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Modeling & Analysis of Shunt Active Power Filter Using IRP Theory Fed to Induction Drive

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Abstract-
Utility distribution networks have sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. Because of sensitivity of consumers on power quality and advancement in power electronics. Active power filter technology is the most efficient way to compensate reactive power and cancel out low order harmonics generated by nonlinear loads. The shunt active power filter was considered to be the most basic configuration for the APF. This paper reviews the basic principle of shunt active power filter, along with the current tracking circuit based on the instantaneous reactive power theory and the main circuit performing as an inverter with PWM hysteresis control. The instantaneous active and reactive current component (id-iq) method and instantaneous active and reactive power (p-q) method are two control strategies which are extensively used in active filters. A shunt active filter based on the instantaneous active and reactive current component (id-iq) method is proposed. This method aims to compensate harmonic and first harmonic unbalance. A Comprehensive control method is analyzed and a harmonic Compensation simulation is conducted, the result of which verifies The harmonic detection algorithm is well-proposed and the power Quality of the grid is overall-enhanced. The results are obtained using MATLAB/SIMULINK software.

Keywords- Harmonics, reactive power, current tracking, active power filter, hysteresis control, Induction Machine Drive.

I.   INTRODUCTION

Nonlinear loads introduce in the power grid current harmonics that cause considerable drawbacks such as low power factor, low efficiency, and electromagnetic interference. Passive filters have been conventionally used to eliminate specific harmonics and improve the power factor, but their bulky size, limited compensation ability and resonance susceptibility with the source impedance reduce their popularity. A considerable progress has been made then in the field of Active Power Filters (APF) in order to overcome such Filters (APF) in order to overcome such Problems [1-4]. A typical APF topology consists mainly of an inverter circuit with active devices (i.e., semiconductor switches), which can be controlled to act as a current or voltage harmonic generator. APFs are superior to passive filters in terms of filtering characteristics and stability towards a possible resonance between reactive components.

Performance of active filters for power line conditioning and their practical applications. The basic principles of compensation were proposed around 1970; however actual designs of active filters

were proposed by Gyugyi and Strycula in 1976[1]. In 1984, H. Akagi et al. [2] introduced a new concept of instantaneous reactive power theory. With the progress of power electronics, engineers started the development of electronically controlled devices that have non linear current consumption. These devices were primordially developed to increase the energy efficiency and the controllability of advanced production processes, but, since they produce harmonics, these devices are now responsible for extra energy losses and bad operation of the electrical distribution system and its components [1].

To assure a good performance Passive Power Filters have to be carefully tuned for which particular case. . Active Power Filters can be easily installed without any commissioning, and instantaneously compensate the current harmonics and the power factor [3-4]. The performance of APF is primarily compatible to the interaction of current tracking control circuit and main circuit, the latter of which acts as an inverter consisting of various power electronic devices that produce the targeted compensating current under the PWM control determined by the reference circuit.

The most widely accepted control mode is to

initially detect and calculate the harmonics in the load current, then the negative value of which represents as the reference current that triggers the control of inverter by PWM current tracking method. Consequentially, a high-pass filter (HPF) is required to eliminate the high-order harmonic generation (a byproduct of PWM hysteresis control) with frequencies close to the carrier wave. The p-q theory or instantaneous power theory is based on time domain; it makes operation in steady-state or transient state, as well as for generic voltage and current waveforms, allowing to control the active power filters in real-time. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation.

II. THE PRINCIPLE OF SHUNT ACTIVE POWER FILTER

A. Basic Structure

The shunt active filter approach is based on the principle of injection of harmonic currents into the ac system, of the same amplitude but opposite in phase to that of the load harmonic currents.
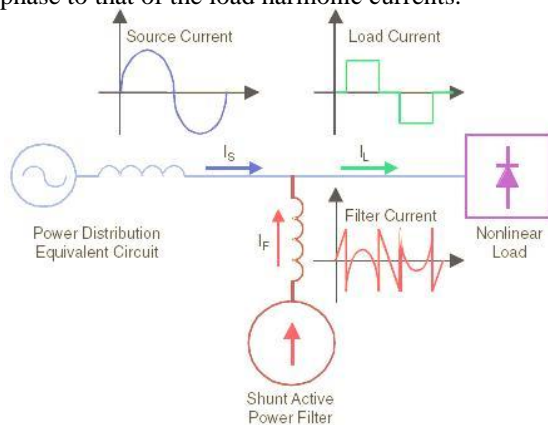

Fig.1. Basic Principle of SAPF System.

