Development of Three Phase Grid Connected Shunt Active Power Filter for Power Quality Improvement

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ABSTRACT: This paper investigates a systematic approach in developing a grid connected three phase shunt active power filter (SAPF) by applying the instantaneous active power *P* and reactive power *Q* concept for mitigating the harmonic currents in the grid system. The grid system will be experiencing significant harmonic current distortion due to the high usage of nonlinear loads by the end users. Therefore, the three phase SAPF with *PQ* control method is developed to improve the grid power quality. The steady state as well as the dynamic performances of the proposed SAPF are analyzed by using Matlab/Simulink. The results show that the SAPF is able to produce almost sinusoidal line currents with low total harmonic distortion and unity power factor.

Keywords: *Shunt active power filter; PQ Controller; Instantaneous active and reactive power.*

1. INTRODUCTION

Power quality problems in the grid system have become one of the main research subjects due to the high usage of nonlinear loads in industries, businesses and residential buildings. Due to the widespread usage of nonlinear loads such as diode or thyristor rectifiers and switch mode power supplies in distribution systems, the harmonic distortion of the current and voltage will increase and degrade the quality of grid power supply [1, 2]. High current harmonic distortion will cause in overheating of electrical devices such as motors, power cables, transformers and incorrect voltage and current meter measurements. International standards such as IEEE 519 and IEC 61000 have introduced standards and regulations to maintain the voltage and current quality of the equipment connected to the utility grids at accepted levels. Therefore, the ability of three phase shunt active power filter (SAPF) to surpress the current harmonics will be investigated in this work. Instantaneous power theory [3] will be extensively used to develop the SAPF controller which is known as *PQ* control method in this paper.

2. SYSTEM CONFIGURATION

Topology of the three phase shunt active power filter (SAPF) connected to the three phase 415V_{RMS}, 50Hz grid system and the three phase diode rectifier at point of common coupling (PCC) is shown in Fig. 1(a). The diode rectifier acts as a nonlinear load which will generate harmonic currents at the supply. The power stage of SAPF is, basically, a voltage source converter (VSC) which consists of a dc-link capacitor. The capacitor acts as a constant dc storage for the VSC to inject current to the PCC. The energy is stored in this capacitor at one moment, and later will be delivered to the nonlinear load. The proposed system consists of 4 voltage sensors to measure grid three phase voltage $E_{g,abc}$, and dc-link voltage V_{dc}; and 6 current sensors to measure load currents $I_{l,abc}$ and compensated currents $I_{c,abc}$. The measured values of grid voltage and load current will be used by the controller to calculate the compensated reference currents $I_{c,abc}^*$. The error signals between the reference and the measured compensated currents will be fed to three hysteresis controllers to produce switching signals for six insulated gate bipolar transistors (IGBT) in the VSC.

2.1 DEVELOPMENT OF P-Q CONTROLLER

The control structure of the PQ control is shown in Fig.1(a). All the three phase grid voltage and load current are transformed from the *abc*-coordinates x_{abc} to the stationary *αβ*-reference frame $x_{\alpha\beta}$ by using the generalized transformation matrix given in eqn. (1).

$$x_\alpha = (\sqrt{2}/3)x_a - (1/2)x_b - (1/2)x_c \quad (1)$$
$$x_\beta = (1/\sqrt{2})x_b - (1/\sqrt{2})x_c$$

Subsequently, input active power *P* and reactive power *Q* of nonlinear load in a stationary reference frame can be calculated by (2) and (3), respectively.

$$P = E_{g,\alpha}I_{l,\alpha} + E_{g,\beta}I_{l,\beta} \quad (2) \qquad Q = E_{g,\beta}I_{l,\alpha} - E_{g,\alpha}I_{l,\beta} \quad (3)$$

The calculated active power P of the load can be separated into its average $\overline{P}$ and oscillating $\tilde{P}$ components. Similarly, the load reactive power Q can be separated into its average $\overline{Q}$, and oscillating $\tilde{Q}$ components as shown in (4) and (5), respectively.

$$P = \overline{P} + \tilde{P} \quad (4) \qquad Q = \overline{Q} + \tilde{Q} \quad (5)$$

A high-pass filter with a cutoff frequency of 5Hz separates the power $\tilde{P}$ from *P*. Consequently, the power $\tilde{P}$ and Q of the load, are compensated to provide optimal power flow from the grid supply. The stationary compensated current reference $I_{c,\alpha\beta}{}^*$ are calculated by (6) where $\overline{P}_{loss}$ is generated from the SAPF dc-link voltage regulator and used to compensate power losses in the active filter. The power minus signs at the right side of

$$\begin{bmatrix} I_{c,\alpha}{}^* \\ I_{c,\beta}{}^* \end{bmatrix} = \frac{1}{E_{g,\alpha}^2 + E_{g,\beta}^2}\begin{bmatrix} E_{g,\alpha} & E_{g,\beta} \\ E_{g,\beta} & -E_{g,\alpha} \end{bmatrix}\begin{bmatrix} -\tilde{P} + \overline{P}_{loss} \\ -Q \end{bmatrix} \quad (6)$$

