ENHANCEMENT OF DISTRIBUTION NETWORKS PERFORMANCE USING POWER FILTER/COMPENSATOR

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ABSTRACT

This paper suggests a power filter/compensator (PFC) device to enhance the performance of distribution networks in low voltage or medium voltage levels. The operation of this device is based on the intermittent switching between passive filter and capacitive compensator. PFC is a combination of two series capacitors and shunt capacitor in series with double tuned filter arm or in series with high-pass filter. The control of this intermittent switching is achieved by two complementary pulse signals that are generated by a pulse-width modulation circuit. The modulating signal of pulse-width modulation is generated by a proportional–integral–derivative (PID) controller that is driven by an error signal generated from a dual loop traditional controller. A radial distribution network comprises hybrid loads, linear, nonlinear and motorized loads, is simulated using Matlab/Simulink to assess its performance with and without PFC. Results illustrate that PFC device has the superiority in enhancing the power factor, stabilizing voltage profile at the system buses, reducing the system losses and eliminating voltage and current distortions that are generated from the nonlinear load.

INTRODUCTION

In the past, the big problem in the power system was the loss of electricity source that is called loss of reliability but nowadays the big problem has become the bad of electricity source quality that is called bad power quality (PQ). Generally, any deviations reveal in voltage and current waveforms, their frequency and their phase shift represent the bad PQ [1]. Where both the voltage and current should be in sinusoidal shape with specified magnitude at a constant frequency without any change in phase. The power quality disturbances are categorized into voltage transient, short duration variations (sag and swell), long duration variations (under and over voltage), interruptions, waveform distortions, voltage fluctuations and frequency variations [2].

The main cause of low PQ is the increase use of non-linear loads, such as electronic circuits, electric furnaces that are used to melt metals and power electronic drives that are used to control electric machines. All these devices cause harmonic distortion generation and consequently low power factor [3]. The harmonic distortions in the current cause the overheating, overcharging and functionality defect (even damage) of the supply network components (transformers, cables, etc.) and loads connected to that system as well [4].

Many devices are designed to eliminate or at least mitigate the power quality problems such as passive and active filters and D-FACTS devices [5].

There are many configuration of passive filters based on the number of passive components, band width of filtering frequency, and power losses. The passive filters have many advantages such as simplicity, low cost, compensation of reactive power. But on the other hand they have some dis-advantages such as fixed filtration, resonance with system reactance bulk construction [6- 7]. Passive filters are widely applied in industry because of their advantages.

Choosing the passive filter configuration or topology depends on the passive parameters of load and grid and on the generated harmonics. Also, the technical and economic merits and demerits of passive filters are very important during choosing the passive filter topology [8].

Active filters have some advantages such as enhancing voltage profile, compensating reactive power, and mitigating voltage flicker, beside their ability to eliminate the non-stationary harmonies [9]. On the other hand, they have some disadvantages such as complexity and high cost [10]

A new kind of series and shunt power filter/compensator devices which can mitigate a wider range of power quality problems has been developed [11- 18].

In this paper, a novel low-cost power filter/compensator (PFC) device is presented to enhance the performance of distribution networks in low voltage or medium voltage levels. The operation of this scheme is based on the intermittent switching between passive filter and capacitive compensation. PFC is a combination of two series capacitors and shunt capacitor in series with double tuned filter arm or in series with high-pass filter. The control of this intermittent switching is achieved by two complementary pulse signals that are generated by a pulse-width modulation circuit. The modulating signal of pulse-width modulation is generated by PID controller that is driven by an error signal generated from a dual loop traditional controller. A radial distribution network comprises hybrid loads, linear, nonlinear and motorized loads, is simulated using Matlab/Simulink to assessment its performance with and without PFC.

PROPOSED POWER FILTER/COMPENSATOR DEVICE AND ITS CONTROL

The power filter/compensator scheme is a combination of two series capacitors (C_{S1} and C_{S2}) and shunt capacitor (C_f) in series with double tuned filter arm or in series with high-pass filter arm depending on the situation of the switches S_A and S_B. This scheme of PFC is shown in Fig. 1 and it has two modes of operation depending on the switching on/off of the gate turn-off thyristor (GTO) switches, S_A and S_B. as follows:

Mode #1

This mode is used when the voltage and current waveforms are distorted due to the effect of nonlinear load operation. When the distortion contains low order harmonics, the PFC is used with connecting the doubled tuned arm filter in series with the shunt capacitor to eliminate these low order harmonics The gate signal, P_1, is high, consequently, the switch S_A will be closed, the switch S_B will be opened, in Fig. 1. In this scenario, the passive filter is tuned to eliminate two harmonic orders of highest values using this equation

$$f_i = \frac{1}{2\pi\sqrt{L_{fi}C_f}} \quad (1)$$

Mode #2

When the voltage and current waveforms are distorted with high order harmonics, the high bus filter arm is inserted in the circuit by switching on the switch S_A to be in series with the shunt capacitor C_f. In this operation mode, the passive filter is tuned to eliminate high orders harmonic.

