

Enhancement of power quality using microprocessor based shunt active power filter for unbalanced load

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ABSTRACT

Power quality is the most significant factor of power sector. The end user equipment such as induction motor, inverters, rectifiers inject harmonics into power system that influences the quality of power delivered. The presence of harmonics forces the use of instantaneous reactive power theory to calculate instantaneous power that helps in finding the compensating currents to eliminate harmonics. The control action required by active filter is accomplished by STM32F303RET6 microcontroller. Single phase induction motor is used as a dynamic nonlinear load in one of the three phases and resistive loads on the other two phases. TRIAC based RC triggering circuit was used to control the single phase induction motor. This paper presents the simulation and hardware implementation of shunt active power filter for 3 phase 4 wire unbalanced system. The hardware results show that THD in the source side has been reduced from 50.7% to 9.6% by implementing the SAPF.

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1. INTRODUCTION

The nature of energy conveyed to the end client is influenced by different factors such as voltage and frequency variations, faults, blackouts and so forth. These power quality issues reduce the life time and productivity of the electrical equipment [1-4]. A large portion of the loads are likewise semiconductor based. However the loads containing semiconductor are nonlinear in nature and draws non-sinusoidal current from the supply [5]. Furthermore the semiconductor devices are utilized for conversion of power from AC to DC or vice versa. This conversion of power largely contains switching operations which is the main reason they draw non sinusoidal current. In order to keep up the standard of power transferred, the harmonics should be reduced. Along these lines, an apparatus named filter is utilized that fills this need. There are a few filter topologies presently being used like passive, active and hybrid [6].

Passive filter are prone to resonance. To improve the performance of passive filter and additionally the power system, it must be combined with active filter to form hybrid power filter. Various control strategies are studied and analyzed in literature. The objective of any control strategy is to develop an active filter that injects a current that is out of phase with the harmonics present so as to compensate them. Instantaneous reactive power theory presents a tool to measure the power of any arbitrary wave, hence this can be very powerful tool to measure the power content of harmonics. Hysteresis controller is a powerful strategy to inject calculated reference current [7-9]. It discusses the various control algorithms to calculate the reference current. The various control techniques such as ANN, artificial intelligence, predictive control on active filter to reduce harmonics due to nonlinear loads [10-13].

There are various topologies in active power filter such as series and shunt active power filter. They vary with respect to DC bus voltage, rating of the inverter required and cost [14]. DC bus voltage is higher in case of pure active filters. DC bus capacitance value has a significant effect on the performance of active power filters [15].

These days several industries are making use of variable frequency drives for control of induction motor. These variable frequency drives produce different harmonics that results in malfunctioning of the motor, electromagnetic interference introduction, faulty measurement of measuring devices. Harmonic distortions mostly happen where loads draw non-sinusoidal current from the network. It is mostly present in a system where AC is transformed into DC [16]. The study of the effect of harmonics on the performance of induction motors has been done in [17, 18]. Around, 60% of loads around the globe are motor loads. More than 90% of these are used up by 3 phase induction motors with a huge utility factor between 0.7 and 0.9 a day. Pulse Width Modulation (PWM) technique is proven to be an effective way of regulating speed of an induction motor [19]. Use of single-phase induction motor and resistive loads on different phases makes the system unbalanced. Hence, study of 3 phase 4 wire unbalanced system becomes crucial [20-22].

Since most of the research work has been carried out on power quality issues due to static nonlinear load, and not many have studied the performance on dynamic nonlinear load for three-phase four-wire unbalanced system and its effect on power quality issues. Since many of the domestic, industrial and commercial loads are dynamic nonlinear loads like motor drives, it becomes essential to study their effect on power quality due to harmonic production in the system and to reduce their effects by adopting a proper harmonic mitigation method.

2. INSTANTANEOUS REACTIVE POWER THEORY FOR THREE PHASE FOUR WIRE SYSTEM

Figure 1 depicts the block diagram of instantaneous reactive power theory for calculation of compensating currents at PCC [23-25]. Using Clarke's transformation the 3 phase voltages (v_a, v_b, v_c) and load currents (i_a, i_b, i_c) are converted into single phase i.e. v_α, v_β, v_0 and i_α, i_β, i_0 . Using this the instantaneous power calculation block calculates the elements of active and reactive power of the non-linear load that need to be remunerated by the filter.