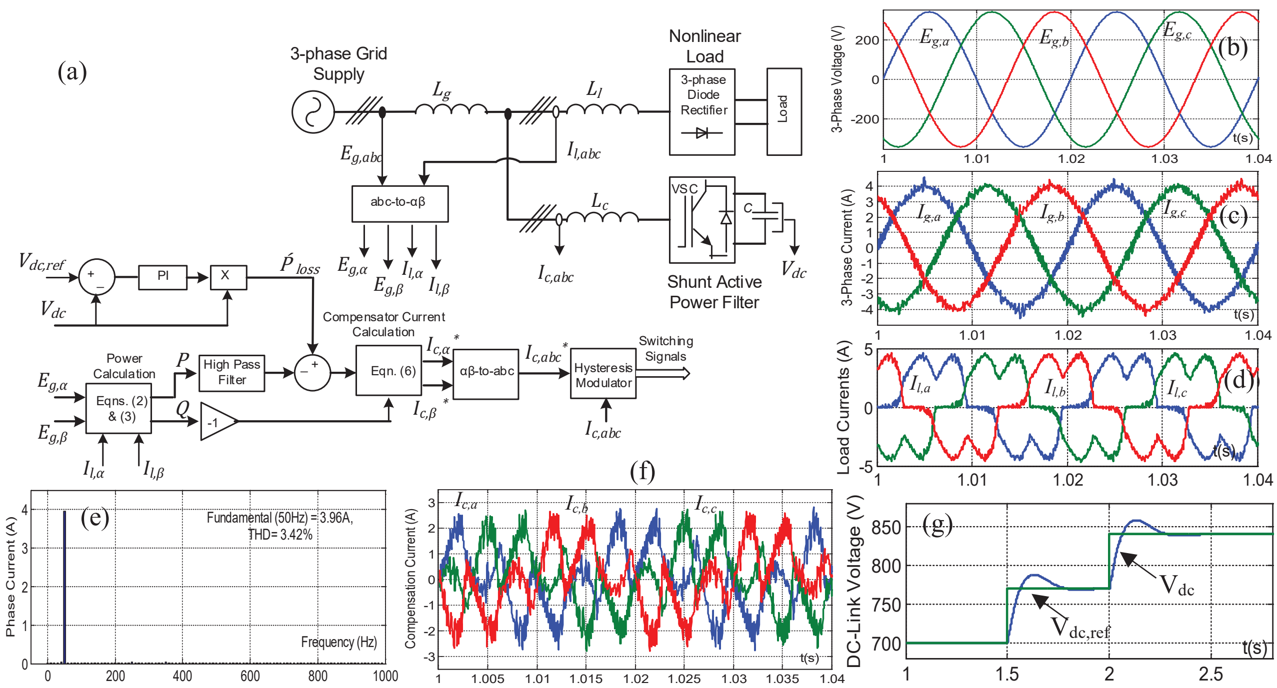

Figure 1. (a) Block diagram of the proposed SAPF with PQ controller. (b) Supply voltages. (c) Supply currents. (d) Load currents. (e) Harmonic spectrum of supply current. (f) Compensation currents. (g) Reference and measured Dc-link voltages of SAPF.

eqn. (6) indicate that the compensator should draw a compensating current that produces exactly the inverse of the unwanted powers drawn by the nonlinear load. Subsequently, the inverse transformation from *αβ*-reference frame to *abc*-coordinates as given in (7) is applied to calculate the three phase compensating current references $I_{c,abc}{}^{*}$. Then the compensated current references $I_{c,abc}{}^{*}$ are compared with the measured current $I_{c,abc}$. The error signals are processed by three hysteresis controllers to produce switching signals for the VSC.

$$\begin{bmatrix} I_{c,a}{}^{*} \\ I_{c,b}{}^{*} \\ I_{c,c}{}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{c,\alpha}{}^{*} \\ I_{c,\beta}{}^{*} \end{bmatrix} \quad (7)$$

3. SIMULATION RESULTS AND DISCUSSION

An insight of the line currents performance during steady state can be observed in the waveforms of supply voltage, source current, load current and the harmonic spectrum of source current shown in Fig.1(b), (c), (d) and (e), respectively. The proposed controller is able to produce almost sinusoidal line currents with unity power factor operation even though the diode rectifier draws load currents with high harmonic contents. The total harmonic distortion (THD) of source line current is 3.42% which is much lower than the current THD produced by the conventional diode rectifier without SAPF. The conventional diode rectifier produces current THD 23.92%. The compensating current $I_{c,abc}$ is given in Fig.1(f) It contains significant harmonic content because the VSC compensator supplies the oscillating active power $\tilde{P}$ to the nonlinear load and at the same time compensates both, the average reactive power $\overline{Q}$ and the oscillating reactive power $\tilde{Q}$. Therefore, the oscillating power $\tilde{P}$ from the grid supply is eliminated by the compensator. The source current becomes sinusoidal as a result of compensating the oscillation power $\tilde{P}$ and $\tilde{Q}$. The source current is in phase with its associate phase voltage due to the compensation of average reactive power $\overline{Q}$. Fig.1(g) shows the transient response of the SAPF dc voltage reference changes from 700V to 770V at 1.5s and further increases to 840V at 2s. Forced by the voltage PI regulator, the dc-link voltage follows the dc reference signal after experiencing slightly overshoot during the voltage transitioning process.

4. CONCLUSION

The three phase shunt active power filter (SAPF) using *PQ* control method is presented in this paper. Several important equations related to the *PQ* theory are explained and used to compensate the instantaneous reactive power and the oscillation components of instantaneous active power in order to obtain almost sinusoidal grid supply current with low current THD and unity power factor operation.

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