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PLL Based Control Technique for Harmonic Elimination using Hybrid Filter

Soneji Meghal[1], Dr. Pramod S. Modi[2]

Student of M S University[1]

Associate Professor, Electrical Engineering Department, M S University of Baroda[2]

Abstract : This paper comparison between control techniques for Harmonic elimination using hybrid filter. In this, filter operation is based on PQ theory with PI control based active filter logic and PLL logic based hybrid filter is done. The proposed approach is comprised of PLL based series active filter with shunt passive filter. Here passive filter design is done based particular frequency calculations. The . The hybrid filter system is used for many simulation of different loads which reveals that it effectively compensate reactive power as well voltage and current harmonics**.**

Keyword : Hybrid Filter, Active filter , PLL, PQ theory with PI logic

I. INTRODUCTION

Electrical energy is vastly used due to it being easily transmitted to long distances and conversion from any energy form to electrical energy is easy because it is vastly studied and more studies are going on. In current times standard are made for transmission of electrical energy based on current ,Voltage and its frequency .In modern time most equipment useselectronic component like Diode, IGBT,MOSFET, SCR, GTO for transmission which have non-liner characteristics [1] .Due to this equipment effect current and voltage ofsinusoidal wave destroyed And produce current and voltage waveform fundamental plus nonfundamentalfrequency components of a distorted power frequency waveform. This nonfundamental component are called harmonics.

The harmonics present in the power lines results in high power losses in distribution which may induce noise problems in communication systems as well can reduce life of electrical equipments and sometimes may cause failure of electronic equipment which have higher sensitivity because of the presence of microelectronic control systems and these systems are low power devices and thus little noise may have higher effects [2]. These are the reasons which make the quality of power one of the most concerned issues for end user. An International standards related to electrical energy usage causes that electrical equipments should not produce harmonic contents more than that of specified values. Mean while it is essential to reduce harmonics that are due to presence of electronic components in the system[2]. Use of the passive filters is one of the classic solutions to resolve harmonic current problems, but they present several disadvantages, which are: 1)they only filter the frequencies they were previously tuned for; 2)their operation are limited to a certain load);3) Because of the interaction between the passive filter and other loads resonances may occur, which causes unpredictable results.

As a result, conventional solutions are being less used than that of active filter to perform a harmonic reduction. In these conditions it has been seen that the most effective solutionsare active filters which are able to compensate not only harmonics but also asymmetric currents which are caused by nonlinear loads and unbalanced loads [1]. Due to the recent progress in the last two decades in power electronics devices which can be force commuted, active filters have beenextensively studied and a large amount of works have been presented. These VSC topologies are further classified into two as series type and shunt type filters same as that with passive filters. There are several disadvantages for active filters as well such as : costly components , usage of extra source (if necessary) ,difficult control schemes .

There are different control strategies for active filter but most control strategies are based on PQ theory and SRF method [3]. Due to recent advancement in devices and a lot of studies based on PQ theory have been done and a few theory modified form of PQ theory has been established modified PQ theory based control strategy is implemented in this paper. A control strategy comparison of active and hybrid filter is presented in this paper. A PQ theory based PI logic control scheme and PLL logic operation on hybrid filter are shown.

1. PQ-Theory With Pi Controller

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Estimating the compensating signal is important part of the active filter control strategy. It has great impact on compensation and rating of active filter and its transient as well as steady state performance.This section deals control strategy of PQ theory based PI controller for cascaded MLI based Active filter.
The PQ theory calculates instantaneous real and imaginary reactive components of power. The theory is based on the α-β transformation which transforms three phase voltages and currents into the α-β stationary reference frame. The 3-phase voltages and currents are transformed into α-β coordinates type voltage and current mathematically.
Estimation of compensating signal is the essential part of the active filter control for better operation. It has high impact on compensation objectives, specification of active filter and its transient and steady state performance. The three phase voltages and currents are transformed into α-β coordinates according to following equation[13].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} * \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

