Power Quality Improvement in AC- DC Networks using PWM and Hysteresis Control for Railway Applications

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Abstract: Power quality is a young challenging subject, which was introduced in the early 1980s. The term power quality has been used to describe the variation of the voltage, current and frequency on the power system. Railways consist of AC-DC converters for auxiliary power supply. These converters produce power quality issues. Electric power quality relates to non-standard voltage, current or frequency deviation that results in failure or misoperation of end-user equipment. Power quality issues like harmonics, ripples and transients are more in ac side. In the project we develop a controller to compensate all the current related issues. This project is done using matlab/simulation software. The simulation results will be presented to illustrate the operating principle, feasibility and reliability of this proposed system.

KEYWORDS: Dynamic Voltage Restorer, Active Power Filter, Pulse width modulation, Hysteresis Controller.

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INTRODUCTION

Power quality (PQ) compensation technologies are widely adopted in AC–DC network with electrified railways due to the PQ issues caused by DC components in both DC parts of the network and DC devices in the electrified railways. PQ issues in the network with electrified railways typically include harmonics, voltage, and current unbalance, and low-power factor.

According to the investigation in [1], most voltage or current unbalance issues are solved partly by distributing the total power of single-phase transformer groups of the traction substations on the three primary phases, or by adopting Scott-connected transformers. These solutions have been developed satisfactorily for several decades, but in some cases, it could still be difficult to obtain an acceptable level of unbalance, especially under extreme operating conditions of the traction supply system. For issues related to harmonics, passive filters have been widely used to reduce the harmonics within an acceptable level [2]. However, the filtering action can become very difficult due to the rapidly changing nature of traction loads [1].

Alternatively, the sinusoidal pulse-width modulation (PWM) is widely adopted to suppress harmonics especially those in high order. Nevertheless, resonance may occur at high frequencies, and the voltages and currents at these resonant frequencies will be amplified, which induce various problems such as interference with adjacent railway communication lines, erroneous operations of the protective devices and even the facility failure. To solve the issue, a resonant harmonic elimination PWM strategy has been developed to suppress high-frequency resonance [3], but it will not be suitable to a network bus which has moderate issues related to harmonics but has severe problems in unbalance or power factor. A similar phenomenon applies to power flow control and static VAR compensation (SVC), which can solve low-power factors but are unable to reduce the harmonics or unbalance at network buses [1, 4, 5]. Another way of solving PQ issues simultaneously as much as possible is employing a hybrid PQ compensator [6–9], which contains a three-phase full-bridge converter connected to the Scott transformer. It integrates advantages of different compensators and can partly solve issues related to harmonics, unbalance, and power factor simultaneously but cost more than compensators that solve specific issues. Generally, at a network bus that needs to be compensated, it is likely that more than one PQ issues need to be solved, but simultaneously, the priority of these issues may vary from buses to buses. Therefore, appropriate compensation technology should be selected based on the performance of different PQ issues at buses. In addition, the PQ performance of all buses in a network is different. Thus, to consider the cost of compensation in some cases when financial or labour support is limited, the buses which need to be compensated in priority should also be investigated. Considering this situation, this study develops a subjective– objective methodology (SOM) to first investigate which buses should be compensated in priority and then which PQ compensation technology should be selected in priority at different buses. The priority of different PQ issues that need to be solved is given by weighting factors, which indicate how important different PQ issues are at different buses. The weighting factors are determined by both subjective weighting factors and objective weighting factors (OWFs). In the derivation of subjective weighting factors, an improved analytical hierarchy process (AHP) is employed with an evaluation matrix of consistency generated, and the evaluation matrix is further used for determination of the subjective weighting factor (SWF).

ACTIVE POWER FILTERS AND SOME BASIC ISSUES

A. *Active Power Filters*

Active power filter has been proposed since 1970s. The advantages of the active filtering process over the passive one caused much research to be performed on active power filters for power conditioning and their practical applications. By implementing the active power filters for power conditioning; it provides functions such as reactive power compensations, harmonic compensations, harmonic isolation, harmonic damping, harmonic termination, negative-sequence current or voltage compensation and voltage regulation. The main purpose of the active power filter installation by individual consumers is to compensate current harmonics or current imbalance of their own harmonic-producing loads. Besides that, the purpose of the active power filter installation by the utilities is to compensate for voltage harmonics, voltage imbalance or provide harmonic damping factor to the power distribution systems.

