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Harmonic Mitigation with Parallel APF for Industrial Type Non-Linear Loads

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Abstract: The paper presents the parallel active power filter concept for harmonic elimination in industrial type of non-linear loads. Harmonics are present predominantly due to non-linear type of loads that are present due to industrial and commercial loads in power system network. Active power filter, a type of custom power devices can effectively address the harmonic problem in power system. Parallel active power filter concept share the harmonic current injection for compensation eventually reducing the rating and as a result switching losses in active power filters. Te parallel active power filters are controlled with a common single control scheme using instantaneous active and reactive power theory. Proposed concept was implemented using MATLAB/SIMULINK software and results were discussed considering different loading conditions of the proposed system like for incremental load and decremented load conditions.

Keywords: *Harmonics, parallel, APF, non-linear.*

1. INTRODUCTION

Power quality issues are not new to power system but their existence creates new problems due to advancements in power electronic sector. Power electronic advancements made it possible to develop adjustable speed drives which are a type of non-linear loads [1]. Arc furnace, ballast lights, electric converters are some of the other examples of non-linear devices. Non-linear loads are main cause for production of harmonics in system. Harmonics, sag, swell, transients, flickers, noise are some of the power quality issues that generally present in power system [2]. Harmonics are dominantly occurred as power system quality issue due to development in electronic sector and evolution of different types of non-linear loads [3-5].

Custom power devices might be a solution to eliminate or reduce power quality problems caused from many loads. FACTS devices are type of custom power devices employed to reduce the risk of power quality problems using power electronics circuits. Active power filter (APF) is a type of FACTS controller placed in parallel to the power system network to filter out harmonics in the system by injecting compensating currents [6-9]. This paper presents the parallel active power filter configuration for harmonic mitigation using instantaneous active and reactive theory. Power switches in active power filter are controlled from pulses obtained from instantaneous P-Q control theory. The paper addresses the harmonic reduction to nominal value of less than 5% when incremental industrial system is connected as load to power system. Active power filter (APF) is a shunt active filter injecting harmonic compensating currents in to the power system point of common coupling to compensate harmonics. Figure 1 shows the power system with APF for harmonic mitigation. Power system is shown with source having some impedance delivering only sinusoidal components. The load being non-linear draws non-linear components of currents injecting harmonics as shown in system. APF delivers required compensating currents to reduce the harmonics to extent below nominal value of distortion.

2. SYSTEM WITH PARALLEL APF CONFIGURATION

The system configuration with proposed parallel active power filter (APF) configuration was shown in figure 2. The system with non-linear loads can deteriorate power system since they draw only non-linear components of source currents from the source parameters. The system consists of source with source inductance delivering power to non-linear industrial load represented with a connection of non-linear components. As source delivers sinusoidal source parameters but load draws only non-linear components of source parameters as they are of non-linear industrial load type. If single APF is connected to system, the total compensating currents are to be sent to point of common coupling for compensation of harmonics from the same one APF which eventually raises the ratings of devices or components connected in APF. Two parallel APF's connected together with common interfacing inductors for harmonics mitigation can eventually reduce the rating of the device which causes switching losses to be reduced. The parallel APF configuration is capable of even handling the harmonic mitigation when non-linear type of industrial load is varied. In this paper variation refers to both incremental non-linear type of industrial load and decremented load type. The proposed parallel APF configuration with incremented load variation is shown in figure 3. The non-linear nature of loads draws only non-linear components of currents inducing harmonics in to the main power system. Active power filter was connected to main power system as compensator for harmonics. Active power filter is a type of shunt compensator and so connected in parallel to main power system. Active power filter compensated harmonics by injecting compensating currents in to main power system at the point where it was connected.