In the two modes of operation, the series capacitors are used to stabilize the voltage and consequently to enhance the power transfer to the loads and also to improve the power factor and decrease the power losses.

The intermittent operation of switches S_A and S_B is controlled by two pulsing signals P_1 and P_2, respectively. These two pulsing signals are complementary and generated form a pulse width modulation (PWM) device that is driven by modulated signal. A conventional dynamic controller based on PID controller, as shown in Fig. 2. Comprises two error loops; voltage error and current ripple error loops. The total error is minimized by PID by generating the modulating control signal to the PWM switching block.

Voltage error limiting loop is:

$$e_{V_2} = V_{2ref} - V_2\left(\frac{1}{1+ST_1}\right) \quad (2)$$

Current error limiting loop is:

$$e_{I_2} = I_2\left(\frac{1}{1+ST_1}\right)\left(1 - \frac{1}{1+ST_2}\right) \quad (3)$$

where V_2 and I_2 are captured voltage and current at bus B_2 that is downstream the power filter/compensator device, respectively.

Total error is the summation of these errors and is the input to PID as:

$$error = e_{V_2} + e_{I_2} \quad (4)$$

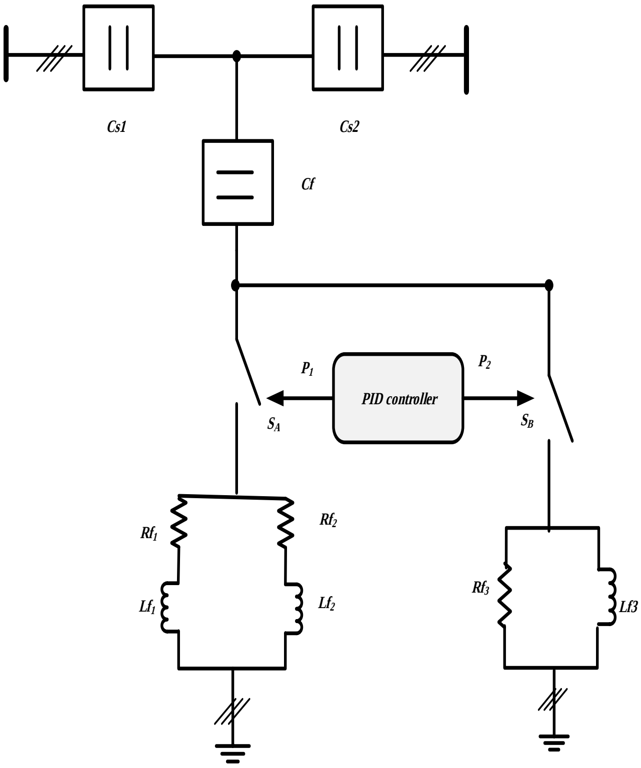

Fig. 1 The structure of proposed PFC device

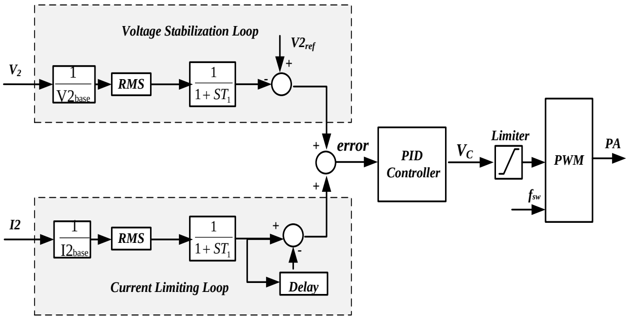

Fig. 2 The block diagram of control of PFC device

RESULTS AND DISCUSSIONS

A simple radial distribution system contains a hybrid load that comprises linear, nonlinear and motorized loads, as shown in Fig. 3, is used to test the capability and the performances of the suggested power filter/compensator device. This distribution system is simulated using Matlab Simulink environment and the system parameters are stated in Table 1.