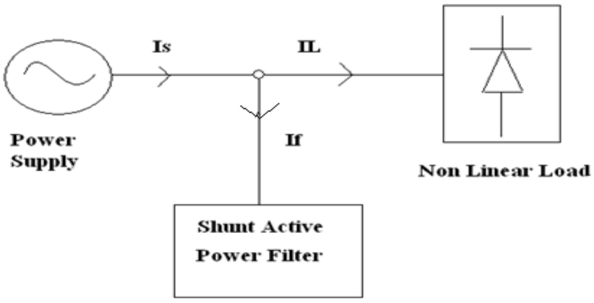


Fig.1:Basic principle of harmonic currents compensations

B.Classification of Active Power Filters

The configurations of the active filters are the shunt, series power filter. The shunt active filter shown in Figure 2 is the most fundamental system configurations. The shunt active power filter is controlled to draw and inject compensating current, I_f to the power system and cancel the harmonic currents on the AC side of a general purpose rectifier. The shunt active power filter is normally used for the thyristor or diode rectifier with a DC link inductor. Besides that, it has the capability of damping harmonic resonance between an existing passive filter and the supply impedance

Figure 3 shows the system configuration of a used alone series active power filter. The series active power filter is connected in series with the utility by a matching transformer. Normally, the series active power filter is suitable for harmonic compensation of a voltage harmonic source such as diode rectifier with a DC link capacitor.

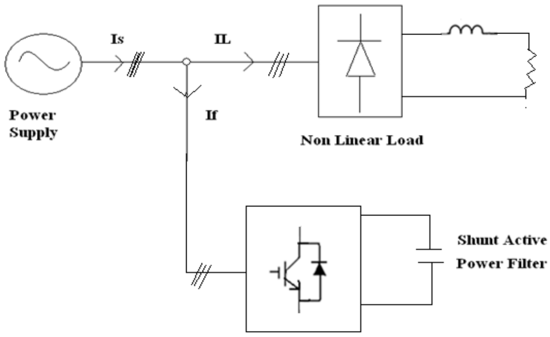


Fig.2:Shunt active power filter

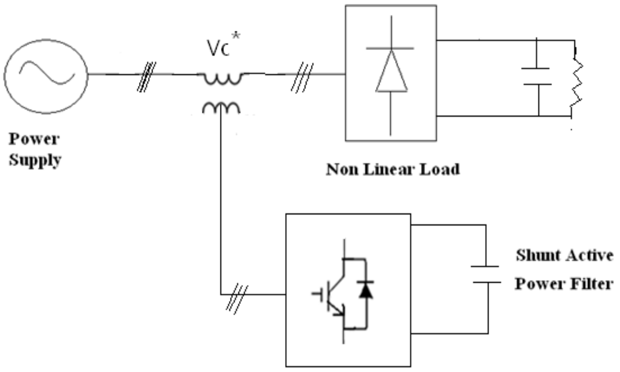


Fig.3:series active power filter

The different of the shunt and series active filter is the compensating harmonic injection method and the type of compensating harmonic. The compensating voltage, VC* of the series power filter is added into the phase supply voltage to cancel the harmonic voltage in each phase. Both shunt and series active power filter carry different role for the harmonic compensation. The shunt and series active filters act as a current source with I_f and a voltage source with VC* respectively in order to compensate the harmonics currents or voltages occurred in the distorted line. In addition, the shunt active power filters also provide function such as compensates reactive power and the series active power filters can be used for ac voltage regulation. The shunt active power filters are now present in the commercial stage and the series active power filters are only usedat laboratory level.

PWM CONTROL OF ACTIVE POWER FILTER

The main aim of an active power filter (APF) is to generate compensating currents into the power system for canceling the current harmonics contained in the nonlinear load current. This will thus result in sinusoidal line currents and unity power factor in the input power system.

A. *Principles of Operation of PWM Control*

Fig. 4 shows the configuration of a three-phase active power filter. The active power filter is connected in parallel with a nonlinear load. It consists of a power converter, a DC-link capacitor (C_2) and a filter inductor (L_2). To eliminate current harmonic Components generated by nonlinear loads, the active power filter produces equal but opposite harmonic currents to the point of connection with the nonlinear load. This results in a reduction of the original distortion and correction of the power factor. The inductor L_2 is used to perform the voltage boost operation in combination with the DC-link capacitor C_2 and functions as a low pass filter for the line current of an active power filter.

The exclusive features of this proposed PWM controlled APF are summarized as follows:

(a) The reference frame transformation and a digital low pass filter are used to compute the harmonics of the nonlinear load current.

(b) The voltage decouplers and pole-zero cancellation method are used in the current controllers of the active power filter to provide fast current harmonic compensation and simplify the control scheme.

(c) The delay times of both current response of an active power filter and DC-link voltage feedback are considered. This results in decreasing the settling time of the DC-link voltage and reducing the high frequency current harmonic components of the power system.