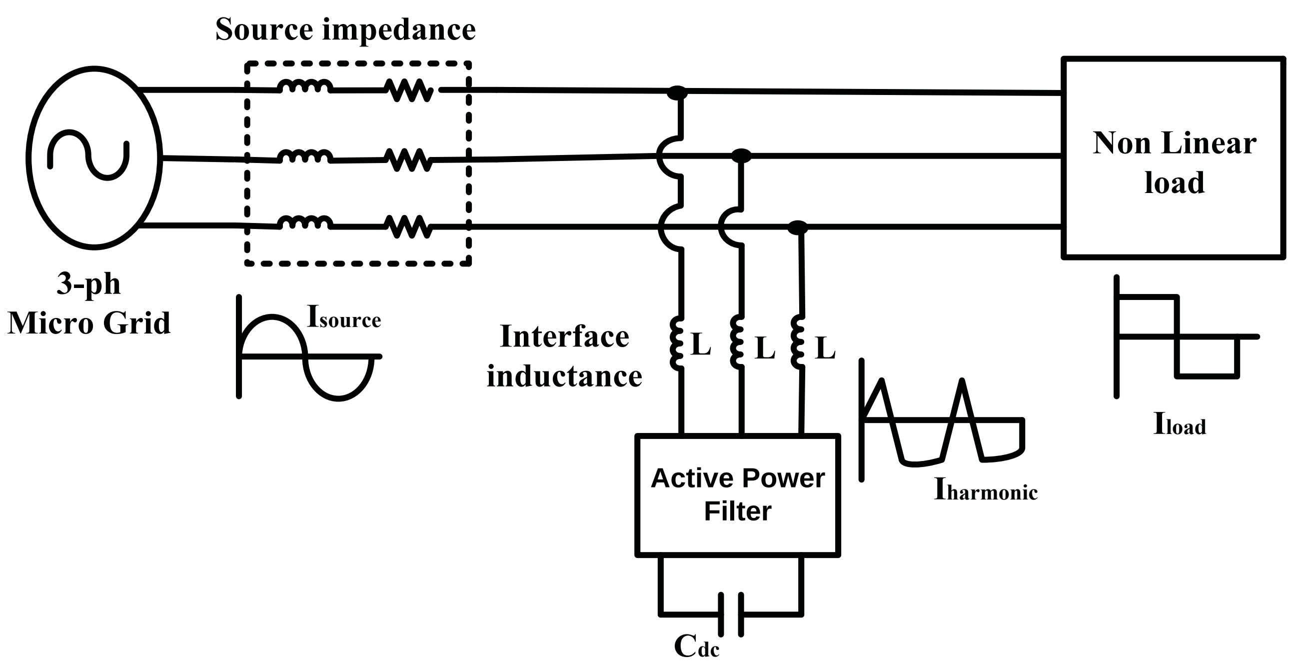

Figure 1: Power system with APF for harmonics mitigation

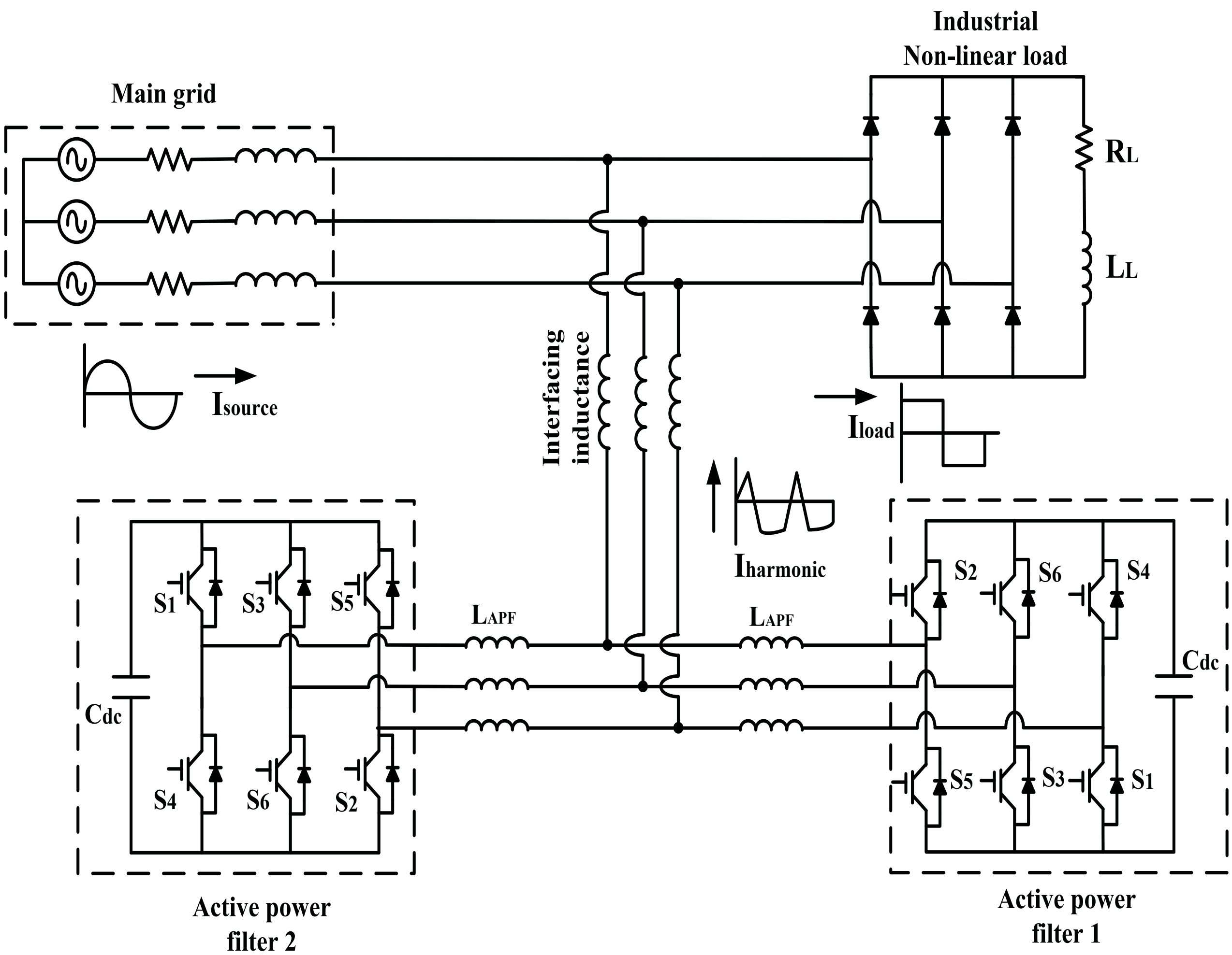

Figure 2: Proposed parallel APF configuration

3. CONTROL OF PARALLEL APF

The control circuit controlling or generating gate pulses to switches of two parallel APF is show in figure 4 and figure 5 denotes the proposed two parallel APF configurations for harmonic elimination employing instantaneous P-Q theory. Instantaneous reactive power theory proposed by Akagi, can also be called as P-Q theory is a powerful tool which can be applied to generate triggering pulses to power switches in active power filters to mitigate harmonics, unbalance conditions and reactive power issues. The *p-q* theory implements a transformation from a stationary reference system in *a-b-c* coordinates, to a system with coordinate's α-β-0. It corresponds to an algebraic transformation, known as Clarke transformation [5], which also produces a stationary reference system, where coordinates α-β are orthogonal to each other, and coordinate 0 corresponds to the zero-sequence component. The three-phase line voltages are sensed and using Park's transformation, coordinates from abc are converted to α-β terms. Similarly line currents are measured and using Park's transformation, coordinates from abc are converted to α-β terms. Active power and reactive power components are extracted from α-β terms and active power component passed through low pass filter and obtained result is compared to original active component. The difference obtains harmonic component of active power. Similarly from α-β terms reactive power component passed through low pass filter and obtained result is compared to original reactive component. The difference obtains harmonic component of reactive power.

Actual DC link voltage is measured with reference DC link voltage and resultant obtains power loss component when compared to harmonic component of active power yields reference value. Then active and reactive component are inverse transformed to abc coordinated using Inverse Park's transformation producing reference current signals. Reference current signals are compared to actual current values to send signal to hysteresis current controller which generates gate pulses to active power filter switches. Hysteresis current controller operates on set of equations with upper and lower bands. When the carrier and reference wave forms touches at band levels, gate pulses are generated to APF switches.

