DYNAMIC HYBRID SHUNT ACTIVE FILTER TO REDUCE THE THD IN 415 V, 50 Hz DISTRIBUTION SYSTEM

Sellakumar S.[1] Vijayakumar M.[2] Rajendran V.[3]

[1]Research Scholar, Sathyabama University
[2]JNTU, Anantpur
Email: [1]sellakumarin@gmail.com, [2]mvk_2004@rediffmail.com, [3]drvrajan@gmail.com

ABSTRACT

This paper deals with the dynamic harmonic filtering using hysteresis current control based hybrid shunt active filter. The main harmonic sources of distribution system are the non linear loads and frequent switching surges industrial loads. The non linear loads have unequal loading over a period of supply thus it alters the voltage and hence current. The switching of loads produces voltage sag and swells which leads to harmonics in the lines. The proposed hybrid shunt active filter is fully characterized by series LC and shunt DC link connected through 3-phase active filter. The disturbances in the supply voltage and load current due to frequent switching and non linear loads of 415 V, 50 Hz distribution system are observed using CW240 power quality meter. The same is simulated in MATLAB with and without filter. The simulation results obtained from the proposed method proves that it gives comparatively better THD value.

KEYWORDS Hysteresis Current Control [HCC], Active Power Filter [APF], Distribution System [DS], shunt active filters, Voltage Regulation [VR], Power Factor [PF] and Total Harmonic Distortion [THD].

I. INTRODUCTION

Harmonic pollution and reactive power in the power system are the important power quality problems. With the proliferation of non-linear loads in industrial applications and frequent switching of loads in the distribution systems, the compensation of harmonic and reactive power is becoming increasingly concerned. Shunt passive filters have been widely used because of their low cost and low loss. However, the performances of the filters are very sensitive to the power system impedance and series or parallel resonance with the power system impedance may occur. Also, the effective compensation with the variation of the voltage cannot be carried out with passive filters. The filter performance of shunt active power filter does not depend on the power system impedance or any other constant parameters. The compensation of harmonic and reactive power can be achieved dynamically in the case of APF. The research in this field has been done for many years and researchers proposed several methods of improving THD value up to 4% by eliminating harmonics selectively or reducing it by using different filtering techniques in the active filters. The References papers have reported field test results of active filters intended for installation on power distribution systems. The active filter is characterized by behaving like a resistor for harmonic frequencies, resulting in damping out the harmonic amplification throughout a distribution line. Since the proposed distribution system consists of four distribution lines, installing the active filter on the end bus of each line is effective in harmonic damping. A static synchronous compensator is one of the most effective solutions to regulate the line voltage. However, no literature has addressed the dynamic behaviour of the active filter when it performs both harmonic damping and voltage regulation at the same time. The reactive power flow, the voltage and current variations in the 415 V, 50 Hz distribution system are observed using power quality meter and same is verified in the simulation. The novel hybrid shunt active filter is designed and simulated in MATLAB for same application. The simulation results are shown to verify the effectiveness of the active filter capable of harmonic damping.

II. HYBRID SHUNT ACTIVE FILTER FOR A DISTRIBUTION SYSTEM

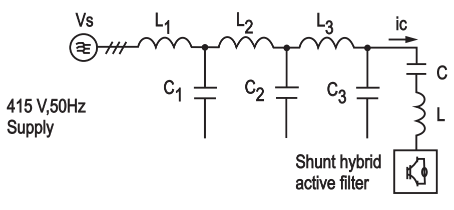


Fig. 1. A Distribution system with filter [one line circuit]

A. Harmonic Amplification & Damping

The Inductor in the fig 1 is the resultant of a leakage inductance of a distribution transformer to line inductances. The Capacitors are the PFC capacitors installed by consumers. It is observed that the fifth and seventh harmonic voltages present in the system. The "harmonic amplification" is resulting from resonance between the inductance and the capacitance on the line and its effect is more during day time compared to night time. The shunt active filter for damping out harmonic propagation is connected to a distribution system. Fig. 2 shows the simplified Distribution System having a shunt hybrid active filter proposed in this paper. The transformer in the pure filter is replaced by a capacitor in the hybrid filter. The purpose of the capacitor is to impose high impedance to the fundamental frequency so that the fundamental voltage appears exclusively across the capacitor. This means that no fundamental voltage is applied across the active filter.