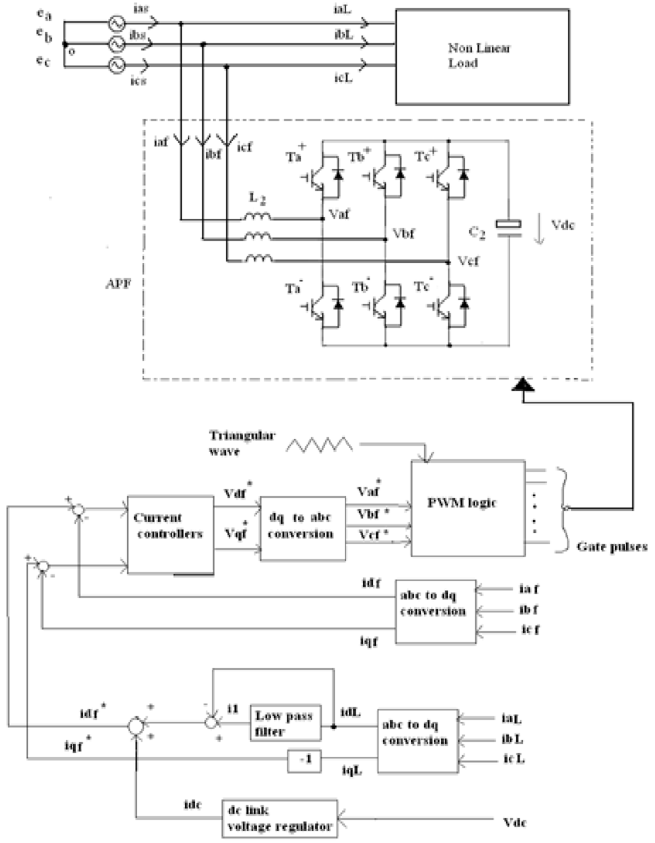


Fig 4: Control Block diagram of PWM controlled Active Power Filter

SIMULATION RESULTS AND ANALYSIS

The simulation was performed on the MATLAB/SIMULINK package. Simulink is a software package for modeling, simulating and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. This chapter shows the simulation models to realize the theorems and derived equations in Chapters 3, 4, 4. The simulation models are built by using the MATLAB Simulink toolbox and are simulated using variable step type of solver.

A. *Simulink Models of Active Power Filter*

Detailed simulink models of power system along with the active power filter is shown below.

Test system data:

TABLE 1

Three-Phase Supply	Phase RMS Voltage (Vrms) = 120v , Source inductance(Ls) = 0.4 mH , Supply Frequency (f) = 60 HZ.
Nonlinear Load components	Diode Bridge Rectifier with Ro = 8.67 Ω , Co =3300 μF, Lo= 3.1 mH.

Active Power Filter components	Input Resistance(R_2) = 0.03 Ω , Inductance(L_2) = 0.25mH, Dc-Link Capacitor Capacitance(C_2) = 4800 μF.
Dc-Link Capacitor	Voltage (V_C) = 400V.