Fig. 1 shows the active power filter compensation principle, which is controlled in a closed loop manner to actively shape the source current into sinusoid.

Fig 2 demonstrates the simplified configuration of shunt APF [4], which could be dichotomized into reference current calculation section and its counterpart—compensating current generator (consisting of current control, drive and main circuit).
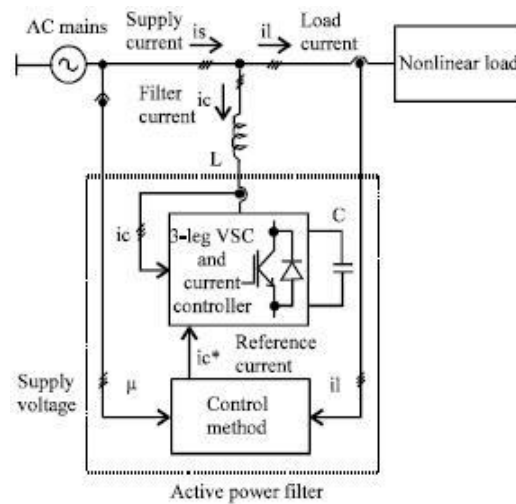

Fig.2. simplified shunt APF configuration

The core function of the reference current calculation circuit is to detect the harmonics as well as the reactive power contributed by the non-linear load.

B. The Calculation of Reference Current

The circuit of reference current calculation is essentially based on three-phase instantaneous reactive power theory [5], which suggests a novel approach to detect the three-phase harmonic current. As shown in Fig 3, i_a, i_b and i_c are initially detected and then served as the input for the next stage of algorithm, which involves specific calculation of instantaneous active current i_p as well as reactive current i_q.

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = C \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (1)$$

Where

$$C = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin \omega t & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ -\cos \omega t & -\cos\left(\omega t - \frac{2\pi}{3}\right) & -\cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \qquad (2)$$

In addition, a three-phase PLL section is prerequisite in order to grasp the angle of phase A. When i_p and i_q flow through the low-pass filter (LPF), the harmonics contained could be eliminated, and thus give rise to the DC component of the load current known as $\overline{i_p}$ and $\overline{i_q}$. With inverse transformation of the transpose matrix of CT, hence the three phase fundamental current of i_{af}, i_{bf} and i_{cf} could be readily obtained. Therefore, the reference current i_a^*, i_b^* and i_c^* is obviously the subtraction

of those fundamental three-phase currents with the correspondingly original load currents.
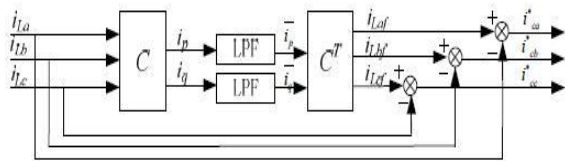
Fig.3. Algorithm of the reference current calculation circuit

*C. Current Tracking Control Circuit*

Current tracking is the first step for the production of targeted compensating current, under the basic function of obtaining the PWM signals that are responsible for the switch modes of each device in the main circuit. In addition, the PWM signal is generated by the comparison between the reference current and the real compensating current.
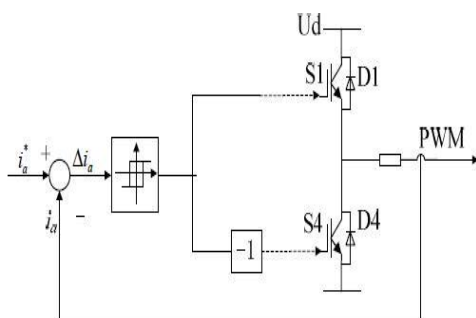
Fig.4.Circuit of current tracking control

