Harmonics Reduction using 4-Leg Shunt Active Power Filters

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Abstract:

Harmonics in power system are caused by highly non-linear devices which degrade its performance. Controlling and reducing such harmonics have been a major concern of power engineers for many years. The line current harmonics cause increase in losses, instability, and also voltage distortion. With the proliferation of the power electronics converters and increased use of magnetic, power lines have become highly polluted. Both passive and active filters have been used near harmonic producing loads or at the point of common coupling to block current harmonics. The "Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", proposed by Akagi et al., and also known as the p-q theory, is an interesting tool to apply to the control of active power filters, or even to analyze three-phase power systems in order to detect problems related to harmonics, reactive power and unbalance. In this project, p–q theory based a new control algorithm is proposed for 3-phase 4-wire and 4-leg shunt active power filter (APF) to suppress harmonic currents, compensate reactive power and neutral line current and balance the load currents under unbalanced non-linear load and non-ideal mains voltage conditions. The APF is composed from 4-leg voltage source inverter (VSI) with a pair of DC-link capacitors and PWM current controller. All simulations are performed by using Matlab-Simulink Power System Block set. The performance of the 4-leg APF with the proposed control algorithm is found considerably effective and adequate to compensate harmonics, reactive power and neutral current and balance load currents under all non-ideal mains voltage scenarios. Simulation results obtained with MATLAB employing a three phase four wire shunt active filter test system.THD plots with and without APF is presented.

Keywords — *Harmonics, DSTATCOM*

I. INTRODUCTION

Due to the widespread increase of non-linear loads now a days, significant amounts of harmonic currents are being injected into power system [1]. Harmonic currents flow through the power system, causing voltage distortion at the harmonic current's frequencies. The distorted voltage waveform causes harmonic currents to be drawn by other loads connected at the point of common coupling (PCC) [2-4]. The existence of current and voltage harmonics in power system increase losses in the lines decrease the power factor and can cause timing errors in sensitive electronic equipments.

The harmonic currents and voltages produced by balanced 3-phase non-linear loads such as motor drivers, silicon controlled rectifiers (SCR), large uninterrupted power supplies (UPS) are positive-sequence harmonics (7th, 13th, etc.) and negative-sequence harmonics (5th, 11th, etc.). However, harmonic currents and voltages produced by single phase non-linear loads such as switched mode power supplies(SMPS) in computer equipment which are connected phase to neutral in a 3-phase 4-wire system are third order zero-sequence harmonics (triplen harmonics-3rd, 9th, 15th, 21st, etc.) [5]. these triplen harmonic currents unlike positive and negative-sequence harmonic currents do not cancel but add up arithmetically at the neutral bus. This can result in neutral current that can reach magnitudes as high as 1.73 times the phase current. In addition to causing damage of cables and transformers overheating the third harmonic can reduce energy efficiency.

The traditional method of current harmonics reduction involves passive LC filters, which are known for its simplicity and low cost. However, passive filters have several drawbacks such as large size, tuning and risk of resonance problems. On the contrary, the 4-leg APF can solve problems of current harmonics [6-8], reactive power, load current balancing and excessive neutral current simultaneously, and can be a much better solution than conventional approach.

The "Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", proposed by Akagi et al., and also known as the p-q theory has been used very successfully to design and control of the APF for 3-phase systems. This theory was extended by Aredes et al. for applications in 3-phase 4-wire systems. The IRP theory was mostly applied to calculate the compensating currents [9-10].

The control strategy for a shunt active power filter generates the reference current, that must be provided by the power filter to compensate reactive power and harmonic currents demanded by the load [11]. This involves a set of currents in the phase domain, which will be tracked generating the switching signals applied to the electronic converter by means of the appropriate closed-loop switching control technique.

II. MODELLING OF 4 LEG SHUNT ACTIVE POWER FILTER

According to EPRI (Electrical power research institute), 70% of the loads are non-linear loads which are injecting harmonics into the power system. These harmonics cause detrimental effects on power quality. To mitigate these harmonics many topologies have been introduced.