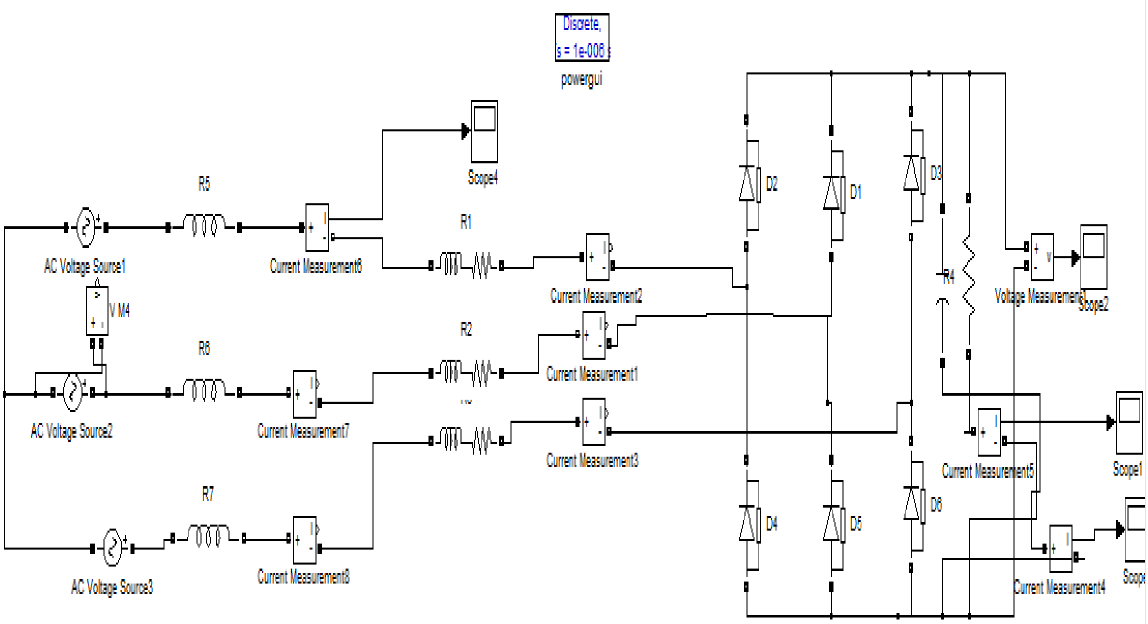


Fig.5: Simulink Model of Three-Phase Power System with non linear load

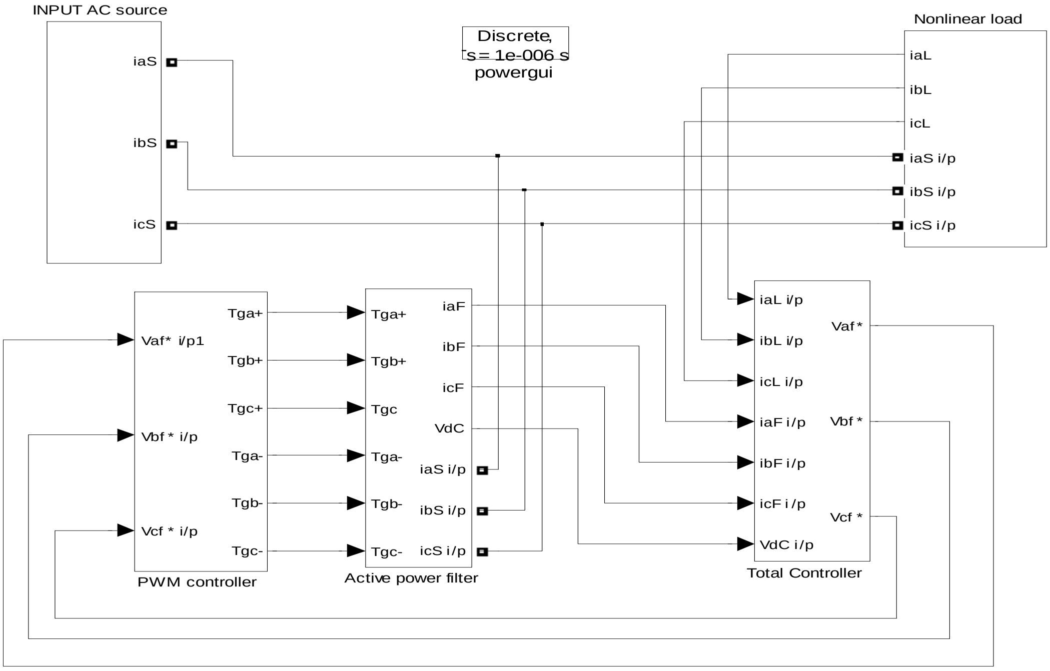


Fig.6 Simulink Model of PWM Controlled APF for the Three-Phase Power System

Here in Fig.5 total system is shown as five sub systems, those are three phase ac source, which is supplying for nonlinear load. Active Power Filter (APF) ,that is connected parallel to the load and also PWM controller subsystem which is giving pulses to the APF such that it will inject compensation currents into the power line which are opposite in phase to the harmonic currents introduced by the nonlinear loads. Total controller subsystem will provide reference voltages to the PWM controller subsystem.

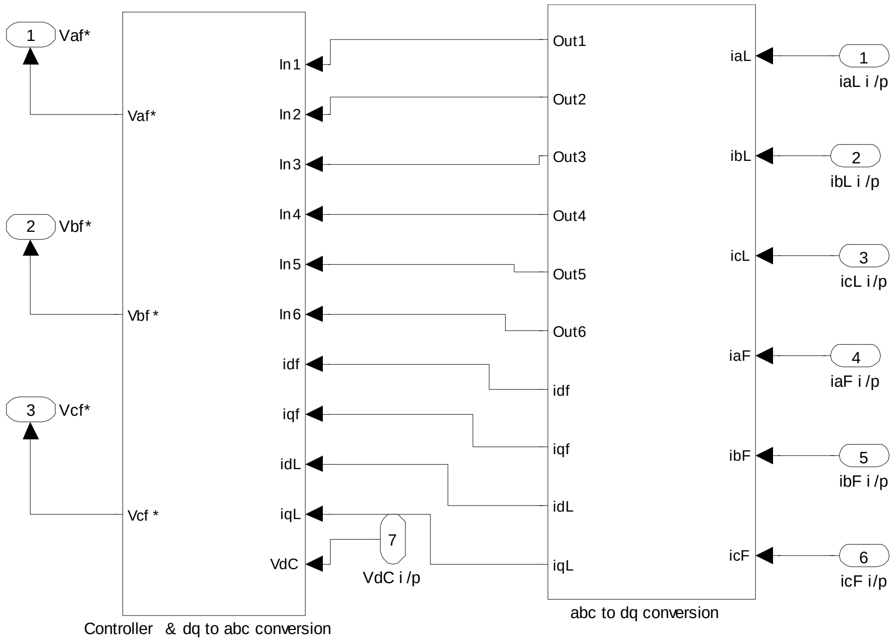


Fig .7:Simulink Model for conversions and for producing reference waves V_{af}, V_{bf}, V_{cf}.

Fig.6 is a simulink model consists of two subsystems one is abc to dq transformation Subsystem another one is dq to abc transformation and also having current controllers. Here transformation is doing for sake of simplicity and easy of calculations for designing the controller to the analytical model of Active Power Filter.