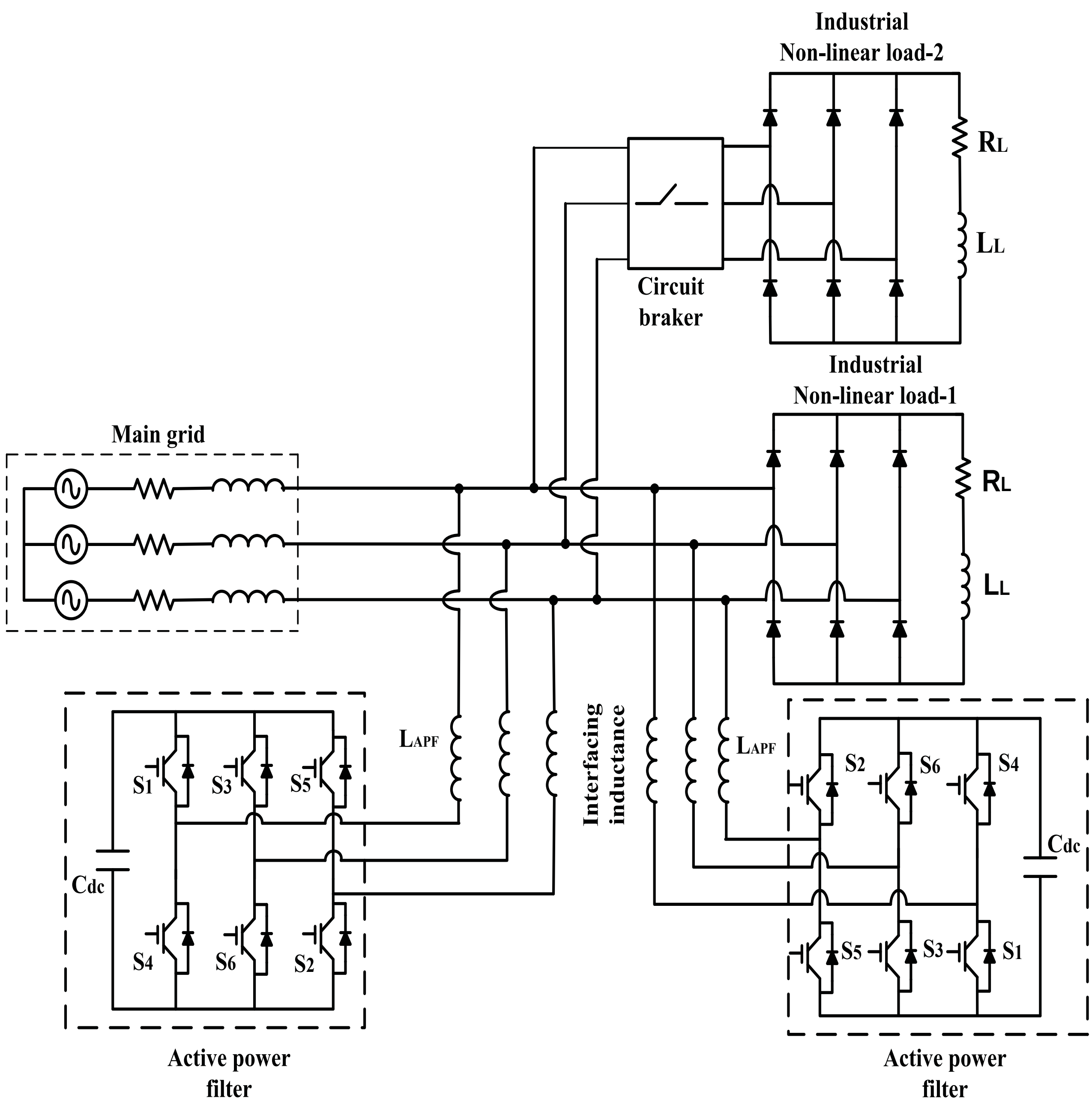

Figure 3: Proposed parallel APF configuration with incremented load variation

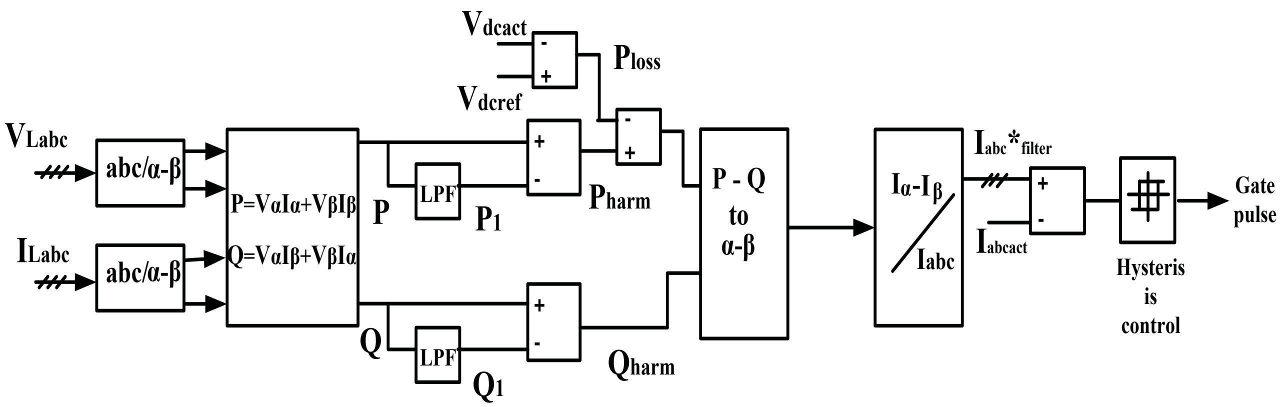

Figure 4: Unit vector control theory for APF

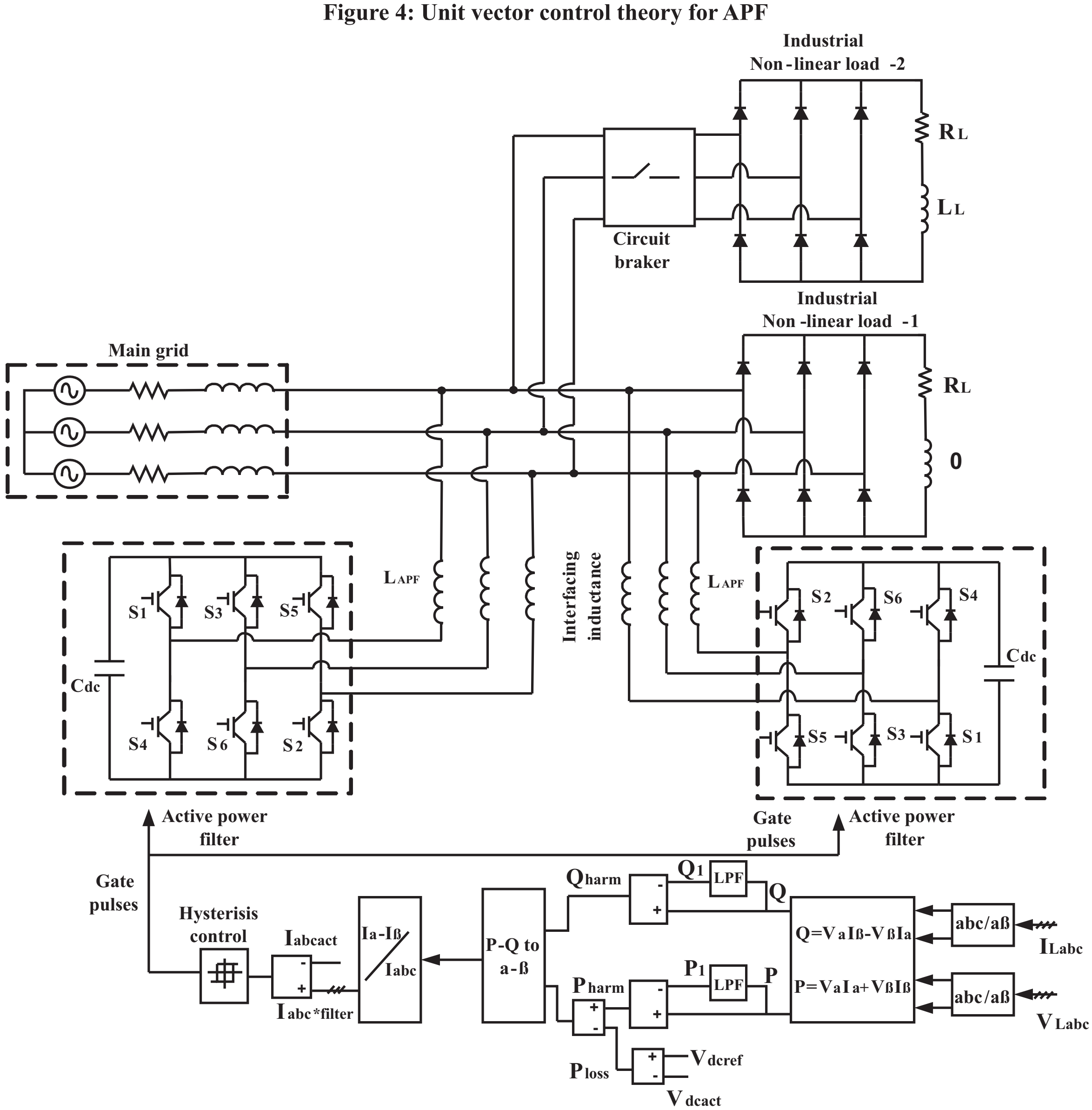

Figure 5: Proposed system configuration with instantaneous P-Q control theory for parallel APF

