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A Comparative Analysis on the Effect of Various Controllers for Shunt Active Power Filter

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Abstract: ***This paper represents the use of different controllers such as Proportionate, Integral, PI and PID and studies its performance on the Shunt Active Power Filter. An active power filter connected in shunt may be used to eliminate voltage and load current harmonics for reactive power compensation. The shunt active power filter has been developed based on control techniques like active and reactive power method (p-q method), active and reactive current method (d-q method) and other algorithms. Considering the simplicity and good performance of the p-q method, it is used in this work for harmonics filtering and the compensation of the shunt active power filter. A theoretical study based on the various control schemes is done in this paper and the theory of p-q control method is implemented in simulation work on MATLAB/Simulink platform and its harmonic compensation results are analyzed.***

Keywords: Controllers, p-q method, harmonics, Shunt Active Power Filter

1. Introduction

The dynamics of electric systems is rather complex due to which it suffers from unexpected sudden changes of current and voltages. These changes are mainly due to the linear and non-linear loads to which they are connected. Due to an increased use of power electronic devices which are mainly non-linear in nature, the electric system gets polluted with different harmonic currents and voltages. The harmonic currents and voltages impair the normal functionality of the electric devices and imposing unnecessary economic losses. Many classical and modern solutions have been proposed in the literature to deal effectively with the harmonic problems.

There are various issues relating to harmonic problems. These issues are related to the nature and impact of harmonics present, the sources that generate harmonics and the ways or the methods to reduce or eliminate these harmonics. The sources of these harmonic currents or voltages arise from the non-linearity of the devices connected. These harmonic contents pose a serious threat to power quality. They also tend to lower the power factor of the power supply resulting in large consumption of reactive power by industrial and domestic loads. The reactive power consumed by these loads causes higher RMS current values, thereby heating power transmissions and distribution systems. In distribution systems, there can be short-term and long-term effects of harmonics. The short-term effects usually results in voltage distortions and is frequently noticeable. On the other hand, the long-term effects are usually associated with high voltage stresses. It is very desirable to have stable voltages and undistorted waveforms for domestic and industrial uses. It is generally important when new sophisticated devices are introduced whose performance is very sensitive to the quality of power supply. The power quality has serious economic implications for consumers and electrical equipment manufacturers. Some of the main power quality problems are voltage sag, swell, transients, harmonics and flickers. The main cause of harmonics is the injection of harmonic currents by the non-linear loads. The economic drawbacks of harmonic currents are many. It leads to premature aging of materials and electrical components. The overloading of the source supplies causes additional losses in the system. In order to face the problems of harmonics, many solutions have been proposed. One of the ways is to modify the load itself for less harmonic emissions as in the case of single-phase and three-phase rectifiers or PWM rectifiers. The traditional solutions for harmonic reduction include the use of harmonic trapping by passive filters based on RLC elements. However, these solutions offer poor efficiency due to several reasons. One of the reasons is that these passive filters operate ineffectively for large bands of harmonic frequencies, thus requiring the use of many filters. Also there is a possibility of a series or parallel resonance interfering with the other frequencies. Another drawback is that they are bulky in nature and have very low flexibility for load variations which means a totally new filter design for each load variation.

The shunt APF is widely used to cancel harmonic currents by injecting currents equal in magnitude and opposite in phase that circulates in the electrical system. There can be two main structures to control the shunt APF. These can either be direct or indirect control. In the direct control, the generated reference currents are compared with the measured APF currents. The error is then used to produce control signals of the filter. In the indirect control method, the measured source currents are compared with the reference currents and the error is then sent to the control circuit which determines the control signal of the APF. In both cases, the error information generated by comparing the reference with the actual currents is used to tune the performance of the APF by using different controllers. There are several methods to calculate the reference currents. In this paper, the instantaneous active and reactive power method also known as p-q method is used. Later the compensation results of the proportionate, integral, PI and PID controllers are compared for further analysis.

2. Methodology

A. Review of Literature

The active power filter has been extensively studied in the past decade for power quality improvement.

Lesjek S. et al. (2006) have applied the p-q method to study the power properties of a three phase system and its harmonic contents. In the mean time the d-q method of harmonics extraction was proposed based on Park's transformation.

Sharmeela C. et al. (2007) have studied the Fuzzy logic DC voltage control with sliding mode current control based on sine multiplication extraction theory.

Leow Pei Ling studied the instantaneous active and reactive power theory with hysteresis SVPWM control.