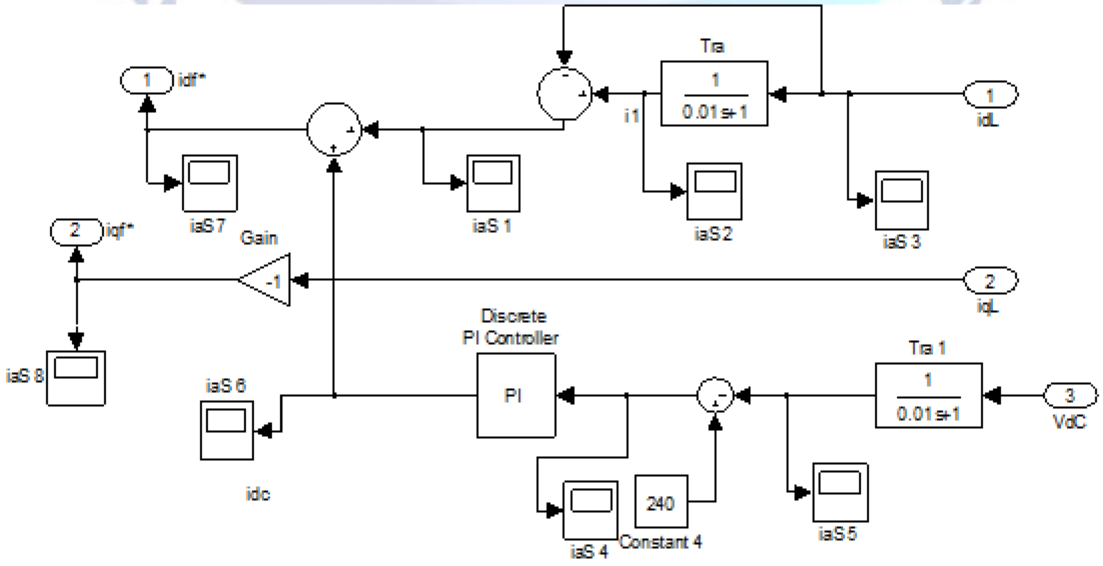


Fig .8:Simulink Model for d- and q- axis reference currents of APF and Dc Link Voltage regulator

Fig 7 shows the simulink diagram for dc-link voltage regulator, reference current calculation. Here dc-link voltage is taken as feedback, to maintain constant dc-link voltage. Maintaining constant dc-link voltage is necessary to avoid real power processing between the converter and main power system. This feedback voltage is compared with the reference voltage and error voltage is considered in the development of d-axis reference current. Here reference currents are nothing but harmonics due to the nonlinear load in the d-,q-axis load currents. In Fig 4.2 the reference currents are compared with the actual filter currents and error is passes through the current controllers, after that from the given model resultant reference voltages will come. Fig.9 is the simulink model for PWM controller. Here the reference voltages are compared with the triangular wave which is having frequency of 10KHZ and produced the switching gate pulses for the power converter.