The digital simulation results using Matlab Simulink environment for the suggested PFC under normal operating condition are shown in Figs. 4 and 5. The dynamic response of the voltage, current, reactive power, power factor and power losses at the source bus, B_S, and at the load, B_L, are monitored in the test system without and with inserting the PFC

Table 1 parameters of the distribution system

	Parameters
Utilitygrid	V = 66 KV, X/R=10, SC. level=5 MVA.
Transformer T_1	1 MVA, 66/11 kV
Transformer T_2	1 MVA, 11/0.4 kV
Hybrid load	*Linear load:*0.2 MVA, 0.85 lag pf
	*Non-linear load:*0.25 MVA
	Induction motor: 3 phase, 0.25 MVA, 0.8 pf
10 Km feeder	R/km=0.35 Ω, X/km=0.4 Ω
The proposed PFC	$C_{s1/phase}$ =$C_{s2/phase}$ =500 μF, $C_{f/phase}$ =100 μF, R_{f1}= R_{f2}= 0.05 Ω, L_{f1}= 28 mH and L_{f2}= 65mH
PID controller gains	K_p= 1 , K_i= 0.5 , K_d= 0.02
PWM frequency	f_s=1750 Hz.

In Fig 4, there is no change of the voltage profile at the source bus. The injected reactive power at the source bus decreases and this increases the power factor from 0.938 to 0.977 pu. Fig. 5 illustrates that the insertion of PFC improves the reactive power compensation at the load bus with a slightly improvement of the power factor. The power factor values of the system buses without and with inserting PFC are collected in Table 2. The system power losses are also decreased with connecting PFC from 0.035 pu to 0.03 pu, as shown in Fig. 6, with a percentage reduction equals 14.3 %

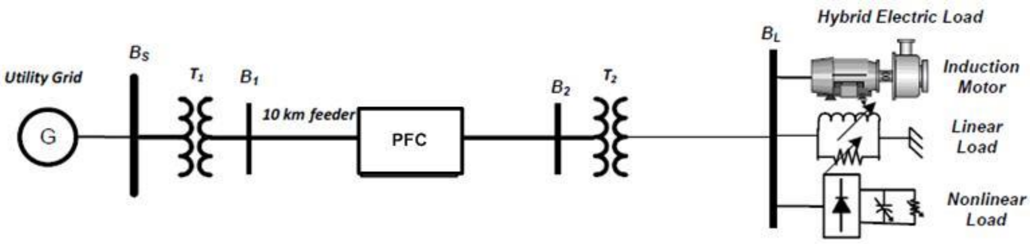

Fig. 3 The distribution system under test

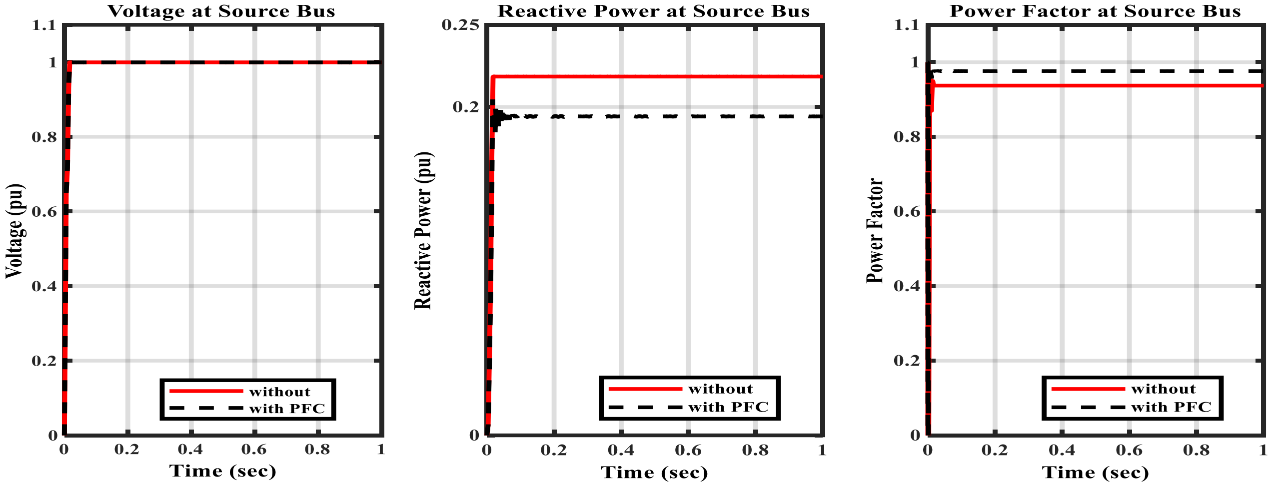

Fig. 4 The voltage, reactive power and power factor at the source bus without and with PFC