4. SIMULATION RESULTS AND DISCUSSIONS

4.1. APF with constant load

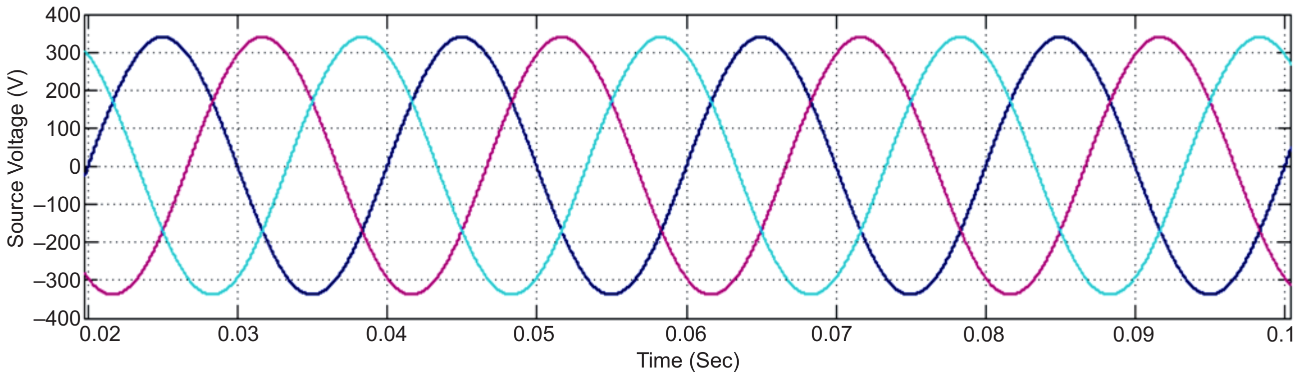

Figure 6: Three-phase source voltages

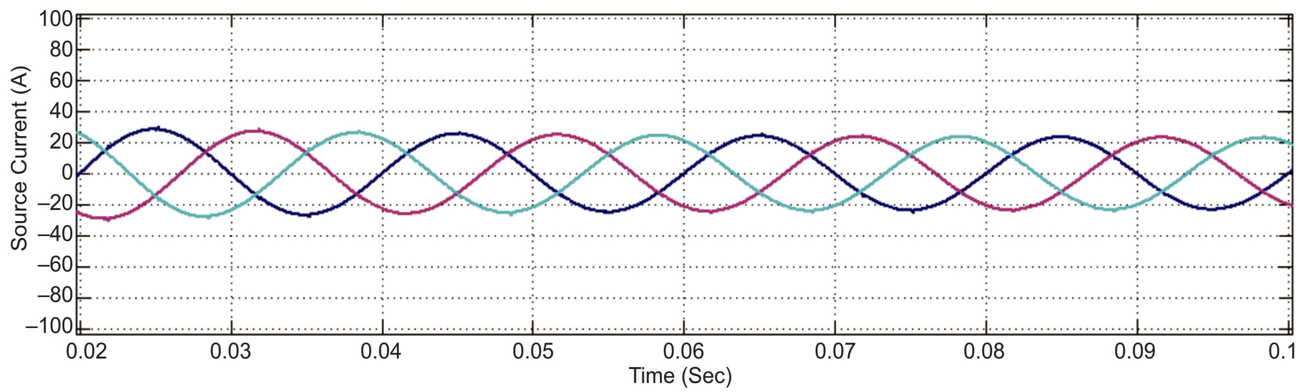

Figure 7: Three-phase source Currents

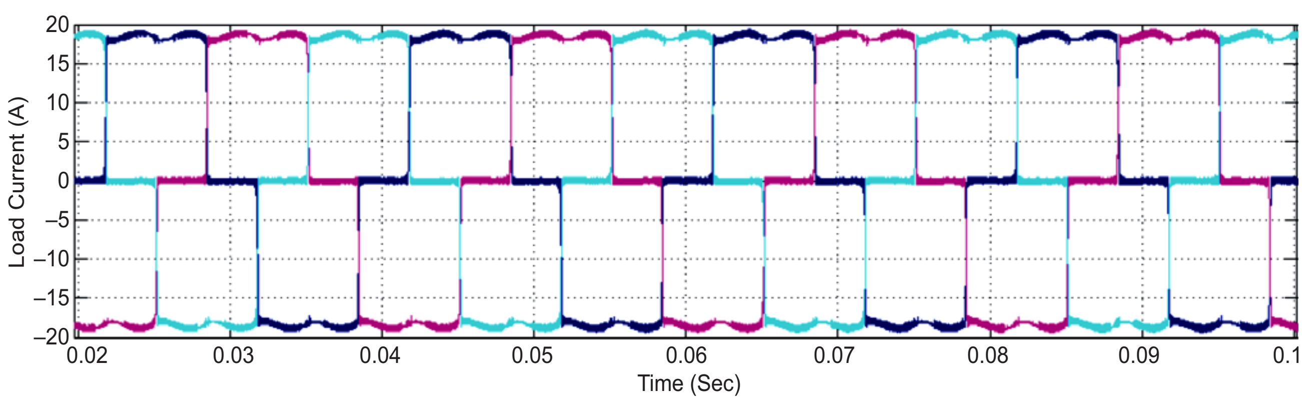

Figure 8: Three-phase load Currents

Figure 6 shows the source voltages in three phases of source and is maintained with constant peak. Figure 7 shows the three-phase source currents maintained near to 20A. Figure 8 shows the load currents in three phases of load and is 20A load current in each phase. Source current does not contain any harmonics and load current contain harmonics since load is of non-linear type.

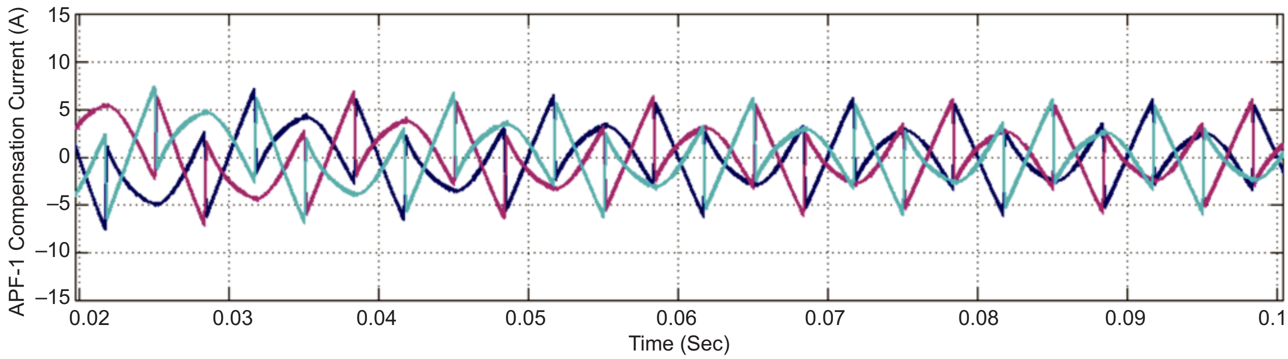

Figure 9: Compensating Currents of APF-1

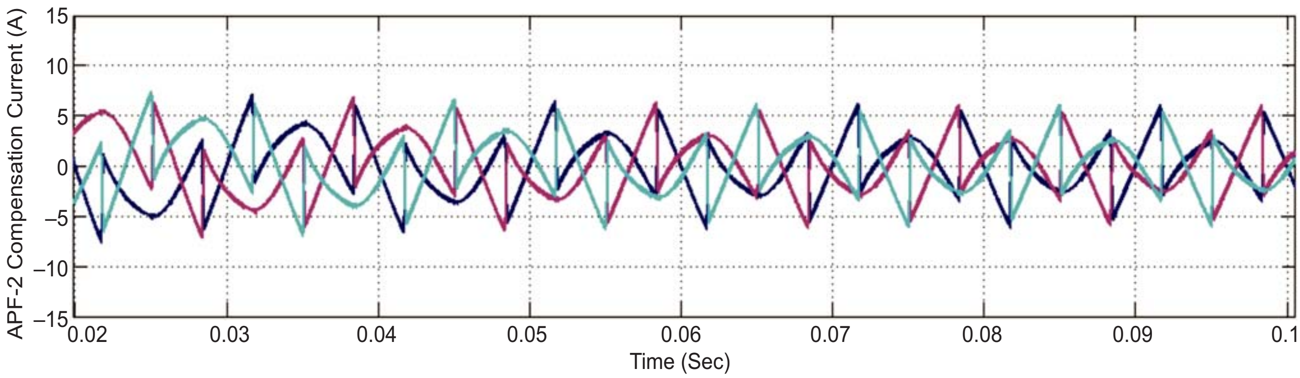

Figure 10: Compensating Currents of APF-2

Figure 9 shows the compensating currents fed to the point of common coupling from active power filter – 1. APF-1 sends compensating currents of 5A. Figure 10 shows the compensating currents fed to the point of common coupling from active power filter – 2. APF-2 sends compensating currents of 5A. the total compensating currents of 10A is shared by two parallel APF's.

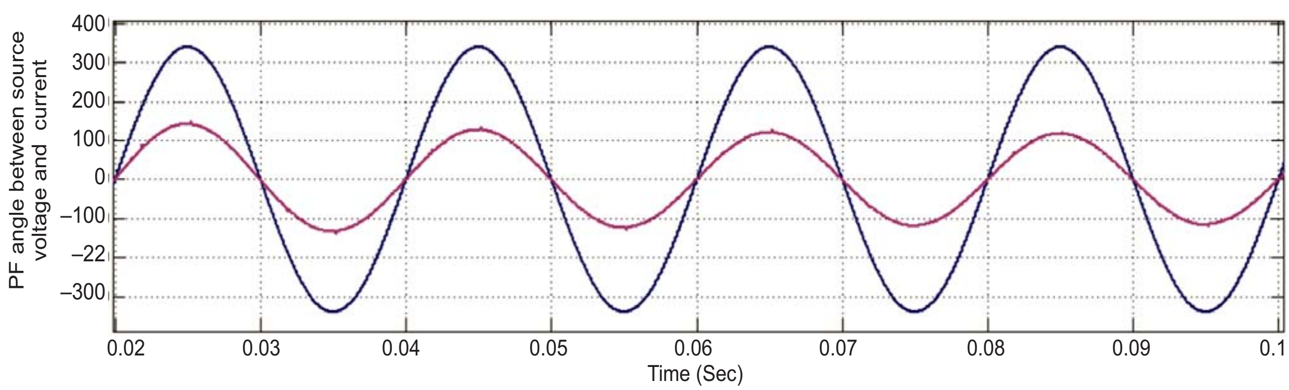

Figure 11: Power factor angle between source voltage and current

Figure 11 indicates the power factor angle between source voltage and current. The phase angle difference is almost zero and thus the power factor is maintained nearer to unity. Figure 12 indicates the total harmonic distortion in source currents is 0.69% which is well within the normal limits and figure 13 shows the total harmonic distortion in load current is 29.6%.