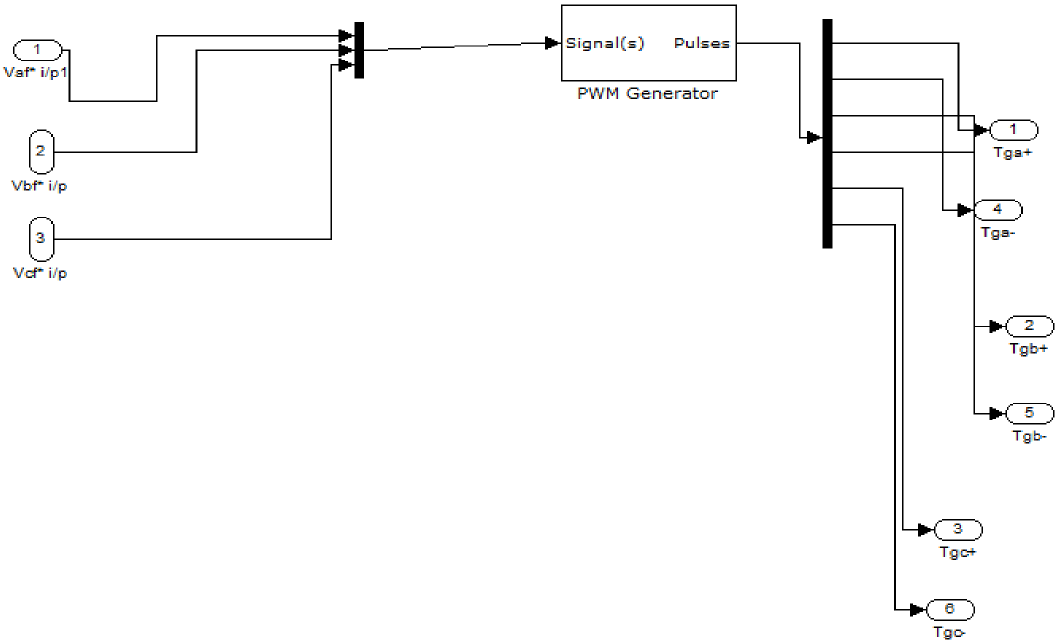


Fig .9:Simulink Model for PWM control of APF for Gating pulses

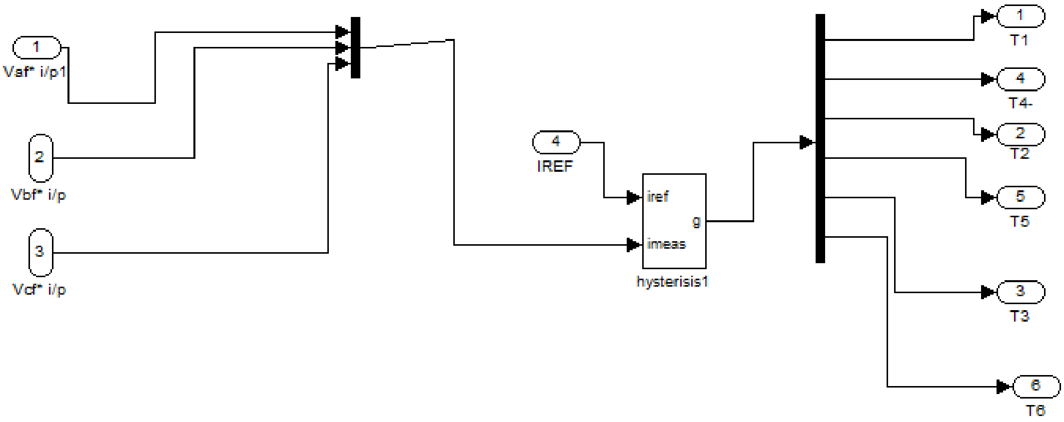
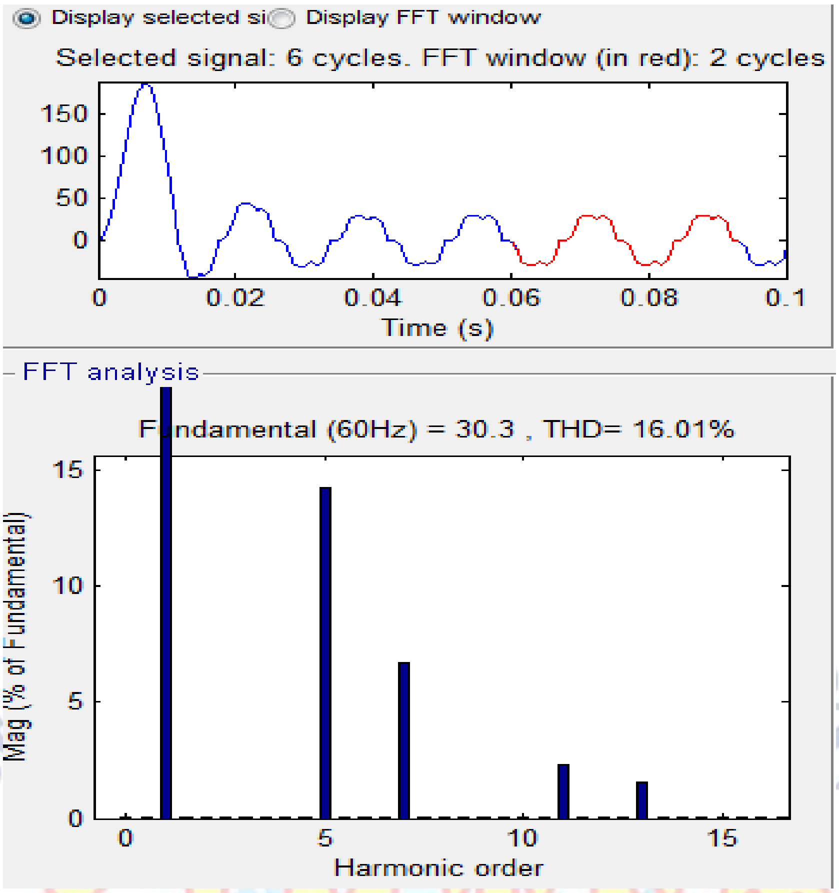