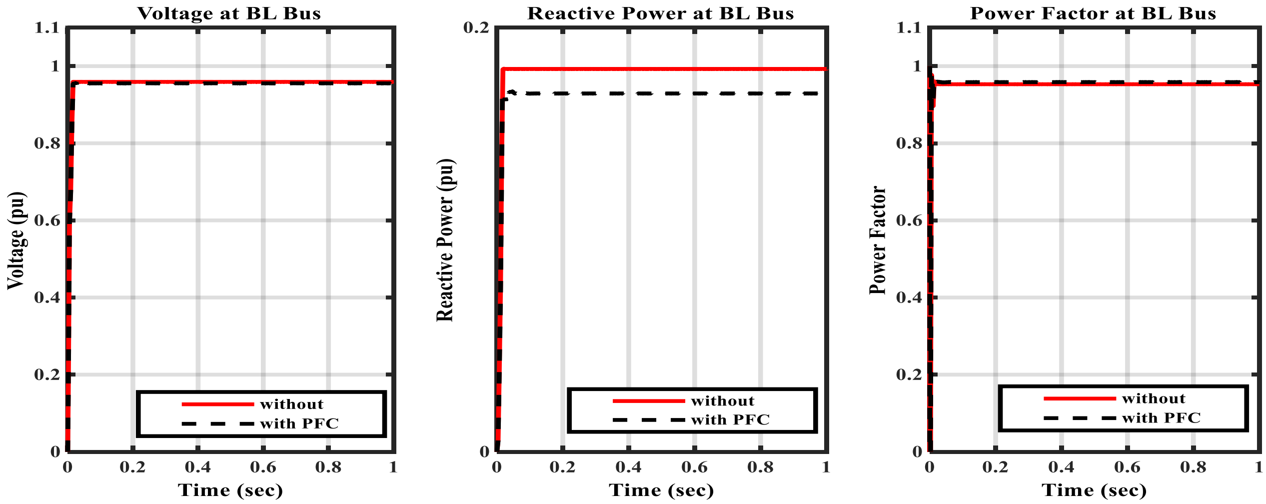

Fig. 5 The voltage, reactive power and power factor at the load bus without and with PFC

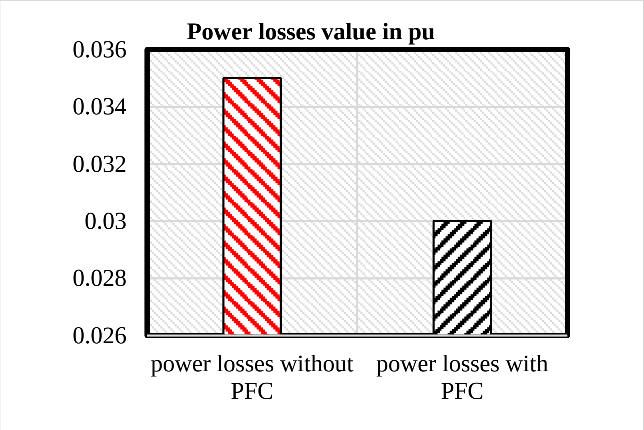

Fig. 6 System power losses without and with PFC

Table 2 Measured values of power factor at system buses without and with PFC

	Source bus, Bs	**B_1 bus**	**B_2 bus**	**Load bus, BL**
Without PFC	0.938	0.943	0.948	0.952
With PFC	0.977	0.98	0.954	0.959

The power factor at system buses are measured and summarized in Table 2. The results show that with connecting PFC the reactive power is compensated and the power factor values are improved at all buses. The voltage and current waveforms at system buses are monitored and analyzed using Fourier transform to test the performance of PFC in mitigating the harmonic distortions. The frequency spectra for voltage and current waveforms at source and load buses are shown in Figs. 7 – 10. From these frequency spectra, total harmonic distortions (THD) are estimated for voltage and current waveforms at all system buses and illustrated in Table 3. Results illustrate that, using PFC, the voltage harmonics are mitigated to be within IEEE standard limits [19] for all system buses while current harmonics are decreased to be within IEEE limits at system buses that are upstream the PFC location, i.e buses B_2 and B_L.