Ilhami Colak et al. (2010) have applied the use of fuzzy logic controller with sine multiplication theorem.

Suresh Mikkili et al. (2011) have applied the PI and fuzzy control methods on shunt active power filter using reference frame method or d-q control strategy.

B. Active Power Filter

Electronic filters are analog circuits that separate some frequencies from others within mixed-frequency signals. Sometimes, it is required to have circuits capable of filtering one frequency or a range of frequencies out of a mix of different frequencies in a circuit. A circuit designed to perform this frequency selection is known as a filter. The usage of filters in stereo systems to suppress certain range of audio frequencies for best sound quality and power efficiency is already known. Also, it is used in equalizers where amplitudes of several frequency ranges are adjusted to suit the listener's taste and designed according to the acoustic properties of the listening area. Filters are also used to mitigate harmonics by 'conditioning' of non-sinusoidal voltage waveforms in power circuits. Some electronic devices are sensitive to the presence of harmonics in the power supply voltages. The current waveforms in these devices contain harmonics having multiple frequencies imposed on fundamental frequency then it is possible to construct a filter that allows the fundamental frequency to pass through blocking all higher frequency components. Active filters are implemented using a combination of passive and active (amplifying) components which requires an outside power source.

In linear load when a pure sinusoidal voltage is applied, the current drawn by the load is proportional to the voltage. Examples of linear load include resistive heaters, lamps and synchronous motors. In non-linear loads, the current vary disproportionately with the applied voltage and hence such current is non-sinusoidal in nature. These current waveforms contain harmonics having multiple frequencies imposed on fundamental frequency. Examples of such loads include battery chargers, electronic ballasts, Switch Mode Power Supplies (SMPS) and uninterruptible power supplies (UPS). These harmonic currents can distort the supply voltages and create problems for computers, telephone lines, motors and power supplies. There are two types of harmonics in electrical power systems, namely current harmonics and voltage harmonics, which are distortions to current and voltage waves respectively. The harmonic content in power systems is measured as the ratio of total harmonics to the value at fundamental frequency known as Total Harmonic Distortion (THD). The voltage THD represents the Total Harmonic Distortion of the voltage waveform.

It is the ratio of the root-sum-square value of the harmonic content of the voltage to the root mean-square value of the fundamental voltage.

$$V_{THD} = \frac{\sqrt{\left(V_2^{\,2} + V_3^{\,2} + V_4^{\,2} + V_5^{\,2} + \ldots\right)}}{V_1} \times 100\% \quad = \frac{\sqrt{\sum_{h>1}^{h_{\max}} V_h^{\,2}}}{V_1} \times 100\%$$

C. Reference Signal Estimation Methods

The aim of active power filtering is to compensate the harmonic currents produced by the non-linear loads. The first step in active filtering is the harmonic currents extraction so that the magnitude of harmonics present in the circuit can be known beforehand. The Shunt APF generates the same harmonics equal in magnitude, produced in the line by the non-linear load but with opposite phase so that the effect of the harmonics is nullified.

D. PI and PID control parameters

The PI controller is the special case of proportional-integral-derivative (PID) controller in which the derivative part of the error is not used. A PID is control loop feedback mechanism used in industrial control systems. In an industrial process, a PID controller attempts to reduce the error between a measured process variable and a desired set point. The PID controller constitutes three separate modes; the proportional mode, the integral mode and the derivative mode. The proportional mode determines the reaction to the current error, the integral mode determines the reaction to the cumulative summation of the recent errors and the derivative mode determines the reaction based on the rate of change of error. The weighted sum of the three modes is outputted as a corrective action to the control element. A PID controller will be called a PI, PD, P or I controller in the absence of respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise.

The proportional mode responds to a change in the process variable which is proportional to the current measured error values. This response can be adjusted by multiplying the error by a constant K_p, called a proportional gain or proportional sensitivity. The integral mode algorithm calculates the controller output by the accumulated proportional offset over time that should have been corrected previously. By doing so, it takes into account the amount and duration of the error signal. The integral constant K_i eliminates any steady state error and also contributes towards the instability of the system where the controller will always be responding to past values. The integral constant will force the controller to approach the set point quicker.

The characteristics equation of the voltage control loop is used to obtain the constants of the PI controller.