The traditional method of current harmonics reduction involves passive LC filters, which are its simplicity and low cost. However, passive filters have several drawbacks such as large size, tuning and risk of resonance problems. On the contrary, the 4-leg APF can solve problems of current harmonics, reactive power, load current balancing and excessive neutral current simultaneously, and can be a much better solution than conventional approach. Here we have implemented shunt active power filter by considering a three phase four wire distribution system.

Developed a model considering a 415v, 3-phase 4-wire distribution system with tapped linear as well as non- linear loads, created a situation such that the linear load switch alternatively for every 0.1 sec which creates unbalance and transients in the system. The below figure shows the Matlab/Simulink based model of the considered system.

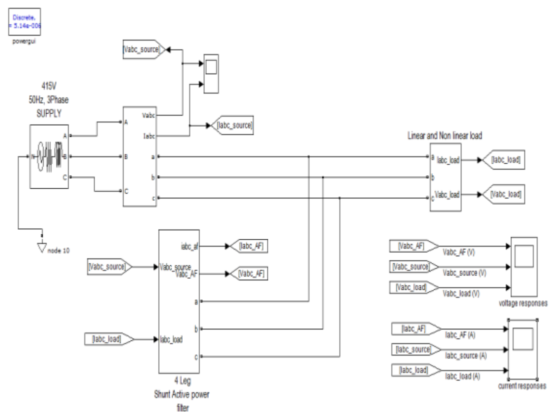

Fig. 2.1 3-Phase 4-Wire Simulink Model with 4-Leg Shunt Active Power Filter

The system model comprises of three main parts.

- ➢ Linear load
- ➢ Non- linear load(diode bridge)
- ➢ 4-Leg Active Power Filter

A. Linear Load

A three phase RL load is considered whose switching is achieved by connecting circuit breaker (CB) which switches for every 0.1 sec. Initially the breaker is closed. The switching of circuit breaker causes unbalance and transients in the system.

Linear load Parameters
Voltage=415v
Active power =100 KW
Reactive power=10 KVAR
Frequency=50 Hz

B. Non-Linear Load

Here a six-pulse diode bridge is connected to RL load as shown below. A star neutral-star connected transformer used to enable the neutral connection. Here the non-linear load is always connected to the circuit.

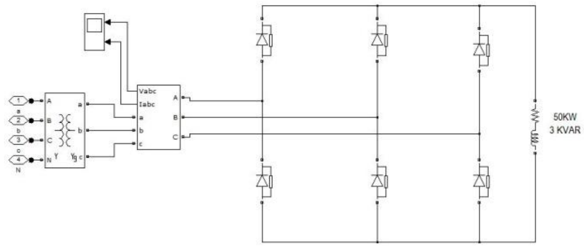

Fig. 2.2.Sub System-Six Pulse Diode Based Converter with R-L Load

Non-linear load parameters
Voltage=415v
Active power=50KW
Reactive power=3KVAR
Frequency=50Hz

C. Active Power Filter

A three- phase four-wire split phase four leg shunt active power filter is modelled based on Instantaneous Reactive Power Theory (pq-theory) as shown below.

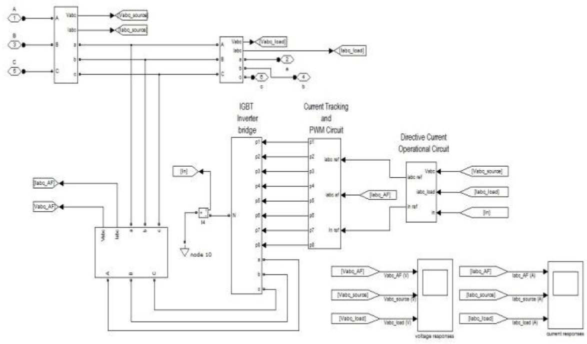

Fig.2.3. Subsystem – IGBT Inverter with pq Controller

It consists of

- ➢ IGBT inverter bridge
- ➢ DC operating circuit based pulse generator
- ➢ Current tracking and PWM circuit.