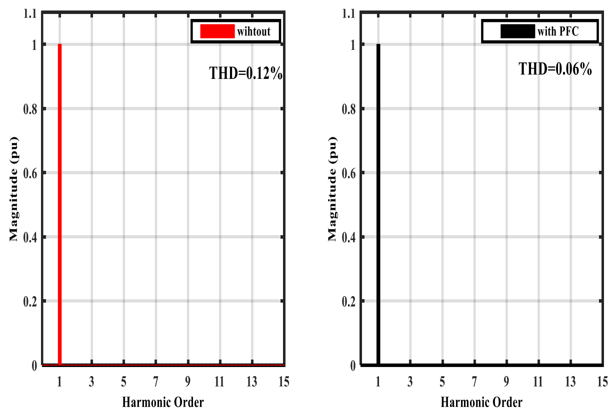

Fig. 7 The frequency spectrum of the source bus voltage

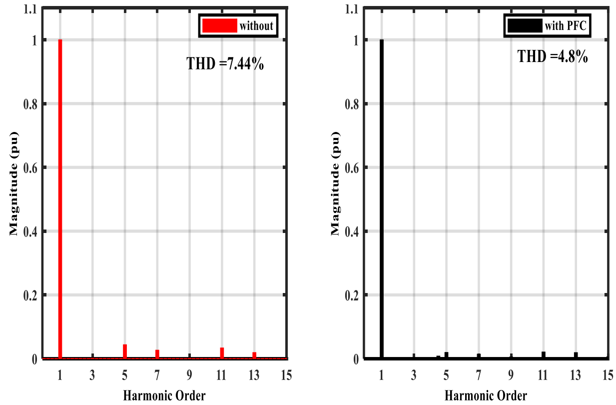

Fig. 8 The frequency spectrum of the load bus voltage

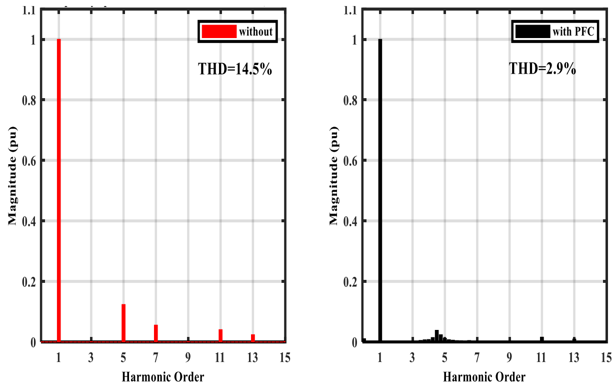

Fig. 9 The frequency spectrum of the source bus current

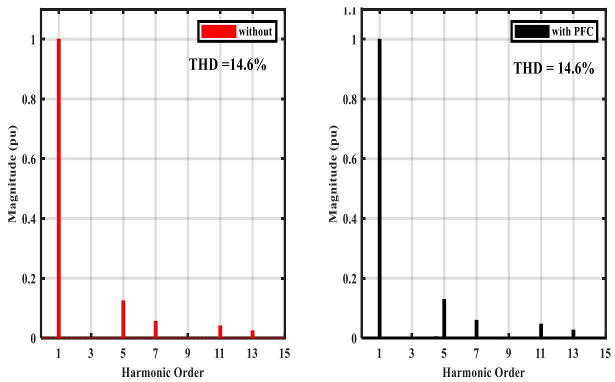

Fig. 10 The frequency spectrum of the load bus current

Table 3 THD values for system's voltages and currents

	THDv (%)		***THDi (%)***	
	Without PFC	***With PFC***	***Without PFC***	***With PFC***
Source bus, B_s,	0.12	0.06	14.5	2.9
B1 bus	1.88	0.79	14.56	2.9
B2 bus	5.6	3.1	14.5	14.5
Load bus, B_L	7.44	4.8	14.6	14.6

CONCLUSIONS

A novel low cost power filter/compensator (PFC) device is presented to enhance the performance of distribution networks in low voltage or medium voltage levels. The PFC operation is achieved by two modes based on the intermittent switching between passive filter and capacitive compensation. PFC is a combination of two series capacitors and shunt capacitor in series with double tuned filter arm or in series with high-pass filter. A radial distribution network comprises hybrid loads, linear, nonlinear and motorized loads, is simulated using Matlab/Simulink to evaluate its performance with and without PFC. Results illustrate that PFC device has the capability to enhance the power factor, stabilize voltage profile at the system buses, reduce the system losses and eliminating voltage and current distortions that are generated from the nonlinear load.

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