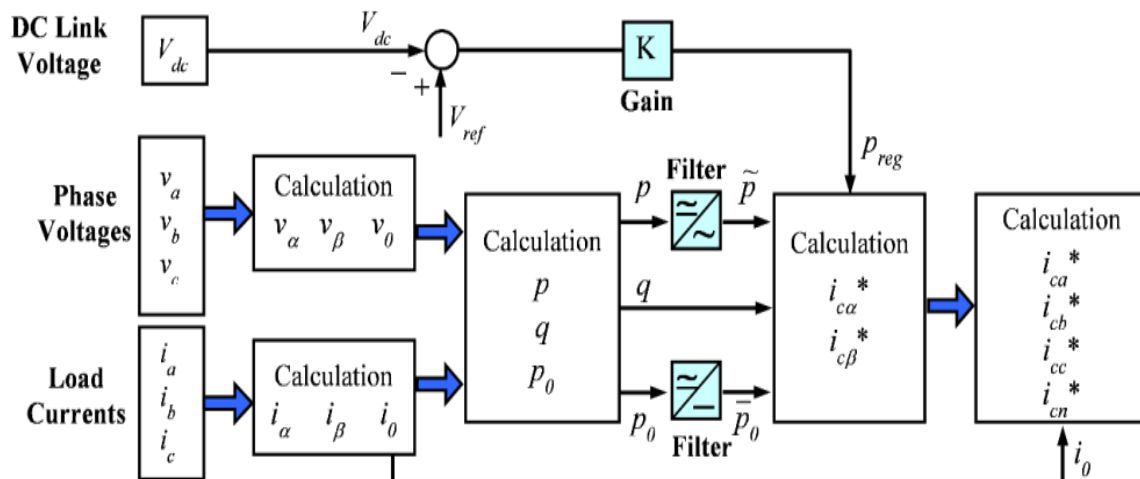


Figure 1. Block diagram of instantaneous reactive power [19]

The dc-voltage regulation block consisting of PI controller determines the additional quantity of power P_{reg} that causes an extra flow of energy to the DC link to maintain its voltage around the reference voltage V_{ref} . This P_{reg} is added to the compensating active power P_c along with the compensating reactive power Q_c , are passed to calculate reference current. It determines the instantaneous countervailing reference current from the unwanted powers. Then by applying inverse Clarke's transformation the single phase is converted into three phase. Figure 2 indicates the simulation model of instantaneous reactive power theory in MATLAB Simulink platform.

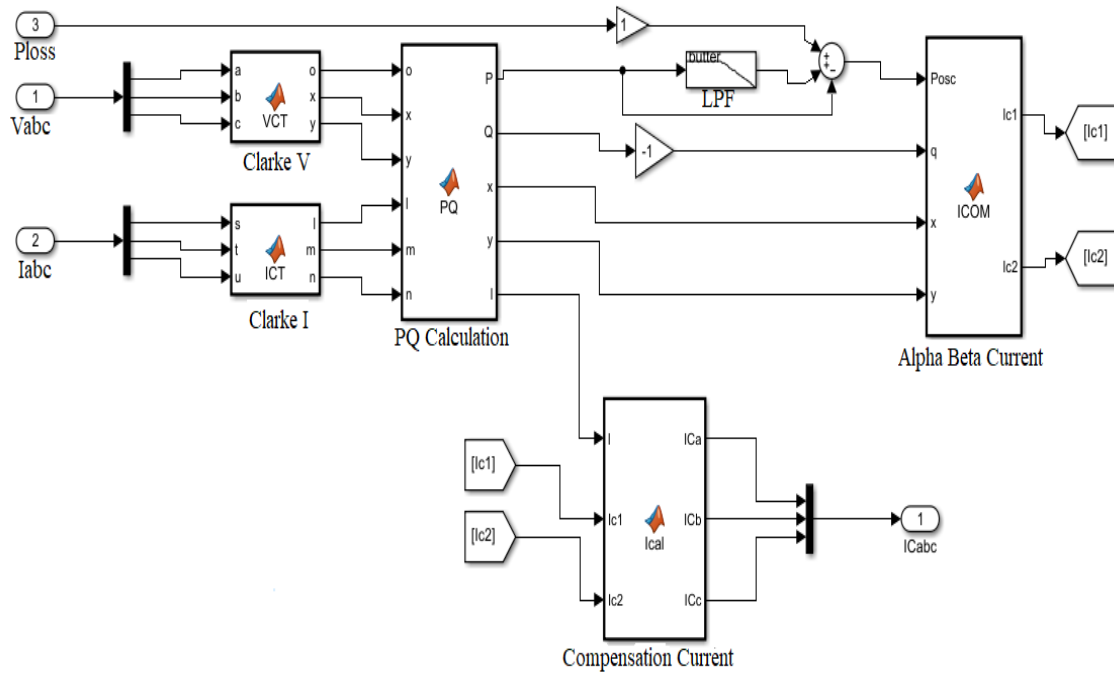


Figure 2. Simulink model of instantaneous reactive power theory for shunt current compensation in SAPF

3. THREE PHASE FOUR WIRE SHUNT ACTIVE POWER FILTER CONTROLLER

Figure 3 shows the block diagram of a 3 phase 4 wire shunt active power filter for harmonic current compensation. It has power circuit and compensation circuit. Single phase induction motor and two resistances in each phase are connected to make a load unbalanced. Voltage controller in phase A is used in series with induction motor that injects harmonics in the line. Voltage controller is a TRIAC based, that uses RC triggering circuit to generate gating pulses. Figure 4 shows the MATLAB Simulink model of complete SAPF. It contains 3 phase source, measurement unit, load and compensating circuit.