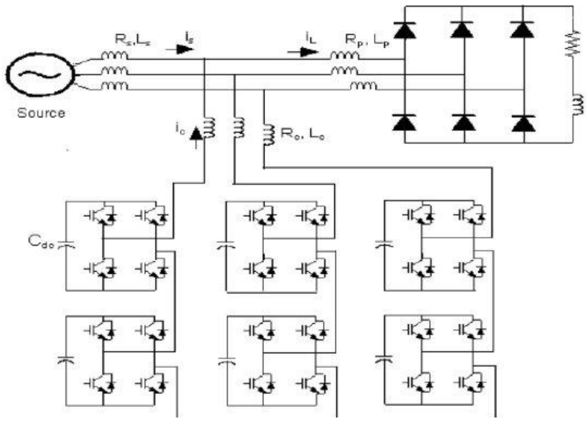

Figure-1 Cascaded five level based Active filter

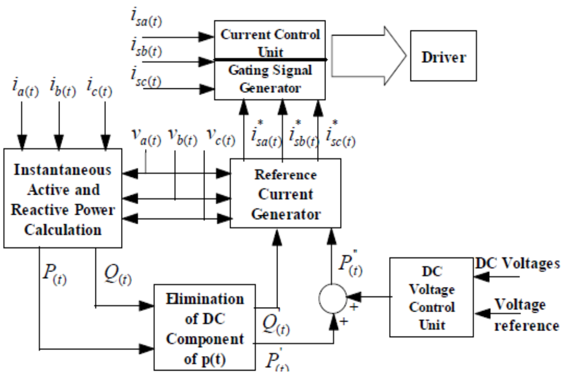

Figure-2: Control system of gating pulses generation for active filter

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} * \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Following equations shows us a way of calculating instantaneous active and reactive power in α-β coordinates [13]:

$$p_t = v_\alpha * i_\alpha + v_\beta * i_\beta$$
$$q_t = v_\beta * i_\alpha - v_\alpha * i_\beta$$

The fundamental active power component is taken out by using low pass filter. Here Active filter loss component gained from controlling DC capacitor voltages are added to fundamental of active power. The compensating currents in α-β plane are derived by following equations[13].

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \left(\frac{1}{v_\alpha^2 + v_\beta^2}\right) * \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix}$$

Then 3 phase currents are obtained by following 2-phase to 3- phase transformation by following equation:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{2/3} * \begin{bmatrix} 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} * \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix}$$

Afterwards these currents are then compared with source currents and error is generated through PI controller to generate reference currents for Active filter. The block set of the control scheme of shunt active filter using PQ theory is shown in Figure-2. In PQ theory the real and reactive powers associated with fundamental components are seen as DC quantities. These quantities can be extracted with LPF. As the signal which needs to be extracted is dc filtering thus α-β reference frame is inaffected by any phase shift errors present into by low pass filter, increasing compensation characteristics of the Active filter [10]. The limits of this theory is the requirement is pure sinusoidal supply voltages wave. In most industrial power system mains voltages are mostly unbalanced and distorted. In such case PQ theory generate errors in reference currents and limits the compensation of harmonics even the PLL is used [13].

2. PLL logic Bases Hybrid filter control technique

Filters are mainly classified into passive filters, active filters. But combining these two will in term give us a better strategy compared to both. In active filter a control strategy is needed for operation and the level of power rating and complexity and costliness while that being said passive filters are not complex but the cost increases due to need of more precise operation needed for particular operation because filters becomes bulkier and number of filters needed becomes high. Thus combining both type of filters and using them in such a way that the operations done by both are divide in both.

A schematic diagram of the system is shown in Figure-3. As seen from figure it is evident the combination of series active and shunt passive filter is done to make hybrid filter. The active filter is an inverter. The inverter operation is based on control technique of PLL logic. The passive filters are so chosen that it eliminates 5^{th} and 7^{th} harmonics. Thus in case of active operation is based on other harmonics elimination and in terms of unbalanced load condition it can eliminate supply side harmonics and reduces strain on supply side. For passive filter a LC

