Conf. on Applied Power Electronics*, Vol. 2, pp. 1059-1065, February 2000.
- A.E.E. Tarmaly, P.N. Enjeti, H.H.E. Tarmaly, "An improved approach to reduce harmonics in the utility interface of wind, photovoltaic and fuel cell power systems", *IEEE 15<sup>th</sup> Annual Conf. on Applied Power Electronics*, Vol. 2, pp. 1059-1065, February 2000.
- N.G. Suan, J.K. Lee, B.T. Kim, M. Park, I.K. Yu, "Novel concept of a PV power generation system adding the function of shunt active filter", *IEEE/PES Transmission and Distribution Asia Pacific Conf.*, Vol. 3, pp. 1658-1663, October 2002.
- B. Delfino, F. Fornari, "Modeling and control of an integrated fuel cell-wind turbine system", *Proc. of IEEE Power Tech Conf.*, Vol. 2, June 2003.