The current-tracking-controlled PWM inverters possess various forms, the most common of which is the hysteresis current tracking control shown in Fig 4. i_a^* represents the reference value and meanwhile the tracking target of the load current. A hysteresis error h is intentionally established in case of the high frequency of switches in inverters. While $i_a^* - i_a \geq$ *h,* the hysteresis controller produces high level which drives the upper bridge arm S_1 in working mode condition, and thus increasing load current i_a even when i_a is outstripping i_a^*. The increase of load current will not be affected unless i_a is exactly greater by h comparing with the reference current, then follows the reverse working mode of hysteresis controller by switching off S_1 and simultaneously acting on S_4, which may not be necessarily switched on, for the current flows through diode D_4 is not reversed in direction but rather begin decreasing.

When the hysteresis control is applied, the real output of the current from inverters could maintain a fluctuation value only within h and − h, bouncing up and down in zigzag forms, as one of the examples illustrated in Fig.5.
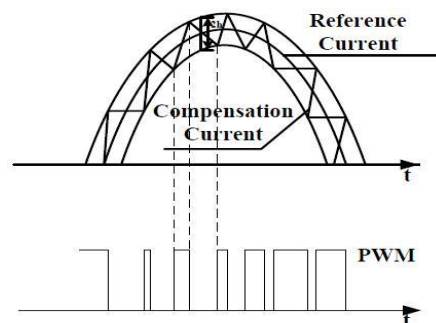
Fig.5. One example of the hysteresis control of the reference and compensating current

D. Main Circuit Parameter Design

The working mode of the main circuit is determined by the condition of its six switches. Generally speaking, there is always a single device switched on in all three groups (S_1/S_4, S_3/S_6 or S_2/S_5), constructing six different combinations all together. The main circuit is shown in Fig.6.
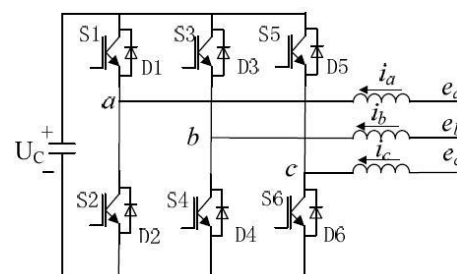
Fig.6. Main circuit

Suppose the sum of three-phase voltage source $e_a+e_b+e_c=0$ along with the current $i_a+i_b+i_c=0$, then the differential equation of phase A could be described as

$$L\frac{di_a}{dt} = e_a + K_a U_c \qquad (3)$$

In which K_a denotes the switching coefficient, while e_a represents as the instantaneous value of the ac side voltage and i_a as the compensating current. In addition, when the upper bridge arm of phase A is switched on, the absolute value of K_a is -2/3; similarly, K_a is 1/3 when the lower bridge arm is working. Provided that the sample working time is long enough, the average effect of AC voltage e_a in (2) would be zero. As the possibility of $K_a=1/3$ is 66.7% while that of $K_a=2/3$ is 33.3%, the mean of K_a is hence 4/9. Within one period of time, (2) could be reshaped as:

$$L\lambda\frac{i_{c\max}^*}{t_c} = \frac{4}{9}U_c \qquad (4)$$

Signal of compensating current; the most appropriate value of coefficient λ varies from 0.3 to 0.4 in terms of the overall effect of compensation,

which could be obtained by simulation. Taking function (3) and safety concerns into consideration, the prerequisite of $U_c \geq 3E_m$ should be granted, in which E_m is the peak value of phase voltage. Assuming that the DC side capacitor is always in transition from charging to discharging states within a single switching cycle, the maximum acceptable deviation of DC side capacitor voltage is [4]:

$$\Delta U_{c\max} = \frac{|i^*_{c\max}|}{Ct_c} \qquad (5)$$

## III.   MATLAB MODELING AND SIMULATION RESULTS

Here simulation is carried out in different cases 1). Implementation of Shunt Active Power Filter using Inverter 2). Implementation of Shunt Active Power Filter using Multilevel Inverter.