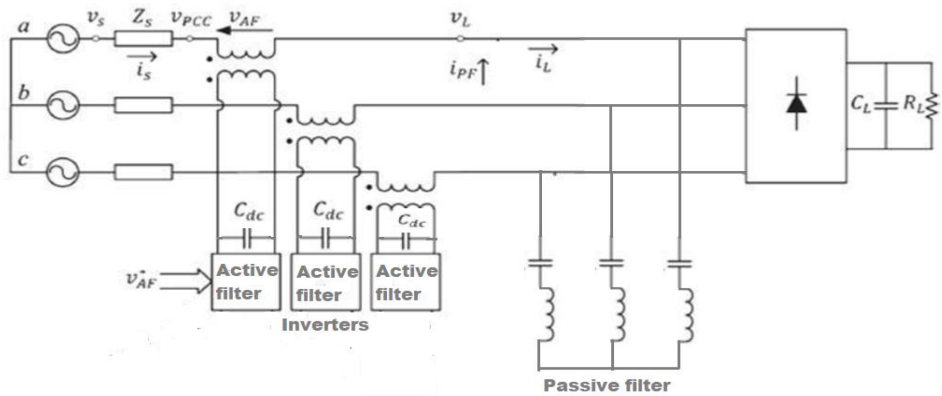

Figure-3. Schematic diagram of hybrid filter

Series combination is used as seen from figure 1. A Diode bridge is used with different combinations of RLC loads as a non-linear load. A 230V(RMS) 50Hz AC supply is used . for active filters a supply of 12V DC is used. The transformers are rated 15:200 from Primary to Secondary. The inverter is made from MOSFET switches. Simulation results for above stated specific system is obtained in MATLAB Simulink model.

2.1. PLL(Phase Locked Loop) Logic: PLL is commonly used in various signal applications e.g. radio- and telecommunications, computers and electrical motor control. The techniques can be adapted to work in a wide frequency spectrum from a few hertz to orders of gigahertz. A phase locked loop (PLL) is a system which synchronizes its output signal with a given input signal or reference signal bothin frequencyand in phase. It is a non-linear closed

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loop control: which automatically changes the frequency of a controlled oscillator depending on the frequency and phase of the input signal such that the output is matched both in frequency and phase with the reference or the input signal. The main components of a PLL are :

1.A phase detector which compares the input/reference signal and the output signal and generates an error signal.
2.A loop filter which removes unwanted harmonics erms from the error signal.
3.A voltage controlled oscillator (VCO) which generates the output signal whose frequency varies around a central frequency depending on the output of the loop filter [4] and [5].

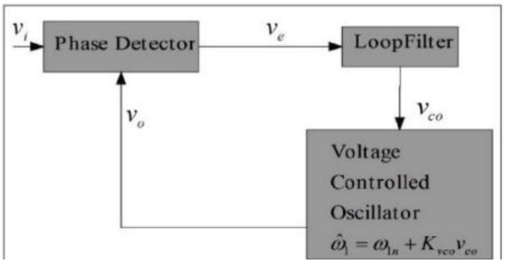

Figure-4. Block diagram of PLL Logic

There are mainly three types of PLL systems for phase tracking: zero crossing, stationary reference frame and synchronous rotating reference frame (SRF) based PLL. The SRF PLL is theone among the above mentioned with the best performance under distorted and non-ideal grid conditions. [4] .

2.1.1 Three-Phase SRF PLL (dq PLL)
The basic idea of the SRF PLL system is a feedback system with a PI-regulator tracking the phase angle. Input is the three phases of the grid voltage and output from the PLL is the phase angle of one of the three phases. In the power supply substation there will be one inverter leg for each of the three phases. There are two alternatives, either assuming the grid voltages are in balance and track only one of the phases and then shift with 120 degrees for each of the other two phases or having three PLL systems, one for each phase. Basic stricture of SRF PLL given below Figure 3.

Stationary Reference Frame αβ0 : To track the phase angle the three phase voltage signals Va, Vb and Vc are transferred from three phases to a stationary system of two phases Vα and Vβ. The grid voltages are given as. Where θ is phase angle π2+2πft. The transformation matrix is given in equation αβ is same as the voltage and write v_α-v_β.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} v_m * \cos\theta \\ v_m * \sin\theta \end{bmatrix}$$
$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} v_{m+} * \cos\theta_+ + v_{m-} * \cos\theta_- \\ v_{m+} * \sin\theta_+ + v_{m-} * \sin\theta_- \end{bmatrix}$$

Synchronous Rotating Reference Frame : The phase angle θ∗is tracked by synchronizing the voltage space vector along q or d axis in the SRF. In above discusses the value of vd and vq from equation of (6) is same as voltage so .