D. IGBT Inverter Bridge

It is a four leg inverter bridge as shown below. The fourth leg is connected to neutral of the system. A pair of capacitors (split phase) are provided to input the dc voltage. Firing pulses are generated by considering pq theory. To limit the filter current use series impedance.

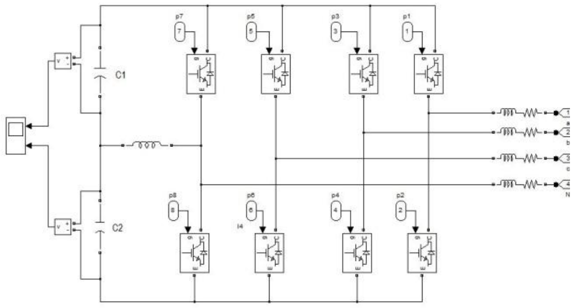

Fig.2.4 3-Phase 4-leg IGBT Inverter

Parameters

$C_1=C_2=2200\mu F$
$R_a=R_b=R_c=3\Omega$
$L_a=L_b=L_c=30mH$
Neutral impedance: $R_n=2\ \Omega$, $L_n=100mH$

III. SIMULATION RESULTS

The simulation results are obtained through Power system tool boxes in SIMULINK by taking system parameters as mentioned in the previous chapter. The simulation and test results without and with shunt active power filter configuration is presented here.

A. Results Without Filter

The current waveforms of source, non-linear load, linear load and Total Harmonic Distortion (THD) of source voltage and source current without filter is shown below

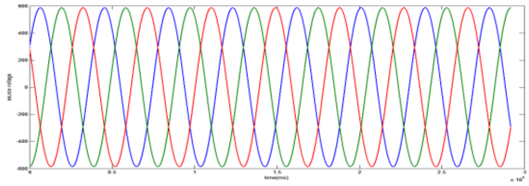

Fig.2.1 Source Voltage Waveform (without filter)

Due to the presence of non-linear load and due to switching action of linear load for every 0.1 sec. observed harmonics in supply voltage.

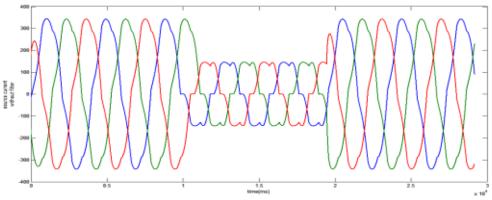

Fig.2.2 Source Current Waveform without Shunt Active Power Filter

In the system considered non-linear load always exists in the system and linear load switches for every 0.1 sec. Due to the switching action source current is abruptly high for 0.1sec when both linear and non linear loads are present. For 0.1 sec. to 0.2 sec. when only non linear load is present source current is reduced greatly. Switching action even though causes unbalance in the system.

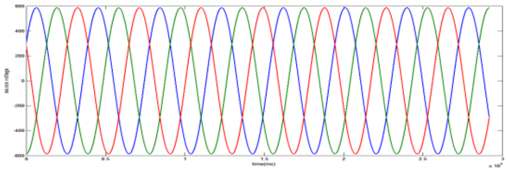

Fig.2.3 Load Voltage Waveform without Filter

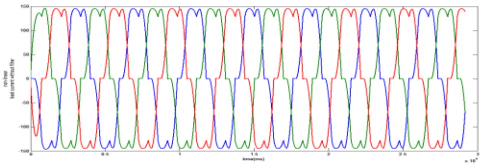

Fig.2.4 Non-linear Load Current Waveform (without filter)

Non-linear load current causes unbalance in the system .The THD of the nonlinear load current is 19.9%.