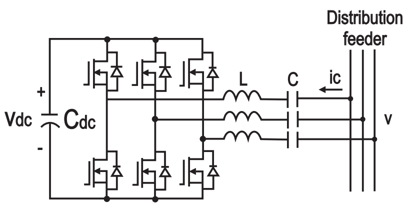


Fig 2. A typical 3 Φ Hybrid Shunt Active filter

Fig 2 shows the detailed power circuit of the hybrid filter, which consists of a three-phase voltage-fed PWM inverter and [switches are named as per their conduction sequence] a series connection of L and C per phase. Note that the tuned frequency of L and C is not the fifth-harmonic frequency but around the seventh-harmonic frequency. The reason is that the seventh-tuned *LC* filter is less bulky than the fifth-tuned *LC* filter as long as both filters have the same inductor as L. The dc-bus of the PWM inverter has only a capacitor without external supply, and the dc-bus voltage is controlled by the hybrid filter. The hybrid filter is controlled so as to draw the compensating current i_c from the distribution line.

B. Operating Principle

The compensating current of the hybrid shunt active filter consists of a fundamental component and harmonic components and they are determined by the impedance of the *LC* filter and are controlled by the active filter. Three-phase voltages and currents are detected in the lines of DS. The harmonic voltage V_h in each phase is extracted from the detected three-phase currents, and then the harmonic current is amplified by a control gain K_v. Thus the harmonic current reference i_{ch} is given by

$$i_{ch} = K_v{}^*V_h \quad ...(1)$$

The actual harmonic compensating current ich is extracted from the detected compensating current i_c. Assuming that it is equal to its reference i_{ch}, the hybrid filter behaves as a damping resistor of$1/K_v$ [V/A] for harmonic frequencies. The optimal value of K_v is equal to the inverse of the characteristic impedance of the distribution feeder. With this value, the hybrid filter can damp out harmonic propagation effectively.

III. EXPERIMENTAL SYSTEM [PROPOSED]

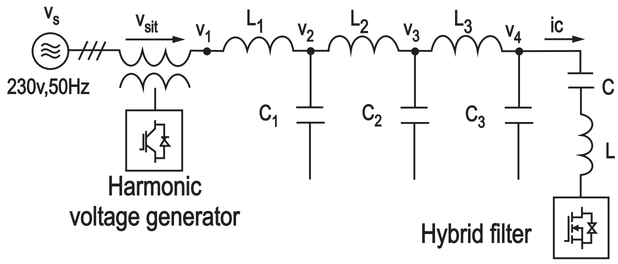


Fig 3. Single line diagram of experimental system

In the experimental the harmonics are generated either by switching the load frequently or by connecting a non linear load as shown in Fig.3. A three-phase power distribution feeder simulator rated at 230 V, 50 Hz, and 20 kW is used for the laboratory experiments. Table 1 summarizes the line simulator parameters. When a lossless line is assumed, the characteristic impedance of the feeder simulator Z_o can be calculated as

$$Zo = \text{sqrt}\ (L/C) \quad ...(2)$$

A shunt hybrid active filter component values given in the table – 2 is connected to the bus. The dc-bus voltage of the PWM inverter is controlled to be 40 V. Note that the dc-bus voltage as low as 40 V in the 230-V system corresponds to a dc-bus voltage as low as 1.3 kV. This means that adopting a diode-clamped three-level inverter allows us to use 1200-V IGBTs that are easily available on the market at low cost. Referring to [7], the control gain Kv should be set to the inverse of the characteristic impedance of the feeder.

Table 1. Parameters of the feeder simulator

Line inductance	L_a=L_b=L_c	0.22 Mh
Line Resistance	R_a=R_b=R_c	0.02 or 0.05Ù
Line Capacitance	C_a=C_b=C_c	350 μ F

Table 2. Parameters of the Hybrid Filter

LC filter inductor	L	2 mH
LC filter capacitor	C	100 μ F
Resonant frequency	fr	356 Hz
Quality factor	Q	20

IV. HCC PRINCIPLE

The bidirectional switches shown in Fig. 2 are controlled with hysteresis current control technique. In the balanced three phase system and unity power factor operation, the three-phase voltages and reference currents are equal in magnitude and displaced by 120^0. The switches S_1, S_3, and S_5 conduct when corresponding Phase voltage is in positive half cycle and the bidirectional switch is in the switch-off state. Similarly, switches S_4, S_6, and S_2 conduct when corresponding phase voltage is in negative half cycle and the bidirectional switch is in the switch-off state. In order to prove the instantaneous power balance between ac source and dc bus, the local average method is adopted [5]-[6]. In fig 4, phase a current i_a is controlled to track the reference current within the window width I_w and same way the other two phases are carried out.