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} -v_m * \cos(\theta - \theta^*) \\ v_m * \sin(\theta - \theta^*) \end{bmatrix}$$
$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} v_{m+} + v_{m-} * \cos(2\omega t) \\ v_{m+} - v_{m-} * \sin(2\omega t) \end{bmatrix}$$

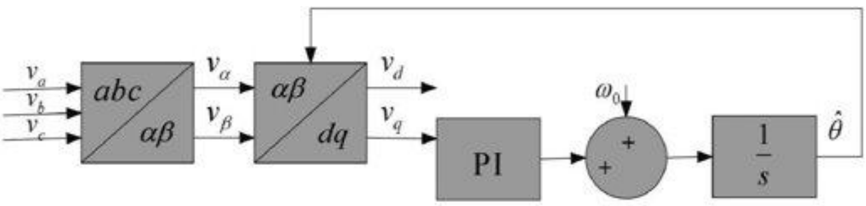

Figure-4 Basic Structure of SRF PLL

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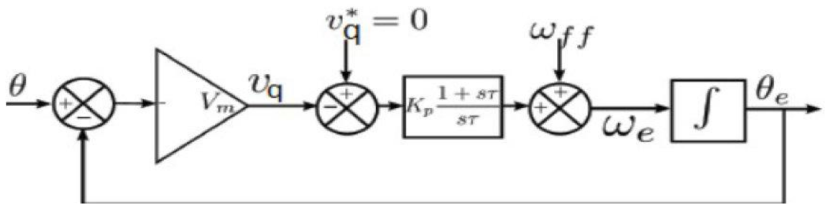

Figure-5. Simplified System for SRF PLL

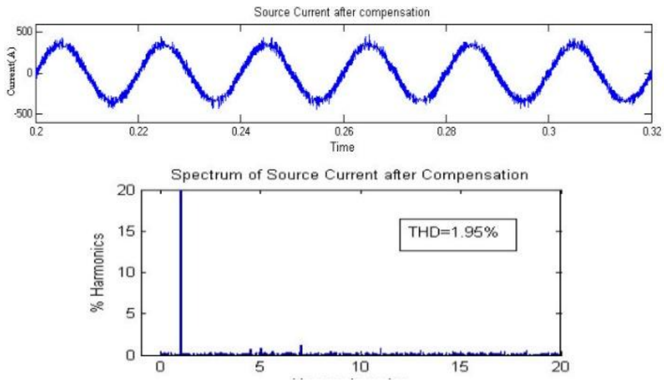

Figure-6. Source Current compensation in steady state Condition with ideal mains voltage after filter application

Here equation represents unbalanced load condition voltage equation.The phase angle θ is estimated with θ∗which the integral of the estimated frequency ω is'. The estimated frequency ω' is the sum of the PI-output and the feed forward frequency ωff. Gains of the PI-regulator is then designed so that Vq follows the reference Vq* = 0.

If Vq = 0 then the space voltage vector is synchronized along the q-axis and the estimated frequency ω' is locked on the system frequency ω. This results in an estimated phase angle θ∗* that equals the phase angle θ. if θ∗ ≈ θ then the small angle approximation for sinus function yields Vq = -Vm (θ -θ∗) and the structure in Figure 3 can be simplified, see Figure 4.

The purpose of the feed forward frequency, ω ff, is to have the PI-regulator control for an output signal that goes to zero. In our case the feed forward frequency will be 2πf = 100π. In the ideal case when the grid frequency is exactly 50Hz once the regulator has tracked the phase the output of the regulator is zero. [5]

II. SIMULATION ANALYSIS AND RESULTS

3.1PQ theory based PI logic: Current in source after compensation in steady state Condition with ideal mains voltage with THD =1.95%, but with distorted supply voltage it becomes 5.78% which is not within IEEE recommended standards. Figure-6 shows us result for PQ theory based active filter [13].

3.2 PLL logic based Hybrid filter: A typical 230V/2kVA medium voltage system is consideredin simulation, which is shown in Figure-3with all theparameters. The non-linear load is simplified as a diode rectifierwith RLC combination loads. A H-bridgeinverter-based active power filter is connected in series with the 230V System through a transformer to distribution line.