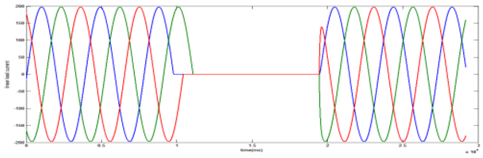

Fig.2.5 Linear load current waveform (without filter)

Linear load switches for every 0.1 sec. During this period load current flows. For 0.1sec to 0.2 sec. linear load is switched off, thereby creating unbalance in the system.

Variation of source current and Non-linear load current due to switching of the linear load is shown in Fig 2.4 and Fig 2.5 respectively. From the above figure it is observed that due to the presence of non-linear load and switching of the linear load the source current waveform is distorted and is not in sinusoidal form.

B. Total Harmonic Distortion Without Filter

The THD in the source current without filter is obtained using FFT analysis tool box in Matlab

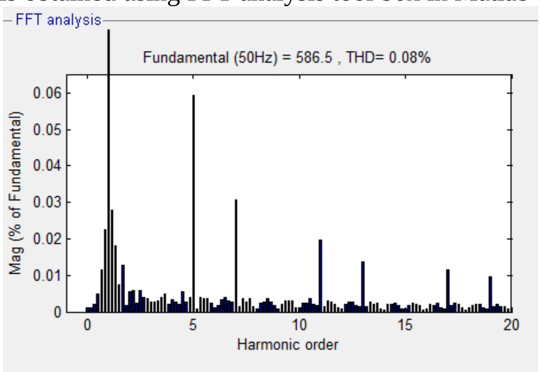

Fig.2.6 THD of Source Voltage

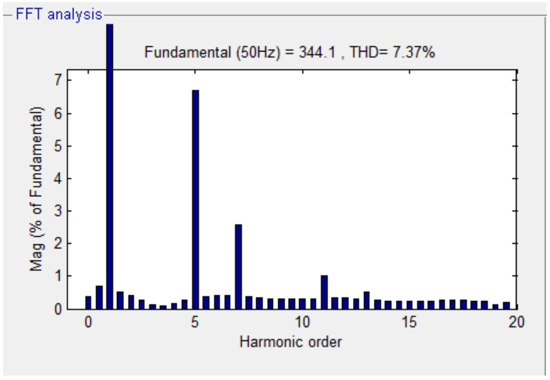

Fig.2.7 THD of Source Current

C. Results With Shunt Active Power Filter

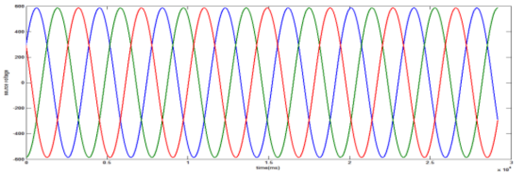

Fig.3.1 Source Voltage Waveform with Shunt Active Power Filter

Due to the presence of non-linear load and due to switching action of linear load for every 0.1 sec. Observed harmonics in supply voltage

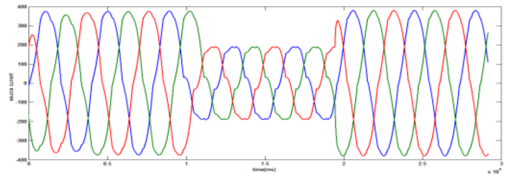

Fig.3.2 Source Current Waveform with Shunt Active Power Filter

In the system considered non-linear load always exists in the system and linear load switches for every 0.1 sec. Due to the switching action source current is abruptly high for 0.1sec when both linear and non linear loads are present. For 0.1 sec. to 0.2 sec. when only non linear load is present source current is reduced greatly. Switching action even though causes unbalance in the system due to filter THD is still maintained to 1.57%