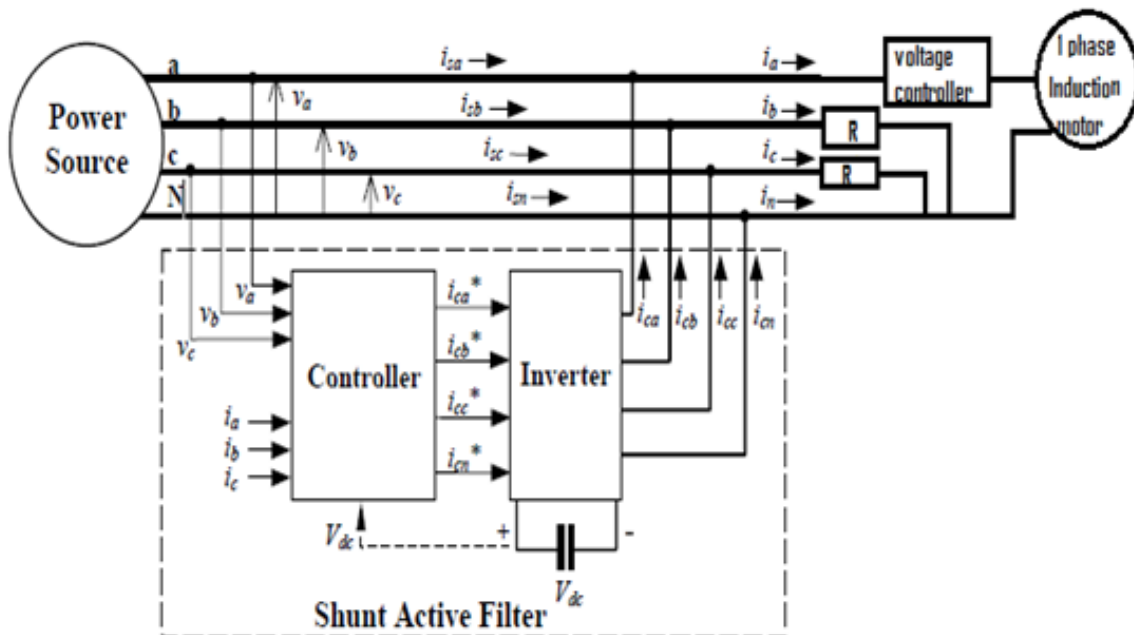


Figure 3. Block diagram of 3-phase 4-wire shunt active power filter

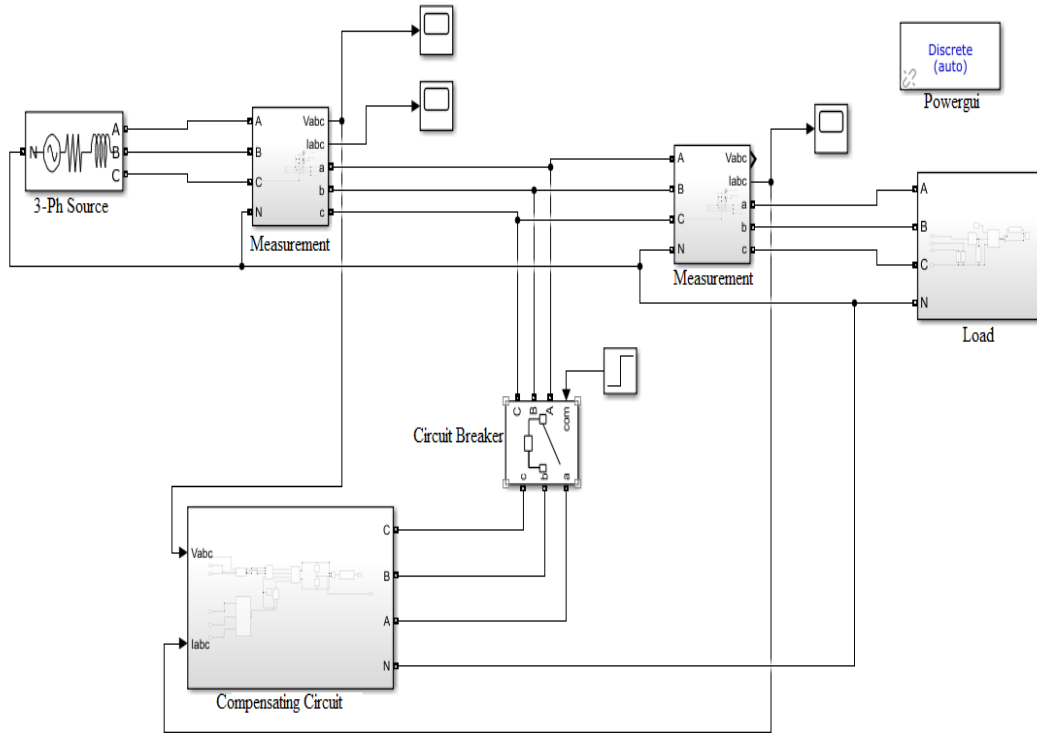


Figure 4. Simulink model of 3 phase 4 wire SAPF

4. THREE PHASE UNBALANCED LOADS

Single phase 0.5HP induction motor with 1500rpm is connected in phase, and resistive load (100 ohms) in other 2 phases as shown in Figure 5. The simulation model is simulated in the discrete mode. The electrical machines are nonlinear loads simulated as current sources. Therefore, these elements can not be attached to an inductive network unless and until a resistive or capacitive