MOSFETs are used as switching device for inverter operation. Gate pulses for each phase are provided by PLL logic as represented in block diagram Figure-7 in which the signals provided are leveled down. Figure-8 and Figure-9 Shows current and voltage waveform and their FFT analysis THD Respectively. As Seen From simulation results the current THD is less than 5% From a THD of around 30%. While voltage THD improvement is not evident as that of current THD reduction. The results are as shown in below table:

Description	Compensation on	%THD
Current	Without Filter	27.40
	Load Side	28.73
	Source Side	1.20
Voltage	Without filter	6.19
	Load Side	1.87
	Source Side	1.84

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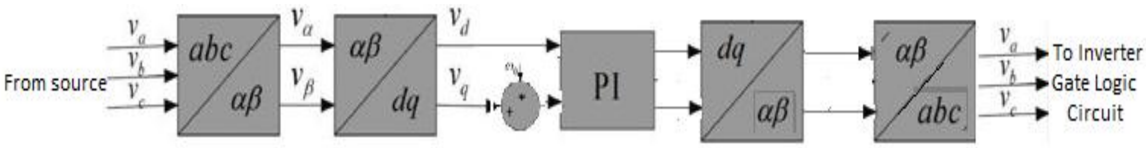
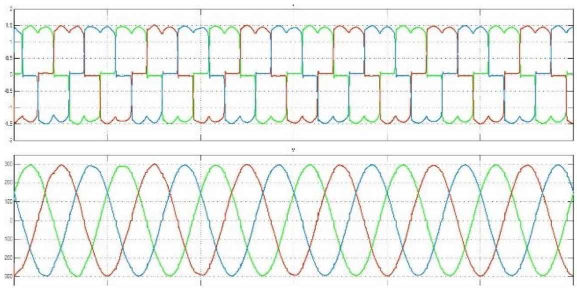
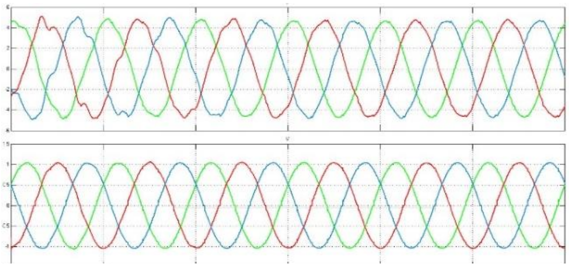


Figure-7. PLL logic Circuit Block Diagram for simulation.

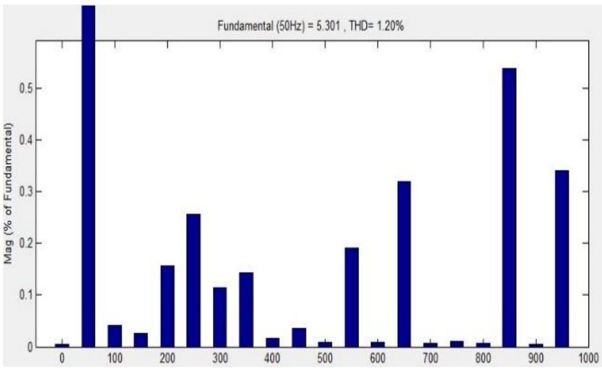


(a)For load side line current and voltage

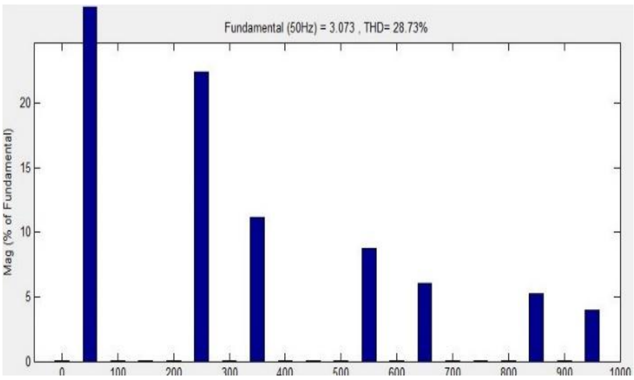


(b)For source side line current and voltage

Figure-8.Simulation Response



(a)Harmonic Spectra for load side line Current



(b) Harmonic Spectra for Source side line Current

Figure-9.FFT analysis for line Current

III. CONCLUSION

A hybrid power filter based on Series active Shunt Passive filter was developed with the control strategy to obtain almost sinusoidal voltages and currents in source side of line. The proposed filter compensates harmonic voltage source generated by contaminating loads. The performance of the system is studied by comparing the harmonic profile with and without filter. Compare to PLL logic based hybrid filter application the PQ theory based 5 level inverter gives us higher THD and the wave shape is not exactly that of sinusoidal. Thus it is evident from following result that the PLL logic is comparatively better but based on application it may become costlier than active filter.

Control strategy	Voltage THD(%)
PQ theory	2.1
PLL logic	1.84

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