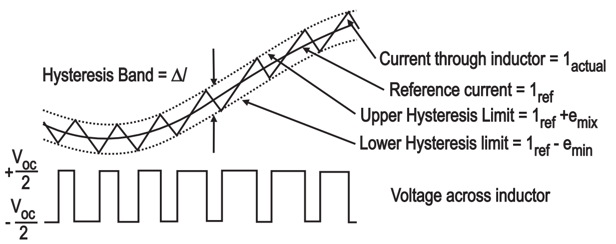


Fig 4. Currents within one switching period

The phase a current being switched between upper and lower bounds to track the reference current (upper trace); Switch S_1 current (mid-trace); bidirectional switch S_a current (lower trace) in the balanced three phase system and unity power factor operation.

V. TEST RESULTS

A 415 V, 50 Hz Distribution system feeds power for the machines laboratory in the college is chosen to test the power quality. The laboratory consists of induction motors and DC motors which will be operated frequently during the experimentation. The DC machines are fed by a SCR based 220 V, 100 A rectifier. Hence the laboratory consists of linear and non linear loads. The voltage sag & swell, current variations, real & reactive power flow, power factor and the THD values monitored using Yokogawa CW 240 power quality analyser. The results of them are given below and are taken by using print screen option in the instrument.

Table 3 Test results

LIST END LOAD1 INST. 2011/06/29 15:13:35

U1	224.5	V	I1	75.1	A	WIRING 3P4W
U2	225.0	V	I2	77.0	A	LOAD 1
U3	226.5	V	I3	35.9	A	
Uave	225.4	V	Iave	62.7	A	U 600V x 1.00
						A 200A x 1.00
P	38.2	kW	PA	25.4	°	
Q	17.3	kvar	f	49.80	Hz	PLL U1 50Hz
S	42.3	kVA				
PF	0.903					INTER. 1min

DISPLAY CHANGE | ITEM CHANGE | SETTING CHECK | HOLD /CLEAR

The table 3 readings are the values of supply voltage, line current, real & reactive power, power factor and frequency under normal condition. The voltages in the phases are acceptable limit but the current in all three phases differs much and it indicates that the system is unbalanced.

The table 4 gives the values of voltage sag occurred in the system. The voltages shown in the tables are phase values and against the standard of 239.6 V. It is observed that non of the phase has the standard value and fluctuates between 185V to 238V.

This 20% of voltage fluctuations leads to abnormal variations of current and performance of the loads.

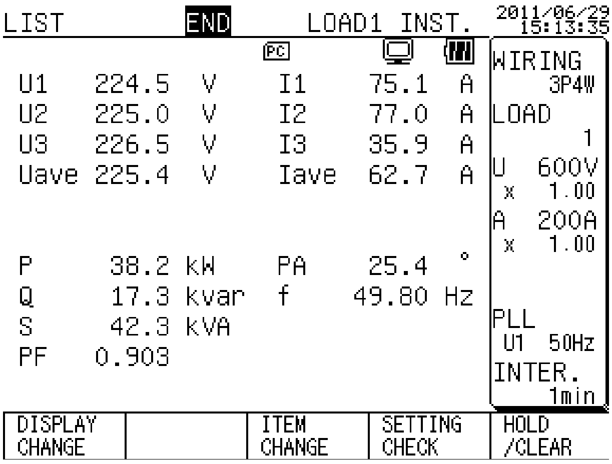
Table 4. Voltage sag in a System

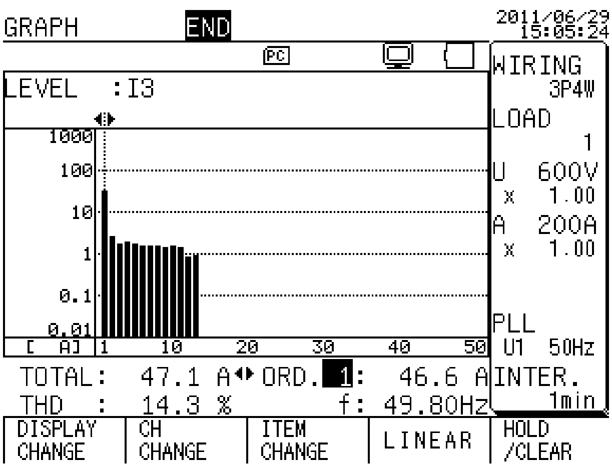
VOLT.QUALITY END ALL 2011/06/29 15:13:29