component is connected across the machine terminals. So, a parasitic resistive load is connected across the motor to avoid numerical oscillations. The size of the parasitic load depends upon the size of the motor. The motor is connected in series with TRIAC converter to generate harmonics.

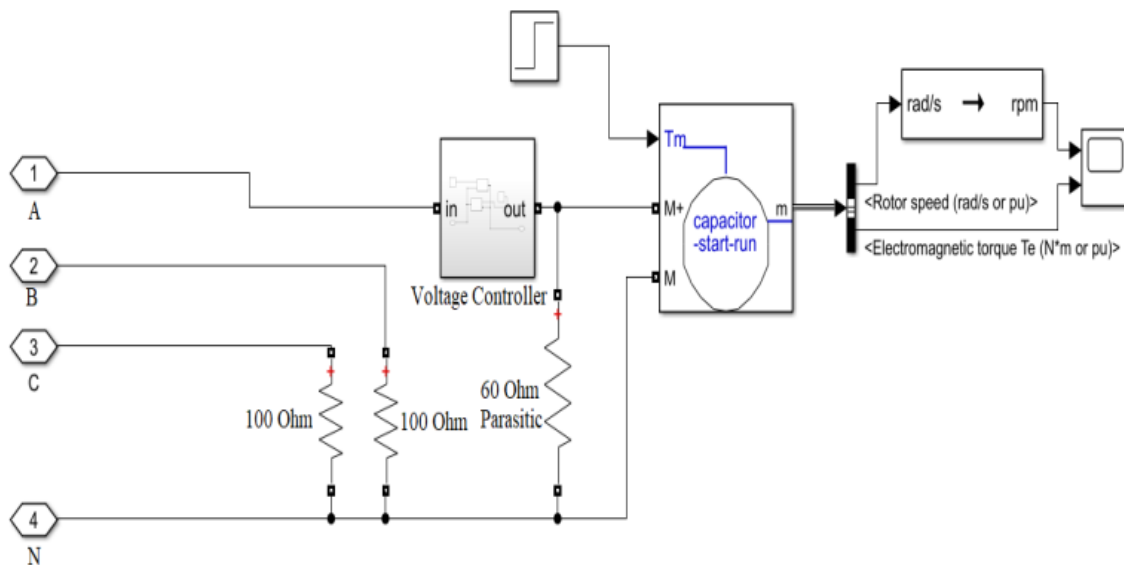


Figure 5. TRIAC voltage controller with motor and resistive load

5. SIMULATION RESULTS

5.1. Waveform and %THD on source side without SAPF

The Figure 6 shows the voltage and current waveform without compensation. Figure 7 represents the percentage of current THD is 14.75%.