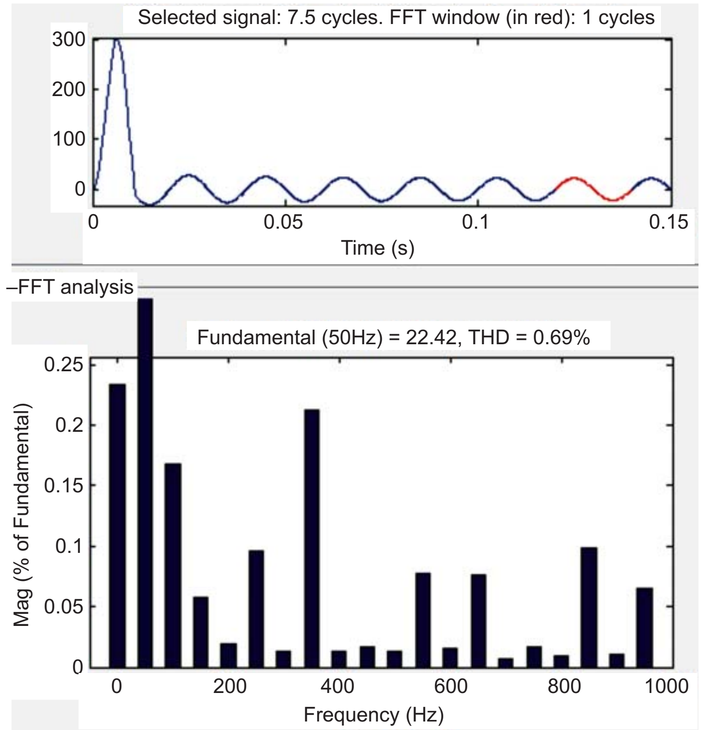

Figure 12: THD in source current

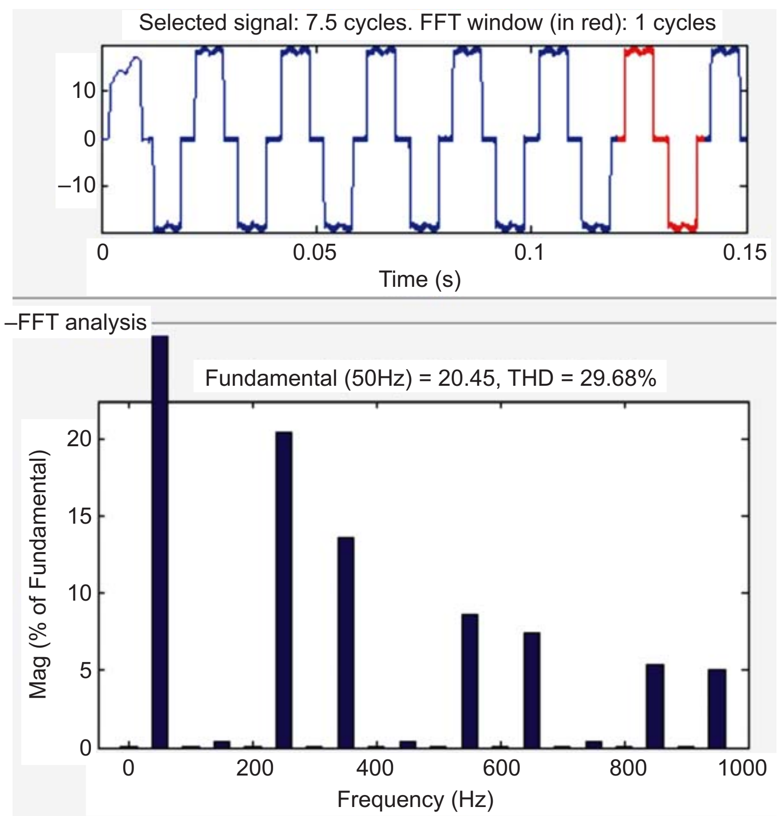

Figure 13: THD in load current

4.2. APF with incremental load

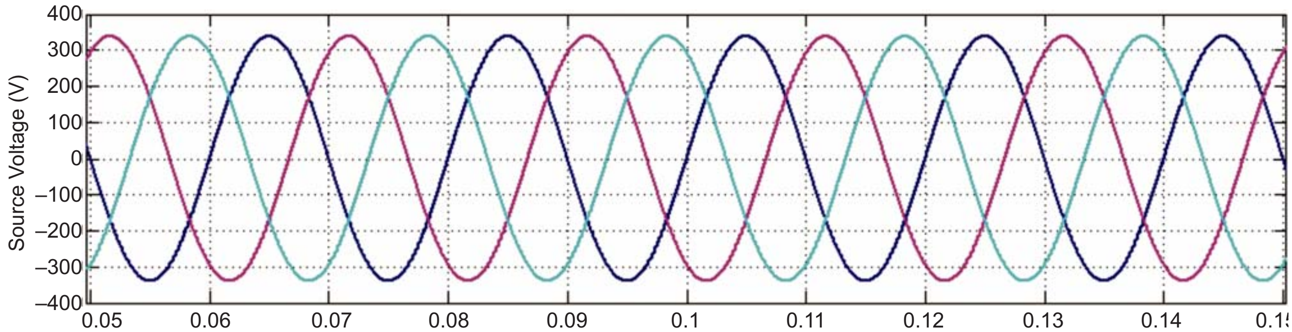

Figure 14: Three-phase source voltages

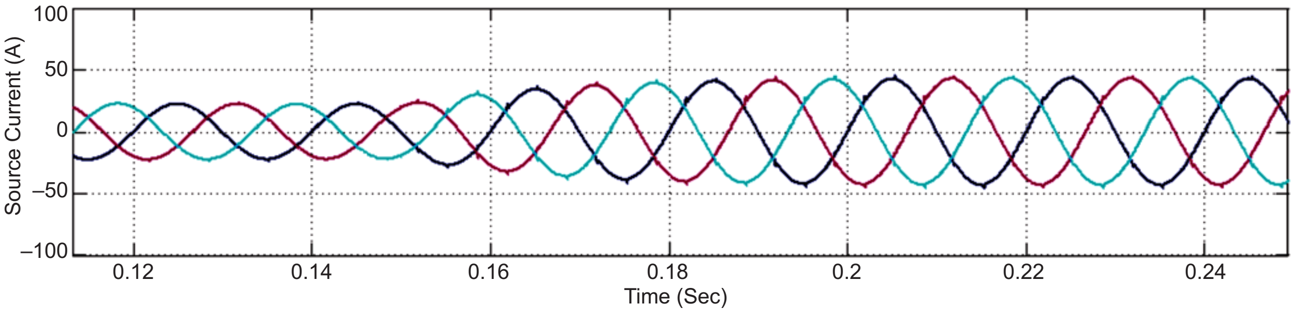

Figure 15: Three-phase source Currents

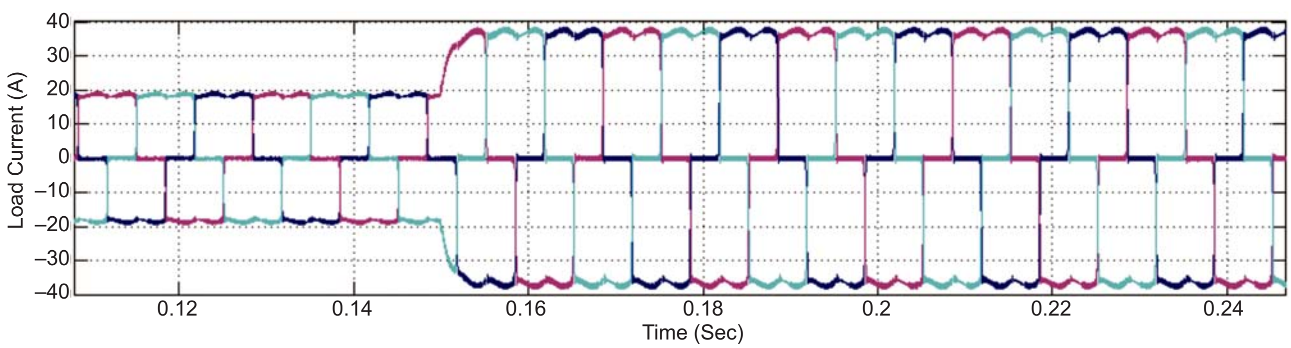

Figure 16: Three-phase load Currents

Figure 14 shows the source voltages in three phases of source and is maintained with constant peak. Figure 15 shows the three-phase source currents maintained near to 20A and after 1.15sec then source current is incremented. Figure 16 shows the load currents in three phases of load and is 20A load current in each phase and after 1.15sec then load current is incremented. Source current does not contain any harmonics and load current contain harmonics since load is of non-linear type.

Figure 17 shows the compensating currents fed to the point of common coupling from active power filter – 1. APF-1 sends compensating currents of 5A. Figure 18 shows the compensating currents fed to the point of common coupling from active power filter – 2. APF-2 sends compensating currents of 5A. The total compensating currents of 10A is shared by two parallel APF's. After 0.15 sec, the compensating signals from both the APF's are incremented with increment in load currents.