26/100

Date	Time	Itm	CH	IO	RMS	Period
06/29	15:11:47.870	Dip	1	I	202.0 V	00:00:00.000
06/29	15:11:47.870	Dip	2	I	208.6 V	00:00:00.000
06/29	15:11:47.890	Dip	2	O	233.5 V	00:00:00.020
06/29	15:11:47.890	Dip	3	I	215.0 V	00:00:00.000
06/29	15:11:47.910	Dip	3	O	226.4 V	00:00:00.020
06/29	15:11:48.185	Dip	1	O	223.9 V	00:00:00.315
06/29	15:11:48.202	Dip	1	I	185.2 V	00:00:00.000
06/29	15:11:48.222	Dip	1	O	220.1 V	00:00:00.020
06/29	15:11:48.222	Dip	3	I	213.4 V	00:00:00.000
06/29	15:11:48.239	Dip	3	O	226.3 V	00:00:00.017
06/29	15:11:48.256	Dip	3	I	210.1 V	00:00:00.000
06/29	15:11:48.274	Dip	1	I	214.6 V	00:00:00.000
06/29	15:11:48.274	Dip	3	O	238.6 V	00:00:00.018

DISPLAY CHANGE | ITEM CHANGE | SAVE | | HOLD /CLEAR





The current in B phase is traced for its THD. It is observed that it consists of abnormal THD of 14%. The poor THD leads to power quality problem and hence it has to be limited to within 5% of allowable value.

The bar chart of the harmonics is shown in the above figure. It shows that the distribution system consists of many harmonics with almost same magnitude. Hence the compensation system can focus on overall Harmonics.

VI. CONTROLLER DESIGN

The load current samples are fed to the PLL to generate their fundamentals and are transferred from three phase to two phase quantities. The ripples are filtered by LPF and then they are transformed to three phase quantities. This reference current ($i_{refa,}$ $i_{refb,}$ i_{refc}) is added with the load current $i_{a,}$ $i_{b\ \&,}$ i_c by comparator. The error generated is then sending to the HCC. The hysteresis current controller (HCC) generates pulses based on the current window width (I_w). The pulses are used to trigger the switches in the filter such a way that the filter observes the harmonics when the error current exceeds the window width and it injects the current i_{n2} when the error current is below I_w. Thus the harmonics in the load currents are minimised much better than the methods like sliding mode control, shunt or series active filters exc. The simulation model and its results are given in the following figures 5 & 6.