Fig .10:Simulink Model for Hysteresis control of APF for Gating pulses



● Display selected si○ Display FFT window

Selected signal: 6 cycles. FFT window (in red): 2 cycles

FFT analysis

Fundamental (60Hz) = 30.3 , THD= 16.01%

Fig .11:THD using without active power filter

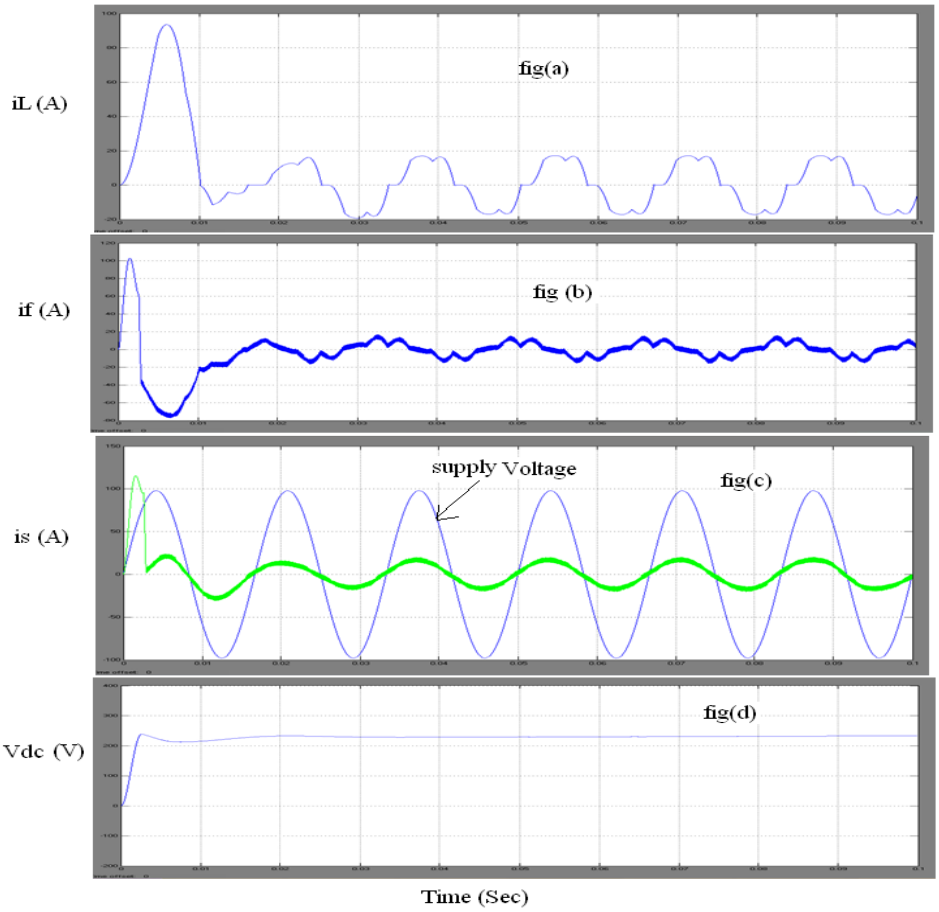


Fig .12: (a) Harmonic current (b) compensating current (c) source Voltage & current (d) DC Voltage to the APF

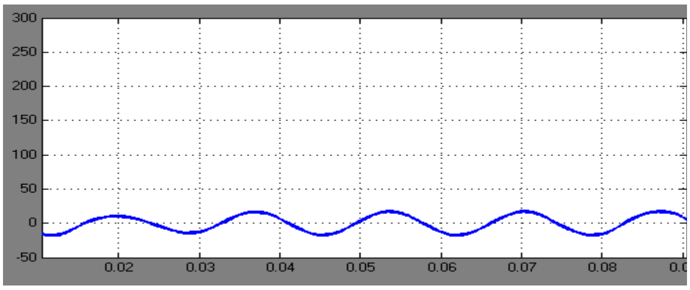
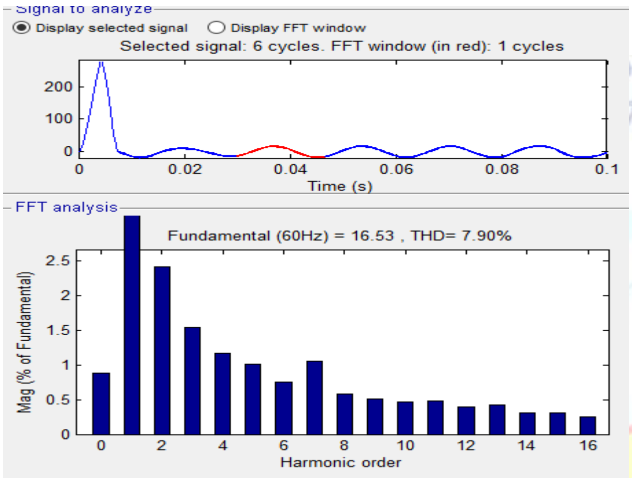


Fig .13:Source current using active power filter with PWM



Selected signal: 6 cycles. FFT window (in red): 1 cycles

Fundamental (60Hz) = 16.53 , THD= 7.90%

Fig .14:THD using active power filter with PWM technique

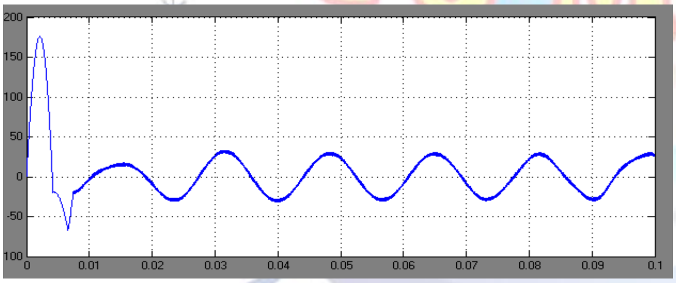
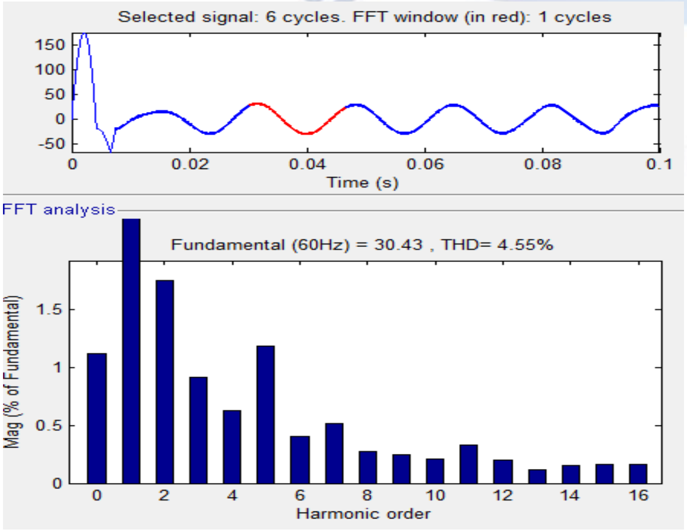