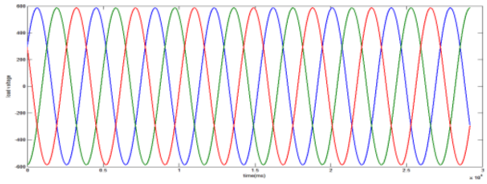

Fig. 3.3 Load Voltage Waveform with Shunt Active Power Filter

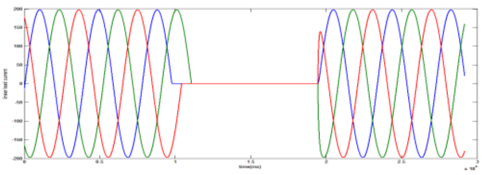

Fig. 3.4 Linear Load Current waveform with Shunt Active Power Filter

Linear load switches for every 0.1 sec. During this period load current flows. For 0.1sec to 0.2 sec. linear load is switched off, thereby creating unbalance in the system.

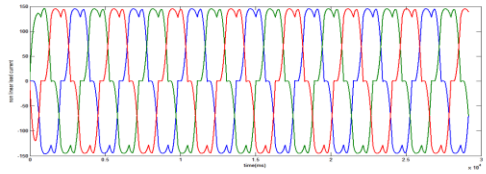

Fig. 3.5 Non-linear load current waveform with shunt active power filter

The non linear load current causes unbalance in the system .The THD of the nonlinear load current is 19.9%. Though non-linear load injects harmonics in the system still source parameters are within limits due to the presence of shunt active power filter.

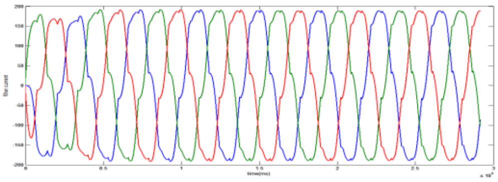

Fig. 3.6 Active Filter Current Waveform

The type of filter here used is band reject filter which rejects 50Hz supply and rest of the harmonics are passed through. The filter injects corresponding current in the system with 180 degrees phase shift to harmonics there by eliminating the harmonics from source current.

The split phase capacitor voltage waveforms are shown below

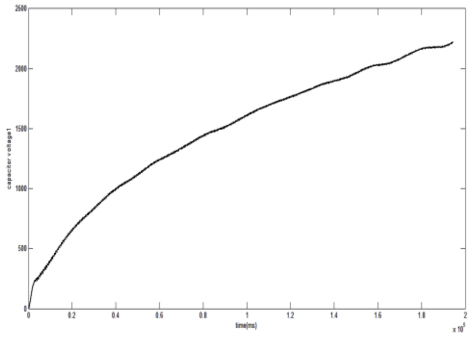

Fig. 3.7 Capacitor-1 Voltage Wave Form

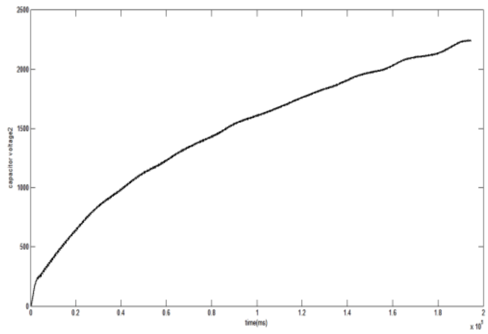

Fig. 3.8 Capacitor-2 Voltage Waveform

PARAMETERS	THD% WITHOUT FILTER			THD% WITH FILTER		
	PHASE A	PHASE B	PHASE C	PHASE A	PHASE B	PHASE C
Source voltage	0.08	0.08	0.07	0.03	0.03	0.02
Source current	9.76	9.92	10.20	1.83	1.94	2.54