Case 1: Implementation of Shunt Active Power Filter using Inverter

Fig.7 shows the Matlab/Simulink Model of Proposed Shunt Active Power Filter using Matlab/Simulink Platform.
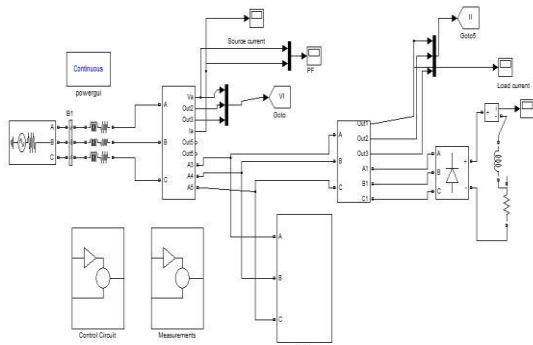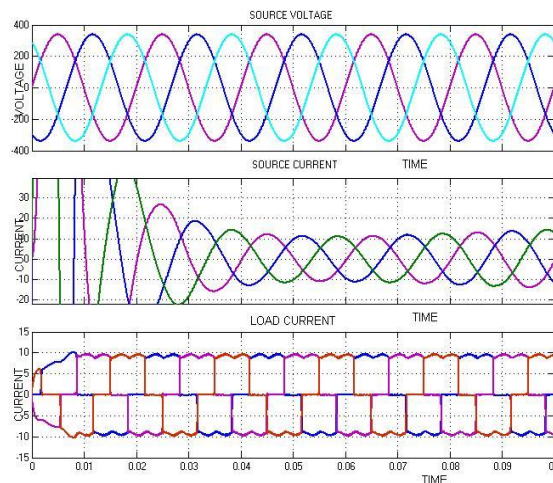

Fig.7 Matlab/Simulink Model of Proposed Shunt Active Power

Filter
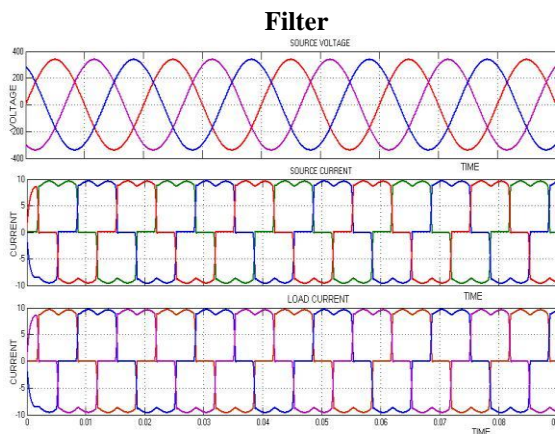
Fig. 8. Source voltage, current and load current without APF

Fig. 8 shows the three phase source voltages, three phase source currents and load currents respectively without APF. It is clear that without APF load current and source currents are same.


Fig. 9. Source voltage, current and load current with APF

Fig. 9 shows the three phase source voltages, three phase source currents and load currents respectively with APF. It is clear that with APF even though load current is non sinusoidal source currents are sinusoidal.
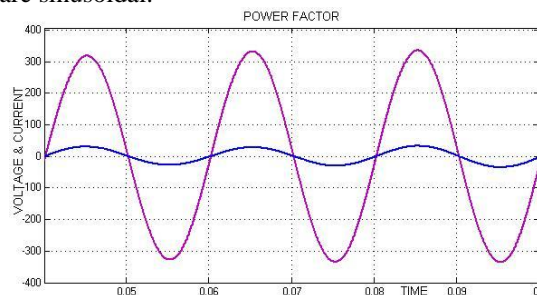
Fig. 10. Phase-A source voltage and current

Fig. 10. Shows the phase-A source voltage and current, even though the load is non linear RL load the source power factor is unity.
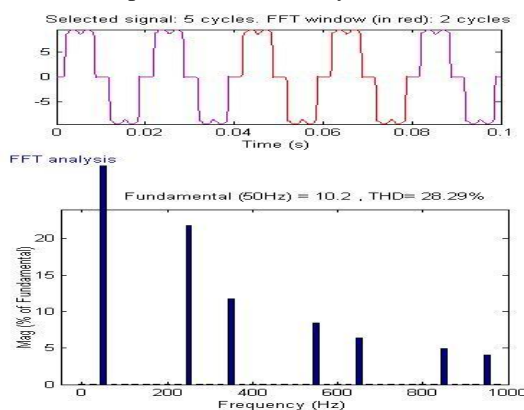
Fig. 11. Harmonic spectrum of Phase-A Source current without APF