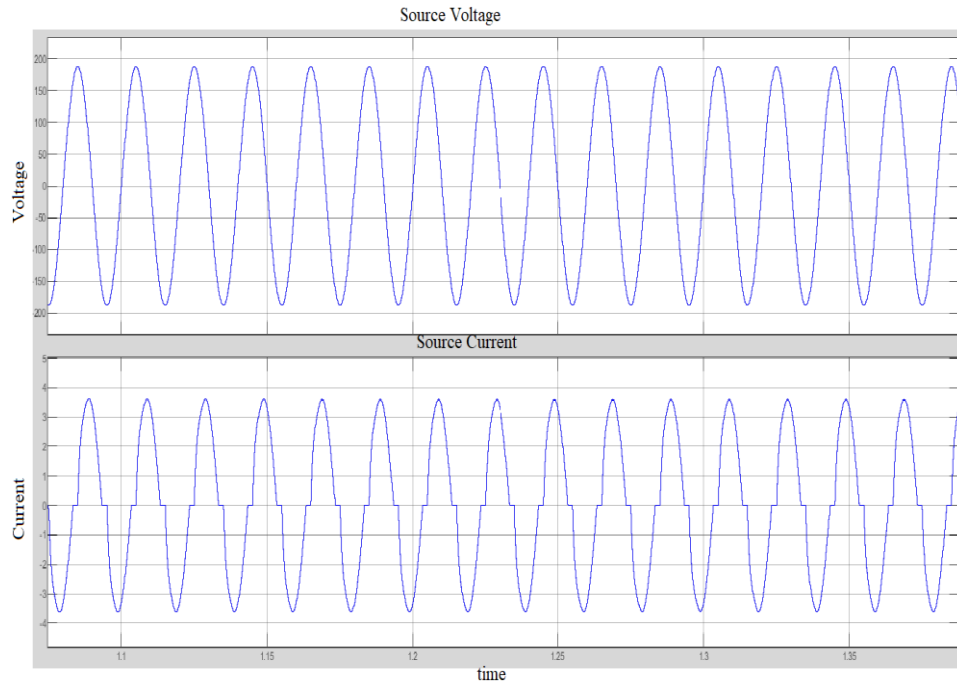


Figure 6. Voltage and current waveform

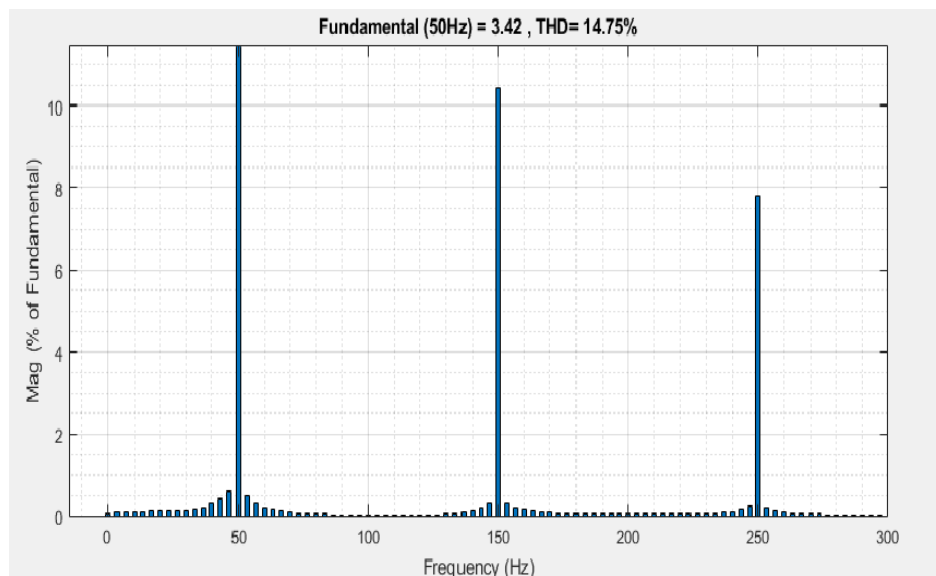


Figure 7. %THD in source current

5.2. Waveform and %THD on source side with SAPF

The Figure 8 shows the voltage and current waveform with SAPF. Figure 9 represents the percentage of current THD is 3.72%. The FFT analysis of load current with 50Hz as fundamental frequency reveals that THD of the current on source side without filter is 14.75%. The THD of the current on source side with filter is reduced to 3.72%.