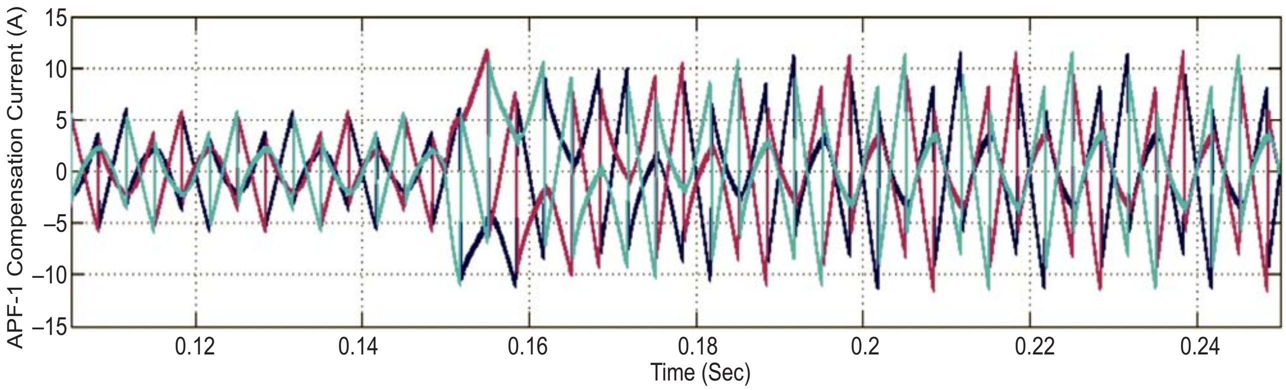

Figure 17: Compensating Currents of APF-1

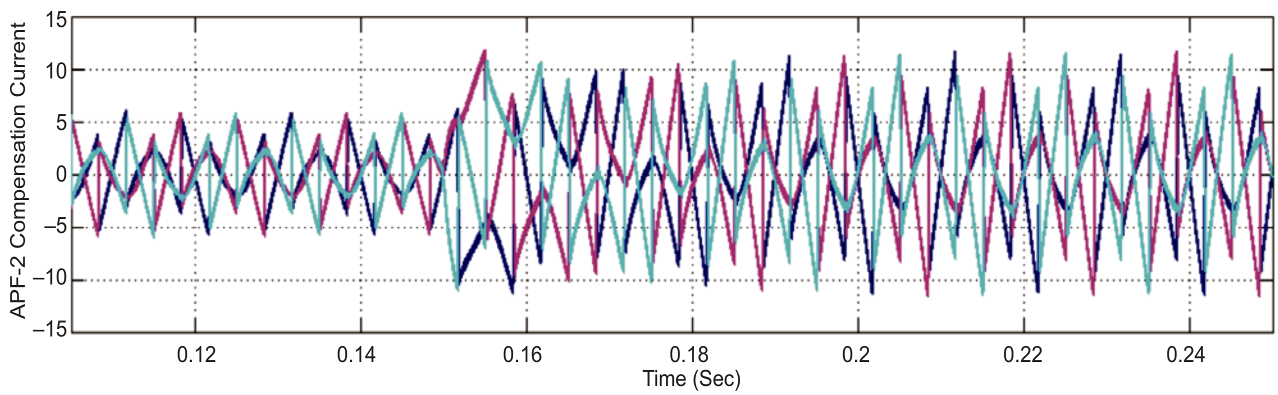

Figure 18: Compensating Currents of APF-2

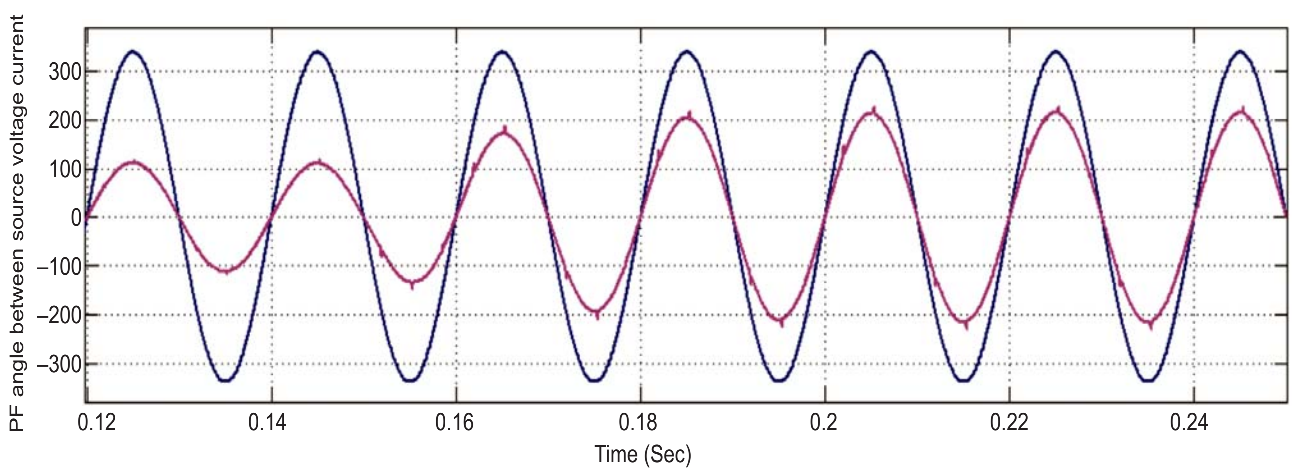

Figure 19: Power factor angle between source voltage and current

Figure 19 indicates the power factor angle between source voltage and current. The phase angle difference is almost zero and thus the power factor is maintained nearer to unity. Figure 20 indicates the total harmonic distortion in source currents is 1.22% which is well within the normal limits and figure 21 shows the total harmonic distortion in load current is 29.1%.