E. System parameters

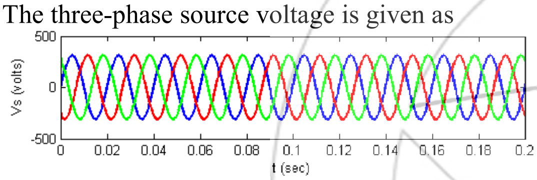
The simulation of various controllers for shunt APF was carried out using MATLAB/Simulink with the following system parameters as shown in Table 1.

Table 1: System parameters for simulation study

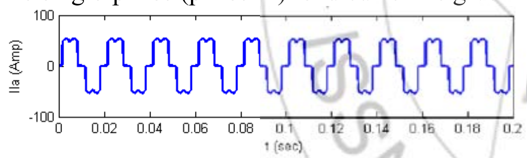
System Parameters	Values
1. Three Phase Source Voltage, V_s	400 V
2. Frequency, f	50 Hz
3. Source Load, R_s, L_s	0.3 Ω, 1µH
4. Load Resistance, R_l	10 Ω
5. Filter Load, L_f	0.66mH
6. DC Capacitance, C_{dc}	2200µF
7. DC Reference Voltage, V_{dc}	850 V
8. Proportional Constant, K_p	0.0052
9. Integral Constant, K_i	1.15
10. Derivative Constant, K_d	1

3. Results and Discussions

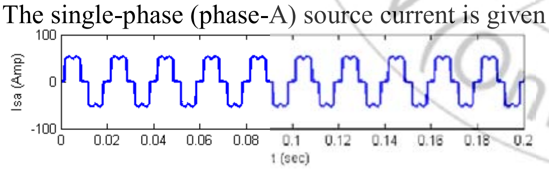
The three-phase source voltage is given as



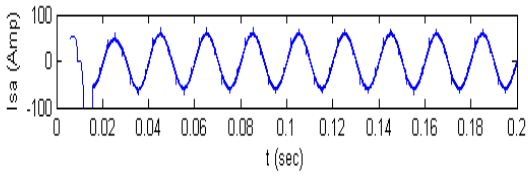
The single-phase (phase-A) load current is given as



The single-phase (phase-A) source current is given as

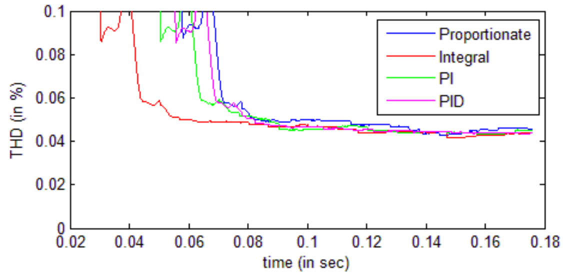


When the controller is applied the source current changes to

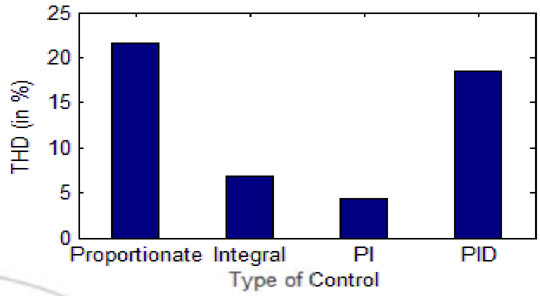


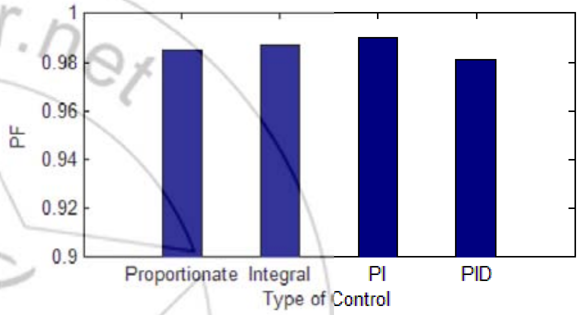
The source current is very much sinusoidal but with spikes. The results obtained for Proportionate (P), Integral (I), PI and PID controllers are as follows:

The THD variation of all the controllers is obtained as



The performance of the various controllers is obtained as





4. Conclusions

The different control methods of shunt active power filter has been analyzed and investigated for power quality improvement. It is observed that the performance of the PI controller is best in terms of reactive power compensation and power factor improvement. The THD obtained for the PI controller was 4.28% while the PF improved to 0.9902. The THD obtained for the PID controller was 18.57% much better than either proportional or the integral controller. The PF is almost same for the other three controllers except PI controller.

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