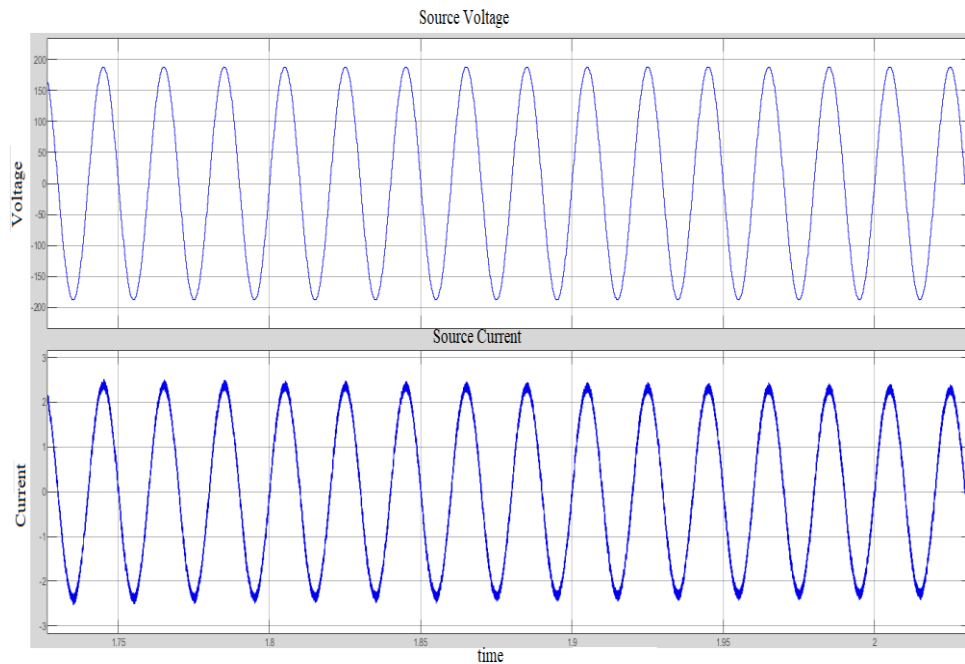


Figure 8. Voltage and current waveform

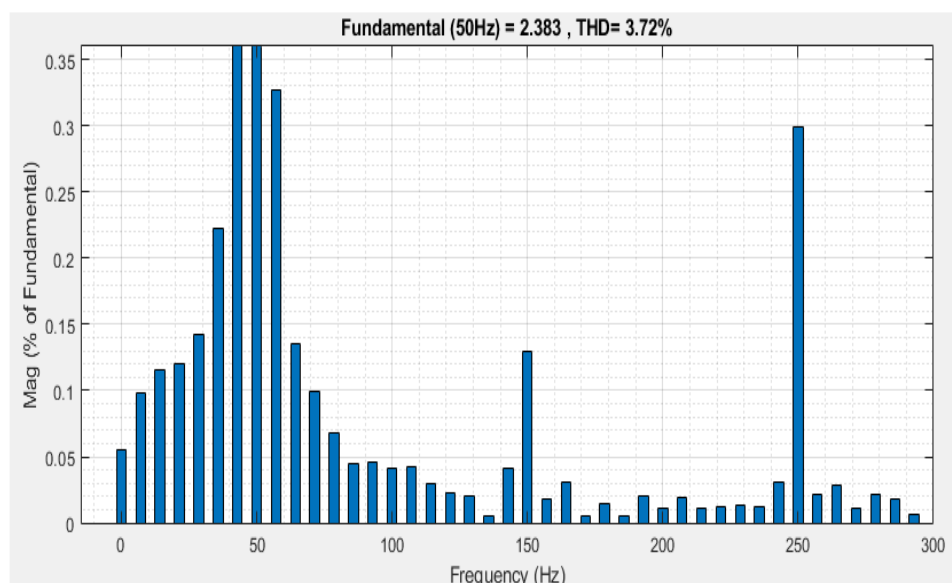


Figure 9. %THD is source current

6. HARDWARE IMPLEMENTATION of SAPF

The Table 1 indicates the rating of SAPF for 3-phase 4-wire unbalanced load. A 230V, 3 phase AC supply is given through a transformer to the dynamic load (i.e. single phase induction motor) at one phase and also resistors in other two phases. The system comprises of 3 phase 4 wire system in unbalanced condition as shown in Figure 10, zero sequence current and voltage also plays a vital role. Current sensor ACS712 is used for current measurement that gives voltage output compatible for microcontroller analogues to current. For I_{sa} , I_{sb} , and I_{sc} represent the current sensor measuring source currents of three phases. I_{ca} , I_{cb} , and I_{cc} represent the current sensor measuring the three phase compensatory currents being injected by three phase inverter into the system. These also form the feedback loop for hysteresis controller. A step-down transformer is utilized to step-down the voltage of 230 volts (RMS) to 24 volts (peak-peak). This voltage

is then fed to an AC voltage measuring unit which gives the required DC shift and attenuates the signal measured by STM32F303RET micro controller. The gate driver provides 15V output required by the inverter as the PWM signals from micro controller are 3.3V signals. The experimental setup of SAPF is depicted in Figure 11.