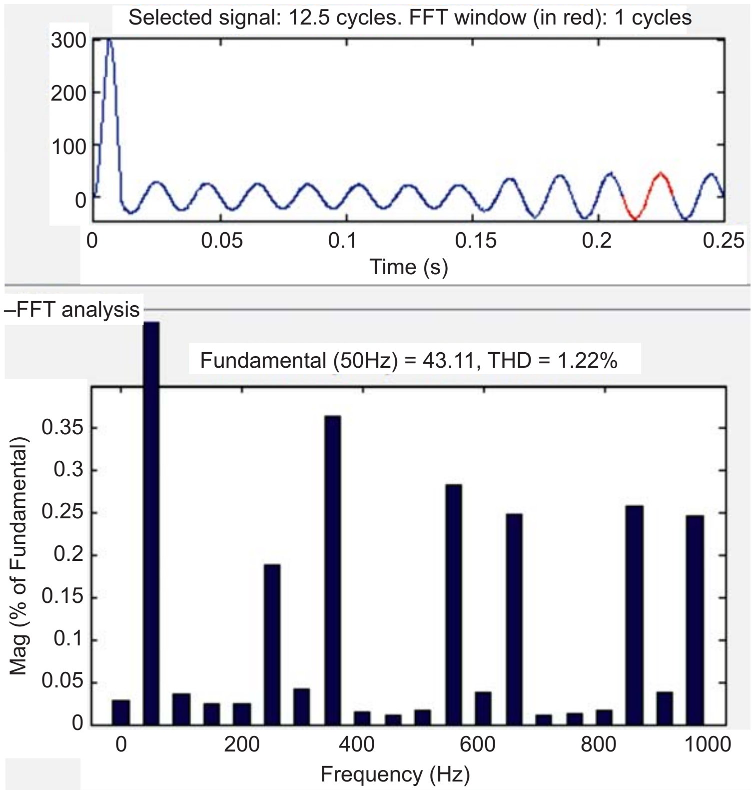

Figure 20: THD in source current

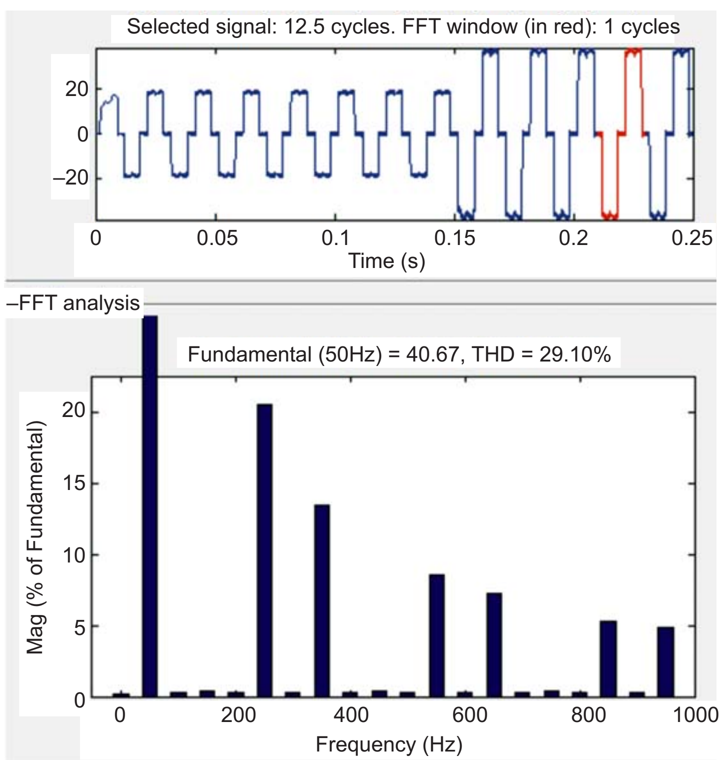

Figure 21: THD in load current

4.3. APF with decremental load

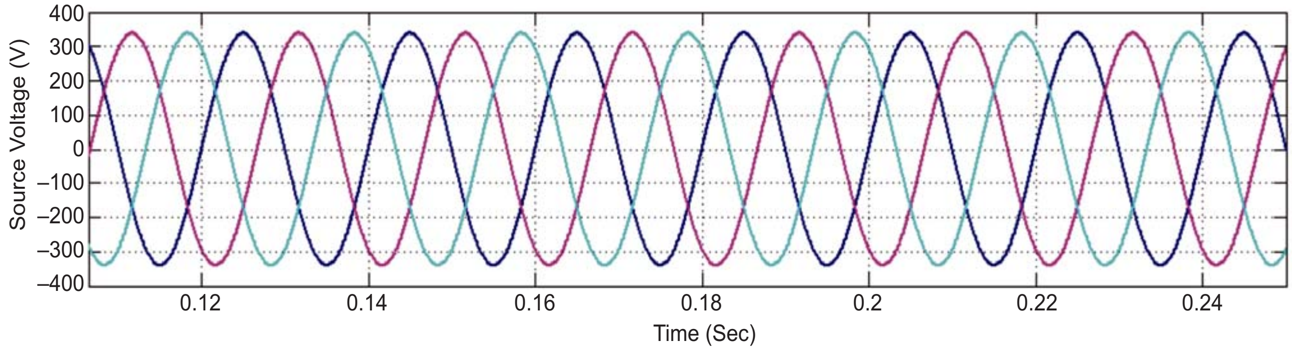

Figure 22: Three-phase source voltages

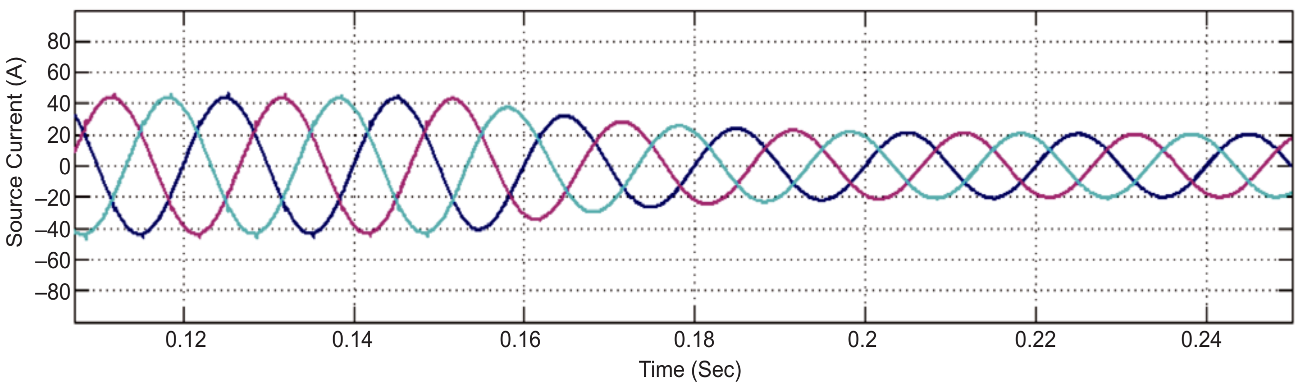

Figure 23: Three-phase source Currents

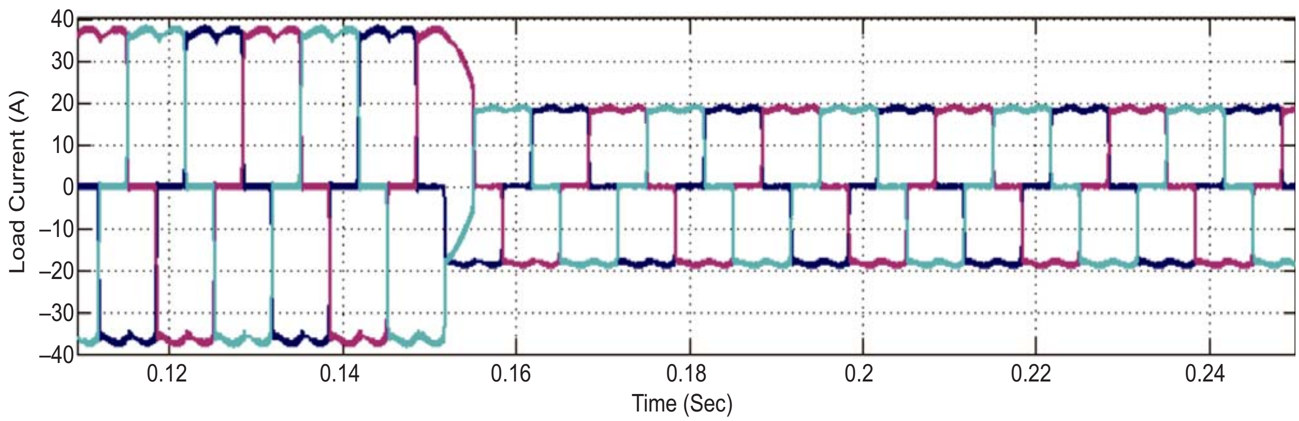

Figure 24: Three-phase load Currents

Figure 22 shows the source voltages in three phases of source and is maintained with constant peak. Figure 23 shows the three-phase source currents maintained near to 40A and after 1.15sec then source current is decremented to 20A. Figure 24 shows the load currents in three phases of load and is 40A load current in each phase and after 1.15sec then load current is decremented to 20A. Source current does not contain any harmonics and load current contain harmonics since load is of non-linear type.