Fig. 11. Shows the harmonic spectrum of Phase −A Source current without APF. The THD of source current without APF is 28.29%.
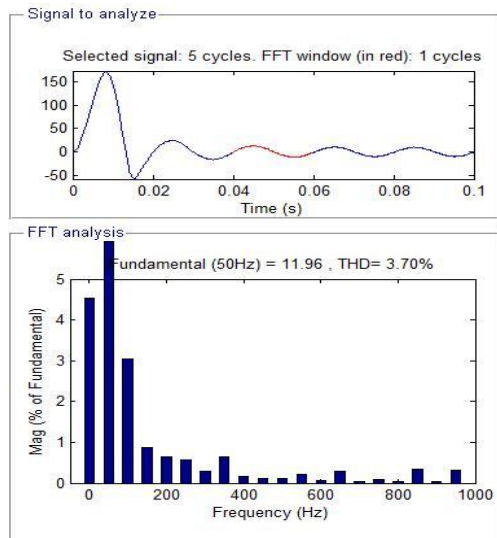

Fig. 12. Harmonic spectrum of Phase-A Source current with APF

Fig. 12. Shows the harmonic spectrum of Phase −A Source current with APF. The THD of source current without APF is 3.70%.

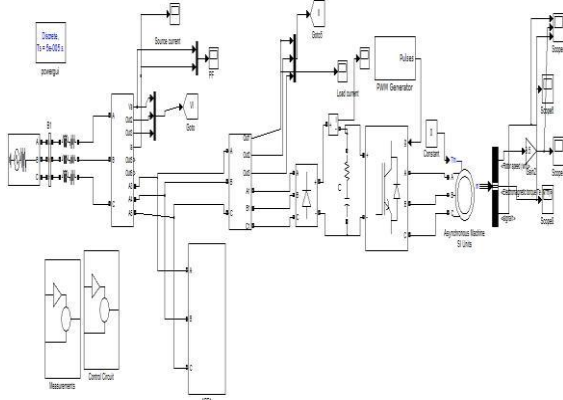*Case 2: Implementation of Shunt Active Power Filter Applied to Induction Machine Drive.*

Fig.13 Matlab/Simulink Model of Proposed Shunt Active Power

Filter Applied to Induction Machine Drive.
Fig.13 shows the Matlab/Simulink Model of Proposed Shunt Active Power Filter with Induction Machine Drive using Matlab / Simulink Platform.
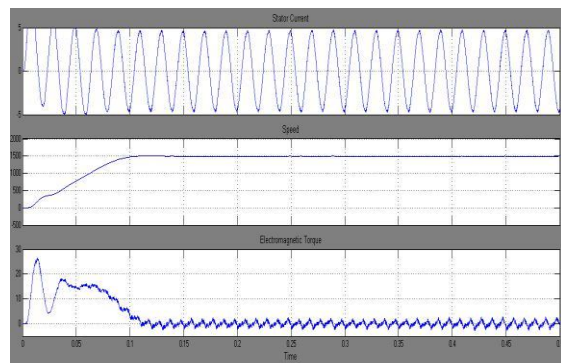

Fig.14 Stator Current, Speed, Electromagnetic Torque

Fig.14 shows the Stator Current, Speed, and Electromagnetic Torque of Proposed Shunt Active Power Filter with Induction Machine Drive.