Table 1. Specifications of SAPF

Voltage Rating	230V
Load	3-Phase 4-wire unbalanced loads. Phase A has 0.5 HP, 1500 RPM single phase induction motor. Phase B and C has resistive loads each of 100 ohms.
Active controller	Three phase VSI inverter with six IGBT's

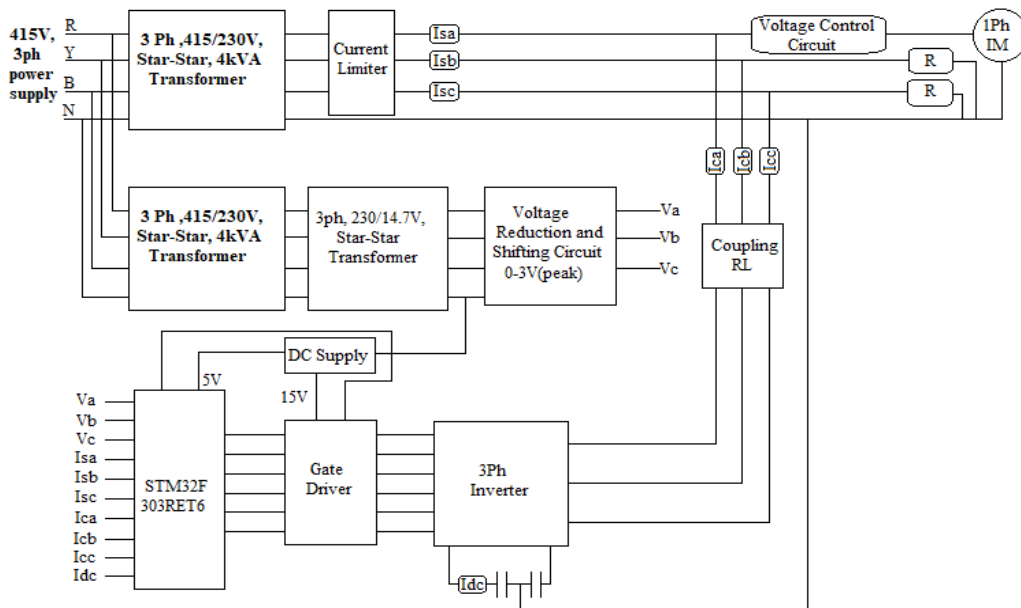


Figure 10. Block diagram for hardware implementation of SAPF

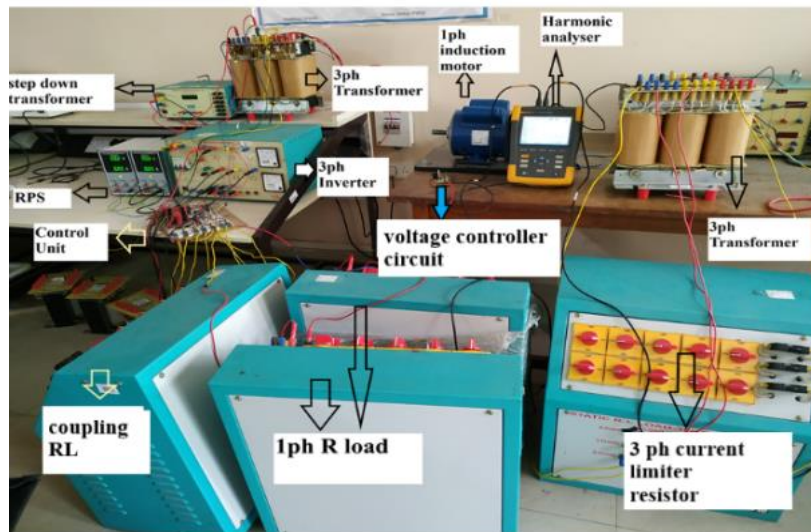


Figure 11. Experimental setup of SAPF

7. THREE PHASE THREE LEG IGBT INVERTER RATED 75A/1200V

The specifications of three phase inverter are indicated in Table 2. Inverter module consists of IGBT switches SKM75GB123D (3 No's), diode bridge rectifier PSD8316, IGBT Gate Drivers SKYPER 32 R and DC Link Capacitors 4700 μ F (2 No's). The controller in SAPF calculates the reference currents for hysteresis controller that will be injected into power system by three phase IGBT inverter.

Table 2. Specifications of three phase inverter

Parameter	Rating
Output AC Voltage	415V(controlled)
Switching frequency	20KHz
Maximum ambient temperature	400 $^{\circ}$ c
Control inputs	5V to 15 V

8. STM32F303RET6 MICROCONTROLLER

A code is designed based on instantaneous reactive power theory for calculating compensating currents in SAPF and implemented using Keil MDK μ Vision v.5 embedded platform to program in STM32F303RET6 microcontroller. The following are the steps to implement the IRP algorithm in SAPF for three phase four wire unbalanced dynamic load using microcontroller.