Fig .15:Source current using active power filter with Hysteresis Control



Selected signal: 6 cycles. FFT window (in red): 1 cycles

Fundamental (60Hz) = 30.43 , THD= 4.55%

Fig .16: THD using active power filter with Hysteresis control

CONCLUSION

In this project at first conventional PWM controlled harmonic reference based Active Power Filter is presented with some exclusive features as given below, when compared to previous conventional methods. (a) The reference frame transformation and a digital low pass filter are used to compute the harmonics of the nonlinear load current. (b) The voltage decouplers and pole-zero cancellation method are used in the current controllers of the active power filter to provide fast current harmonic compensation and simplify the control scheme.(c) The delay times of both current response of an active power filter and DC-link voltage feedback are considered. This results in decreasing the settling time of the DC-link voltage and reducing the high frequency current harmonic components of the power system. The THD values for APF with PWM and Hysteresis are compared.

REFERENCES

[1] Technical Guide No.6 by ABB;"Guide to Harmonics with AC Drives".

[2] H.Akagi;" Modern active filters and traditional passive filters" , Technical sciences vol. 54, no. 3, 2005.

[3] Dinesh, L., Sesham, H., & Manoj, V. (2012, December). Simulation of D-Statcom with hysteresis current controller for harmonic reduction. In 2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM) (pp. 104-108). IEEE

[4] G. Ledwich & P. Doulai; "Control techniques for Active Power Filters",IEE International Conference on Advances in Power System Control, Operation and Management, November 1991.

[5] Hideaki Fujita and Hirohmi Akagi ; " A Practical Approach to Harmonic Compensation in Power Systems-Series Connection of Passive and Active Filters", IEEE Transactions on Industry Applications, vol. 21, no. 6, November/December 1991.

[6] Sami Valiviita and Seppo J. Ovaska; "Delayless Method to Generate Current Reference for Active Filters", IEEE transactions on industrial electronics, vol. 45, no. 4, august 1998.

[7] Richard M. Duke and Simon D. Round; "The Steady-State Performance of a Controlled Current Active Filter", IEEE Transactions on Power Electronics, vol. 8, no. 3, April 1993.

[8] Manohar, K., Durga, B., Manoj, V., & Chaitanya, D. K. (2011). Design Of Fuzzy Logic Controller In DC Link To Reduce Switching Losses In VSC Using MATLAB-SIMULINK. Journal Of Research in Recent Trends.

[9] Manoj, V., Manohar, K., & Prasad, B. D. (2012). Reduction of switching losses in VSC using DC link fuzzy logic controller Innovative Systems Design and Engineering ISSN, 2222-1727

[10] Sami V¨aliviita and Seppo J. Ovaska; " Delay less Method to Generate Current Reference for Active Filters", IEEE Transactions on Industrial Electronics, vol. 45, no. 4, august 1998.

[11] Manoj, V. (2016). Sensorless Control of Induction Motor Based on Model Reference Adaptive System (MRAS). International Journal For Research In Electronics & Electrical Engineering, 2(5), 01-06

[12] Keyue M. Smedley and Slobodan Cuk; "One-Cycle Control of Switching Converters",IEEE Transactions on Power Electronics, vol. 10, no. 6, November 1994.

[13] Dinesh, L., Harish, S., & Manoj, V. (2015). Simulation of UPQC-IG with adaptive neuro fuzzy controller (ANFIS) for power quality improvement. Int J Electr Eng, 10, 249-268

[14] Chongming Qiao ,Keyue M. Smedley and Franco Maddaleno; "A Single-Phase Active Power Filter With One-CycleControl Under Unipolar Operationn", IEEE Transactions on Circuits and systems vol. 51, no. 8, august 2004.

[15] J. Sebastian Tepper, Juan W. Dixon,Gustavo Venegas, and Luis Morh; "A Simple Frequency-Independent Method for Calculating the Reactive and Harmonic Current in a Nonlinear Load", IEEE Transactions on Industrial Electronics, vol. 43, no. 6, December 1995.

[16] V. B. Venkateswaran and V. Manoj, "State estimation of power system containing FACTS Controller and PMU," 2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO), 2015, pp. 1-6, doi: 10.1109/ISCO.2015.7282281.