IV. CONCLUSION

The improvement was successfully done by providing an alternative pathway for the distorted current that complementary to the nonlinear current. All power switches in the APF were well controlled using the active PWM signal and the pulse generator to perform safe commutation operation. The proposed instantaneous real-power controller uses reduced computation for reference current calculations compared to conventional approach. The proposed inverter switching signals are generated using triangular-sampling Current controller; it provides a dynamic performance under transient and steady state conditions. On the basis of the simulation, to detect harmonic wave and reactive load current efficiently, compensate the load current effectively by reshaping the source current to that similar to sine wave and reducing the THD value to below 5%. The compensation performance of the simulation result provides a practical approach to the basis of APF & applied to Induction Drive to check the performance characteristics.

REFERENCES

[1] L. Gyugyi, E. C. Strycula, "Active AC Power Filters"-in Proc.IEEE/IAS Annu. Meeting, 1976.
[2] Hirofumi Akagi, Yoshihira Kanazawa, Akira Nabae "Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components"- IEEE Trans on Industry Appl, 1984.
[3] H. Akagi, "New Trends in Active Filters*," Proceedings of EPE's 95,* Sevilla, 1995. pp. 17-26.
[4] G.Satyanarayana., K.N.V Prasad, G.Ranjith Kumar, K. Lakshmi Ganesh, "Improvement of power quality by using hybrid fuzzy controlled based IPQC at various load

conditions," Energy Efficient Technologies for Sustainability (ICEETS), 2013 International Conference on , vol., no., pp.1243,1250, 10-12 April 2013. [5] H. Akagi, Y. Kanazawa and A. Nabae, "Generalized theory of the instantaneous reactive power in three-phase circuits," *IEEE & JEEE. Proceedings IPEC, Tokyo*: IEEE, 1983, pp.1375-1386.

[4] Hongda. Li, Cao Kang, "Active Power Filter Simulation Based on Instantaneous Reactive Power Theory and the PWM Hysteresis Control Mode," *ICEMI'2011, Chengdu*: IEEE, 2011, pp.95-100.

[5] K.N.V Prasad, G.Ranjith Kumar, T. Vamsee Kiran, G.Satyanarayana., "Comparison of different topologies of cascaded H-Bridge multilevel inverter," Computer Communication and Informatics (ICCCI), 2013 International Conference on , vol., no., pp.1,6, 4-6 Jan. 2013

[6] K.A Corzine. and Y.L Familiant, "A New Cascaded Multi-level Hbridge Drive:' IEEE Trans. Power.Electron • vol. I 7. no. I. pp. I 25-I 3 I . Jan 2002.

[7] J.S.Lai. and F.Z.Peng "Multilevel converters - A new bread of converters, "IEEE Trans. Ind.Appli .• vo1.32. no.3. pp.S09-S17. May/ Jun. 1996.

[8] T.A.Maynard. M.Fadel and N.Aouda. "Modelling of multilevel converter:' IEEE Trans. Ind.Electron .• vo1.44. pp.3S6-364. Jun. I 997.

[9] P.Bhagwat. and V.R.Stefanovic. "Generalized structure of a multilevel PWM Inverter:' IEEE Trans. Ind. Appln, VoI.IA-19. no.6, pp. I OS7-1069, Nov.!Dec .. 1983.

[10]. J. Yang, Harmonic & Reactive Current Detecting Methods and a Study of Shunt Active Power Filters,Ph.D. dissertation, Xi'an Jiaotong Univ., Xi'an, 1996.

[11] Roozbeh Naderi, and Abdolreza rahmati, "Phase-shifted carrier PWM technique for general cascaded inverters," IEEE Trans. Power Electron., vo1.23, no.3, pp. I 257-I 269. May.2008.

[11]. N. G. Jayanti, M. Basu, I. Axente, K. Gaughan and. F. Conlon, "Development of Laboratory Prototype of a 12 kVA Digital Shunt Active Filter," *Proceedings of 34th IEEE Industrial Electronics Conference (IECON)*,Florida, 10th-13th November 2008, pp. 3129-3134

[12]. P. Rodriguez, J. I. Candela, A. Luna, L. Asiminoaei, R. Teodorescu and F. Blaabjerg, "Current Hormonics cancellation in Three-Phase Four-Wire Systems by Using a Four-Branch Star Filtering Topology," *IEEE Transac-tions on Power Electronics*, Vol. 24, No. 8, August 2009, pp. 1939-1950.

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