1. Start
2. Initialize GPIO pins
3. Initialize DMA to Circular mode and data width to 32bit
4. Initialize ADC1 and ADC2 to dual regular simultaneous mode and set external trigger conversion source to be Timer 3
5. Initialize Timer 3 to up count mode, timer period to 7200
6. Start timer 3
7. Start ADCs in multimode with DMA
8. Wait for end of sequence of conversion flag to be set
9. IfEOC is set retrieve ac voltages, currents and dc voltage from DMA values
10. Calculate α , β , o , values for voltages and currents from the data stored in DMA

$$V_0 = \sqrt{\frac{2}{3}} \left(\frac{1}{\sqrt{2}} V_a + \frac{1}{\sqrt{2}} V_b + \frac{1}{\sqrt{2}} V_c \right), V_\alpha = \sqrt{\frac{2}{3}} \left(V_a - \frac{1}{2} V_b - \frac{1}{2} V_c \right) \text{ and } V_\beta = \sqrt{\frac{2}{3}} \left(\frac{\sqrt{3}}{2} V_b - \frac{\sqrt{3}}{2} V_c \right)$$
 Same formulae are also applicable for currents by replacing voltages by currents.
11. Calculate instantaneous power p and q using the formula

$$p = (V_\alpha * I_\alpha) + (V_\beta * I_\beta) + (V_o * I_o) \text{ and } q = (V_\alpha * I_\beta) - (V_\beta * I_\alpha)$$
12. Filter out the fundamental components present in the instantaneous active power and add the switching losses to it.
13. Calculate compensation currents in α , β coordinates using the below formulae

$$I_{c1} = \frac{-1}{(V_\alpha^2 + V_\beta^2)} * [(P_{osc} * V_\alpha) + (q * V_\beta)] \text{ and } I_{c2} = \frac{-1}{(V_\alpha^2 + V_\beta^2)} * [(P_{osc} * V_\beta) - (q * V_\alpha)]$$
14. Calculate the compensation current in abc coordinate using inverse Clark transformation using below formulae and compare it with reference

$$I_{ca} = \sqrt{\frac{2}{3}} * \left(\frac{i_o}{\sqrt{2}} + I_{c1} \right), I_{cb} = \sqrt{\frac{2}{3}} * \left[\frac{i_o}{\sqrt{2}} - \left(\frac{1}{2} * I_{c1} \right) + \left(\frac{\sqrt{3}}{2} * I_{c2} \right) \right] \text{ and}$$

$$I_{cc} = \sqrt{\frac{2}{3}} * \left[\frac{i_o}{\sqrt{2}} - \left(\frac{1}{2} * I_{c1} \right) - \left(\frac{\sqrt{3}}{2} * I_{c2} \right) \right]$$
15. If reference current is greater than measured current than set upper switches, else lower switches.
16. Go to step 8.

9. HARDWARE RESULTS

Figure 12 shows that the %THD of the source side is 50.7% without compensation for unbalanced dynamic load as measured with harmonic analyser (fluke make). Figure 13 shows that the %THD of the source side is reduced to 9.5% from 50.7% with compensation for unbalanced dynamic load as measured with harmonic analyser.

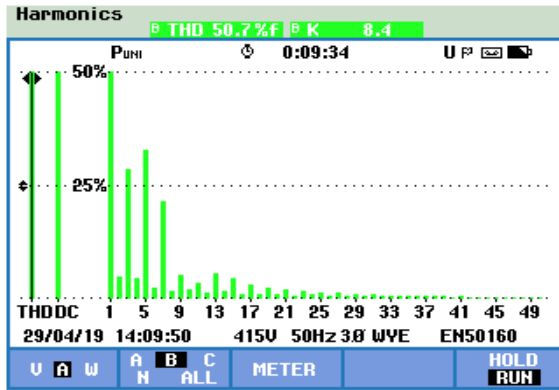


Figure 12. %THD without compensation

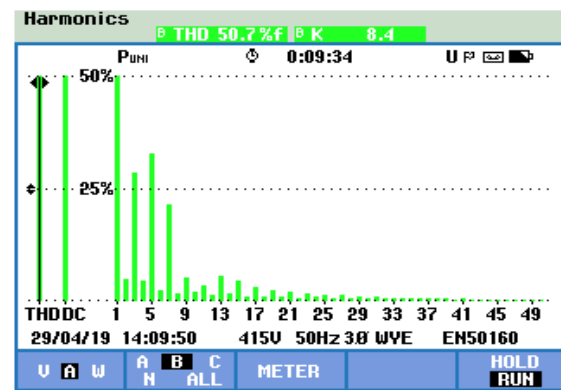


Figure 13. %THD with compensation

10. CONCLUSION

The SAPF works well with dynamic non-linear load and improves the power quality of the power system. Results of simulation evidences that the total THD percentage in the source current is seen to be reduced to 3.72% from 14.75% by implementing Shunt APF for a converter controlled single phase induction motor load. Experimental result shows that the total THD content in source current is reduced to 9.6% from 50.7% by implementing the Shunt APF for a converter controlled single phase induction motor load. Further the same system can be tested for compensation of harmonics in a system having three phase induction motor.

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