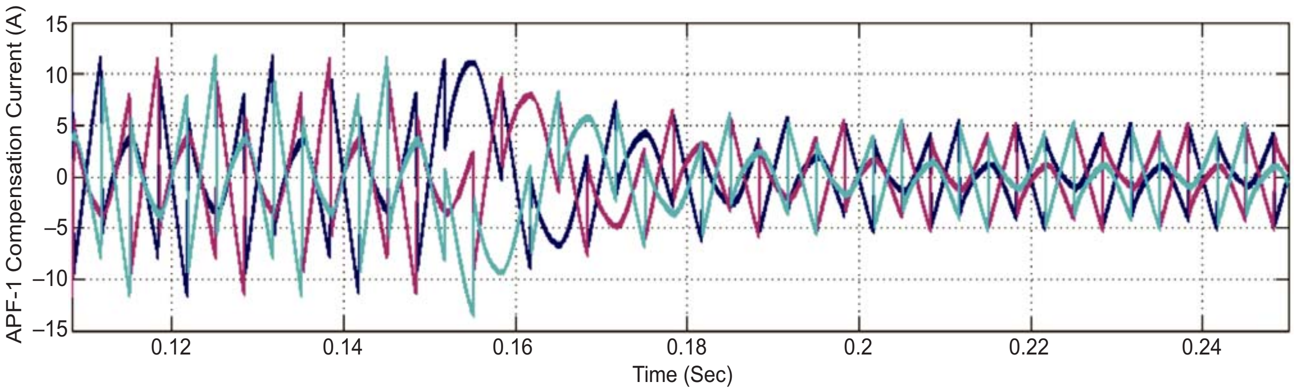

Figure 25: Compensating Currents of APF-1

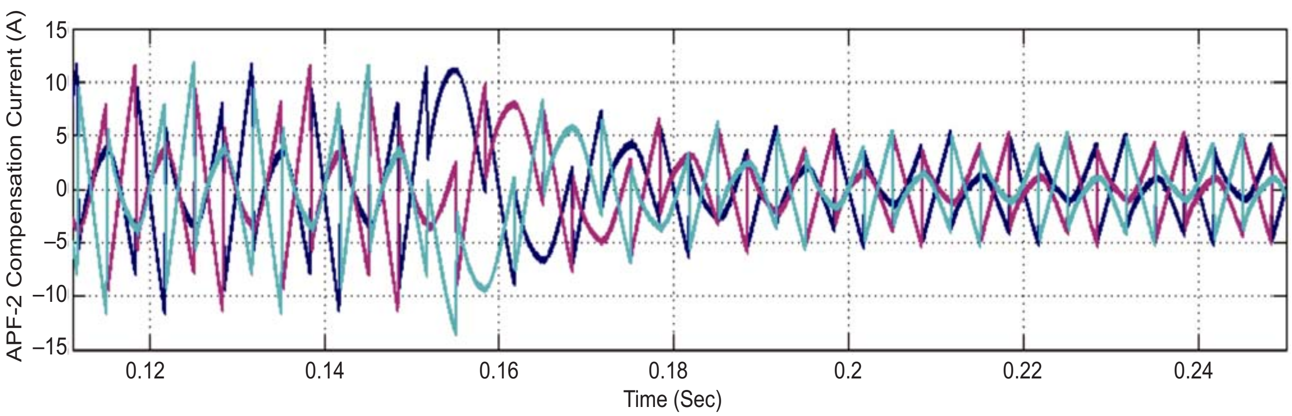

Figure 26: Compensating Currents of APF-2

Figure 25 shows the compensating currents fed to the point of common coupling from active power filter – 1. Figure 26 shows the compensating currents fed to the point of common coupling from active power filter – 2. The total compensating currents of 20A is shared by two parallel APF's. After 0.15 sec, the compensating signals from both the APF's are decremented with decrement in load currents.

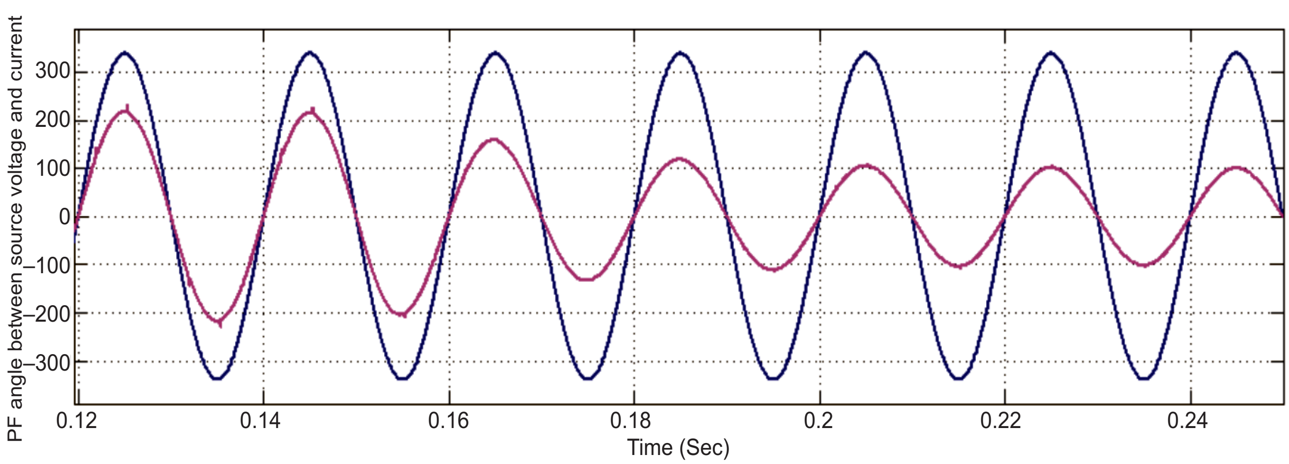

Figure 27: Power factor angle between source voltage and current

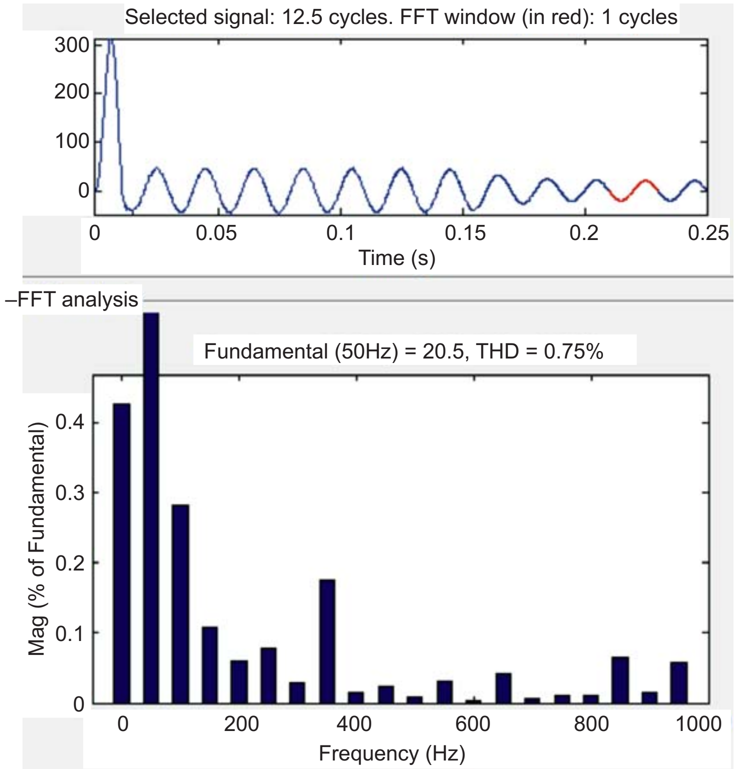

Figure 28: THD in source current

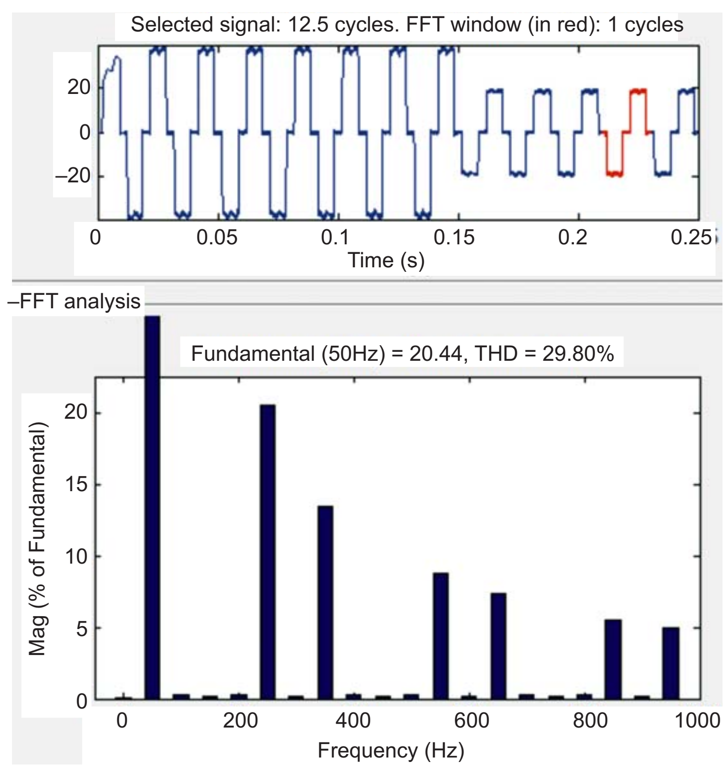

Figure 29: THD in load current

Figure 27 indicates the power factor angle between source voltage and current. The phase angle difference is almost zero and thus the power factor is maintained nearer to unity. Figure 28 indicates the total harmonic distortion in source currents is 0.75% which is well within the normal limits. Figure 29 shows the total harmonic distortion in load current is 29.8%.

5. CONCLUSION

The paper presents the parallel active power filter concept for harmonic elimination in industrial type of non-linear loads. Active power filter, a type of custom power devices can effectively address the harmonic problem in power system. Parallel active power filter concept share the harmonic current injection for compensation eventually reducing the rating and as a result switching losses in active power filters. The parallel active power filters are controlled with a common single control scheme using instantaneous active and reactive power theory. Proposed concept was implemented using MATLAB/SIMULINK software and results were discussed considering different loading conditions of the proposed system like for incremental load and decremented load conditions. Results shown prove to have no harmonics in source currents due to compensation with parallel active power filters. Load current does contain harmonics as load is of non-linear type.

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