D. Total Harmonic Distortion With Filter

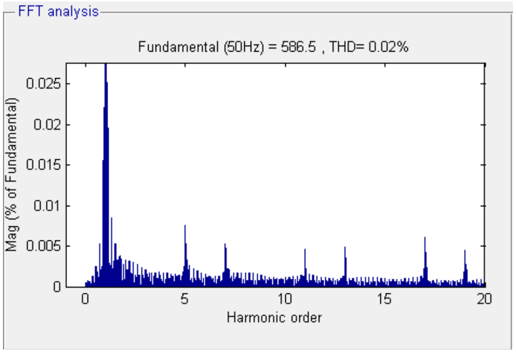

Fig. 3.9 THD of Source Voltage

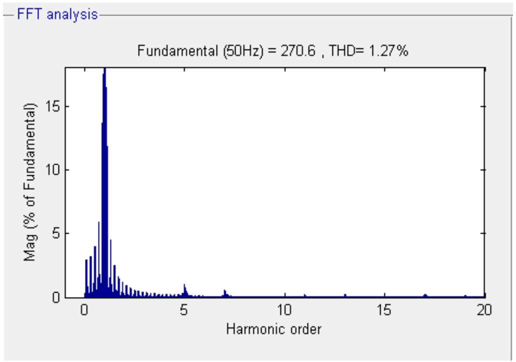

Fig. 3.10 THD of Source Current

Table 3.1 Comparison Table of %THD without and with Filter

IV. CONCLUSIONS

A generic 3-phase 4-wire distribution system was considered. 4-leg Shunt active power filter is implemented in order to provide acceptable THD.

THD of source voltage waveform has been reduced from 0.076% to 0.025%, THD of source current waveform has been reduced from 9.96% to 1.85%

REFERENCES

[1] H. Akagi, Y. Kanazawa, A. Nabae, "Generalized Theory of the Instantaneous Reactive Power in Three- Phase Circuits", IPEC'83 - Int. Power Electronics Conf., Tokyo, Japan, 1983, pp. 1375-1386.

[2] H. Akagi Y. Kanazawa, A. Nabae, "Instantaneous Reactive Power Compensator Comprising Switching Devices without Energy Storage Components", IEEE Trans. Industry Applic., vol. 20, May/June 1984.

[3] E. H. Watanabe, R. M. Stephan, M. Aredes, "New Concepts of Instantaneous Active and Reactive Powers in Electrical Systems with Generic Loads", IEEE Trans. Power Delivery, vol. 8, no. 2, April 1993, pp. 697-703.

[4] M. Aredes, E. H. Watanabe, "New Control Algorithms for Series and Shunt Three-Phase Four- Wire Active Power Filters", IEEE Trans. Power Delivery, vol 10, no. 3, July 1995, pp. 1649-1656.

[5] J. L. Afonso, C. Couto, J. S. Martins, "Active Filters with Control Based on the p-q Theory", IEEE Industrial Electronics Society Newsletter, vol. 47, nº 3, Set. 2000, pp. 5-10.

[6] J. L. Afonso, H. R. Silva, J. S. Martins, "Active Filters for Power Quality Improvement", IEEE Power Tech'2001, Porto, Portugal, 10-13 Set. 2001.

[7] [7] Simulink – Model-Based and System-Based Design, Modelling, Simulation, Implementation, version 5, The MathWorks, July 2002.

[8] M. Peterson and B. N. Singh, "Active and passive filtering for harmonic compensation,"IEEE Conference 40th south-eastern symposium on system theory, USA, pp. 188-192,March 2008

[9] Roger C. Dugan, Mark F. McGranaghan, H. Wayne Beaty: Electrical Power Systems quality. New York: McGraw Hill, c1996

[10] IEEE STD 1531-2003, IEEE Guide for Application and Specification of Harmonic Filters.

[11] J. Arrillaga, R. W. Neville, "Power System Harmonics", 2nd Edition, 2003, John Wiley & Sons.J. Breckling, Ed., The Analysis of Directional Time Series: Applications to Wind Speed and Direction, ser. Lecture Notes in Statistics. Berlin, Germany: Springer, 1989, vol. 61.