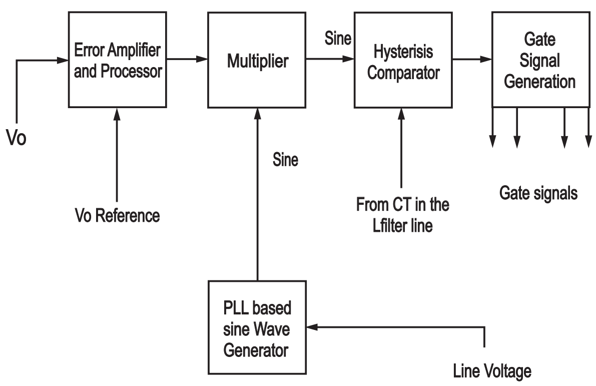


Fig 5 Block Diagram of Triggering Pulse Generator

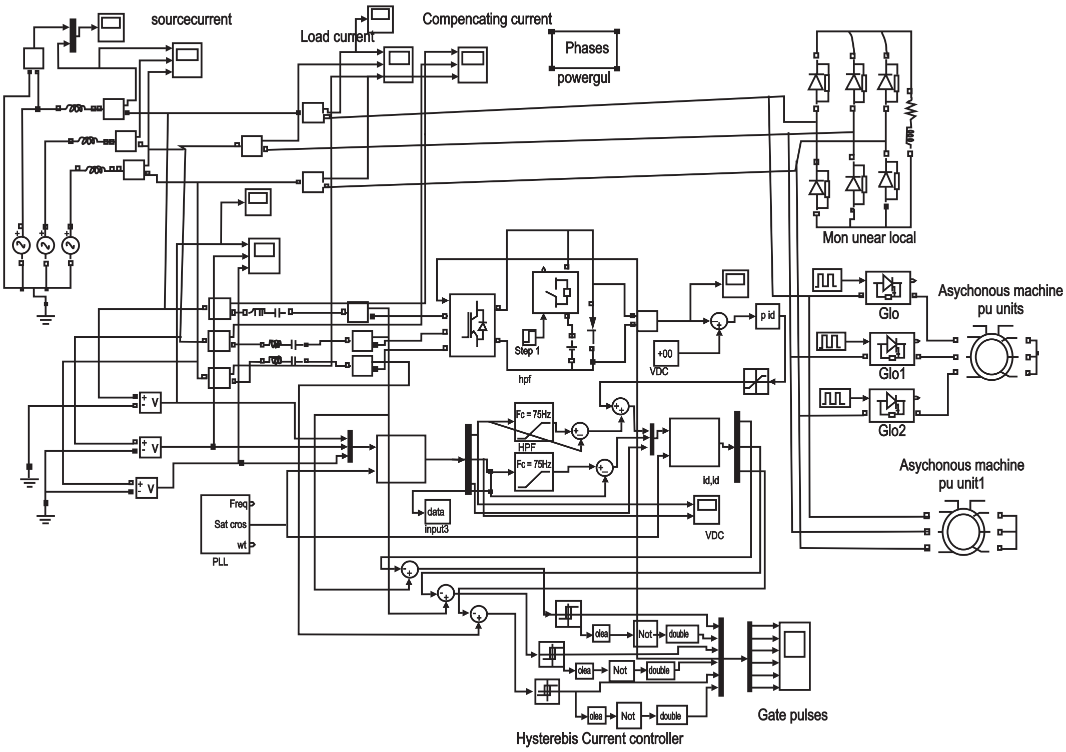


Fig. 6. Simulation Model

VII. SIMULATION RESULTS

The simulation model identical to the 415 V, 50 Hz DS is developed with the dynamic hybrid shunt active filter. The results are obtained from the simulation. The actual THD measured in the DS without filter is 14%. The THD value with filter is 2.77%. This results proves that the large amount of harmonics in the distribution system can be minimised using the proposed technique.

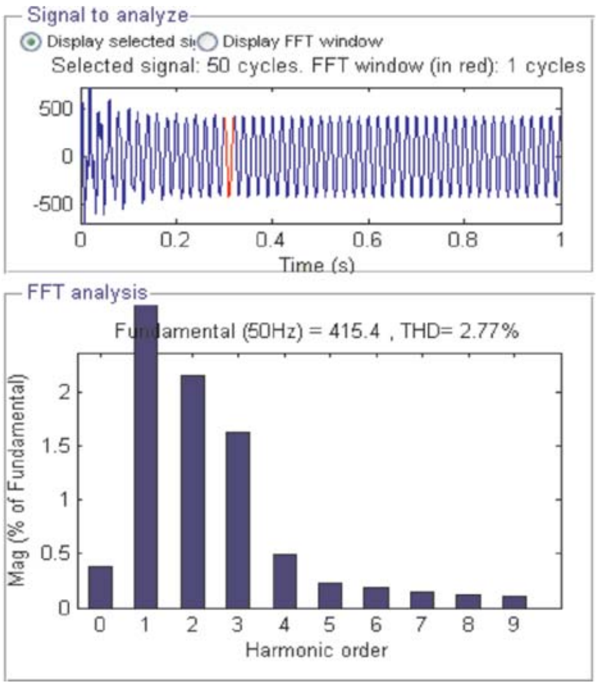


Fig. 7. Simulation Results

VIII. CONCLUSION

The harmonic pollutions in the 415 V, 50 Hz distribution system due to switching of heavy loads and non linear loads are analysed with the simulation and measured results. The HCC principle and its implementation are explained. The dynamically produced triggering pulses for the hybrid shunt active power filter fetches good results for this method. The results of this method can be validated and it will be the future scope of this study.

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S.Sellakumar was born in Tamilnadu India, on June 25, 1978. He received the B.E (with first class) from University of Madras, M.E (First class with honours) from Sathyabama University. Currently he is doing research in harmonics in the power system due to non linear loads and working as Assistant Professor in Jeppiaar Engineering College, Chennai, India. His research interests include power electronics, active filtering, and control systems.

Dr. M. Vijayakumar, Graduated from NBKR Institute of Science and Technology, Vidyanagar, A.P, India 1988. He obtained M.Tech Degree from Regional Engineering College, Warangal, India in 1990. He received Doctoral Degree from JNT University Hyderabad, India in 2000. 1 Ph.D is awarded under his guidance and guiding 6 Ph.Ds at present. He is the recipient of **"Pandit Madan Mohan Malaviya"** memorial prize. Currently he is the **Registrar of JNTU Anantapur University**, Anantapur.

Dr.V.Rajendran., Graduated from MK University, Completed his M.Tech from IISC Bangalore and received doctorate from Chiba University, Japan in 1993. He has been working in different institutions like Indian Institute of Science (IISc), Bangalore, Indian Institute of Technology (IIT), Madras and NIOT Chennai. He received MONBUSHO Fellowship Award of Japanese Government and Distinguished Scientist Award '07 from Jaya Engineering College. He has also been Elected Member twice as Vice Chairman - Asia of Executive Board of Data Buoy Co-operation Panel (DBCP) of Inter-Governmental Oceanographic Commission (IOC) / World Meteorological Organization (WMO) of UNSCO, in October 2008 and September 2009.