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Investigation the Performance of the Various Types of Harmonic Filters

R. Sriranjani and S. Jayalalitha

EEE Department, School of EEE, SASTRA University
Thirumalaisamudram, Thanjavur, Tamilnadu, India

Abstract: The nonlinear load such as UPS, fan controller, mobile charger is distorting the supply current waveform. This current harmonics derates the power system equipment. To avoid this current harmonics, filters namely passive filter / active filter /hybrid filters are introduced in the supply line. In this paper the overall view of the performance of the various filters are studied and the performance of the transformerless single phase hybrid filter using artificial neural network(ANN) is analysed using Matlab simulink and the results are presented.

Key words: Nonlinear load · Harmonics · Passive filter · Active filter · Hybrid filter · ANN

INTRODUCTION

Harmonics have existed in power systems for many years. The steep development of solid state electronics resulted in the introduction of delicate appliances which affects the quality of the power. Some application of power converters are battery charger, UPS, Static VAR compensator, electric drives and HVDC transmission line etc. because of the advantages of power converters it is also used in medical field. The major problem of these electric utilities is the distortion of current and voltage waveforms. This current harmonics causes higher RMS current and voltage in the system which results in misfiring of AC and DC drives, extra loss in transformer winding this leads to increase in their hot spot temperature and reduction in insulation life, tripped circuit breakers, overheated conductors, voltage distortion, high neutral current and increased system losses [1-9]. Solutions are aimed to avoiding or overcoming harmonics include, phase cancellation, filters and circuit detuning.

Harmonics can be efficiently reduced through the use of passive filters. The passive filters are series tuned filter, double band pass filter and damped filter. The series tuned filter is used to compensate a single tuned harmonic frequency and double band pass filter is used to compensate two harmonic frequencies. These filters will compensate lower order harmonics. The damped filter is used to compensate higher order harmonics so it will acts as a high pass filter [3, 10-16]. But these types of filters have the disadvantages like the filtering characteristic depends of source impedance, blow the tuned frequency the impedance gets aggravated and fixed compensation [2]. Then there was a demand for the use of Shunt active filters because it will provide harmonic compensation and reactive power compensation [4]. The voltage source inverter/current source inverter is act as an active filter. This filter is designed to inject the harmonic current and fundamental reactive current. So supply is free from harmonics and it is in-phase with the supply voltage. The transformers are used to step down the voltage to the active filter and also it acts isolation between the filter and the load [4]. But the active filter carries the dominant harmonic current and the fundamental reactive current then the cost of the device used in the filter is increased. In order to reduce the cost of the active filter, the passive filter are connected so that the dominant harmonic current are injected by the passive filter also the drawbacks of the passive filters are overcome by the active filter. This type of filter is the hybrid filter. The transformerless hybrid filter will reduced the cost of the active filter [14]. In this paper, the various types of filters such as passive, active and hybrid filters for three phase nonlinear load and the control strategy for the filter are widely discussed. In the traction application the single phase active filters are used [17]. Single phase hybrid filter with Artificial neural network control is designed and the results are analysed using Matlab simulink. The ANN control used for the Shunt active filter is reducing the complexity of the conventional control design.

Corresponding Author: R. Sriranjani, Department of EEE, School of EEE, SASTRA University, Thirumalaisamudram, Thanjavur, Tamilnadu, India.

Filters: The current harmonics are reduced by the Passive, Active and Hybrid filter.

Passive Filter: Fig 1 shows the passive filters connected to the supply system and it is tuned to the dominant harmonic frequency. The cost of the passive filter is very low and it is easy to tune the particular frequency. This filter acts as zero impedance at the tuning frequency that absorbs the harmonics. There are many passive filter namely series tuned filters, double tuned band pass filters damped filters and anti resonant filters. Fig 1(b) shows the different configurations of passive filter. This filter has some drawbacks that the filtering characteristics dependent on the source impedance, not appropriate for variable load and there is a parallel resonance [2-8, 18,19]

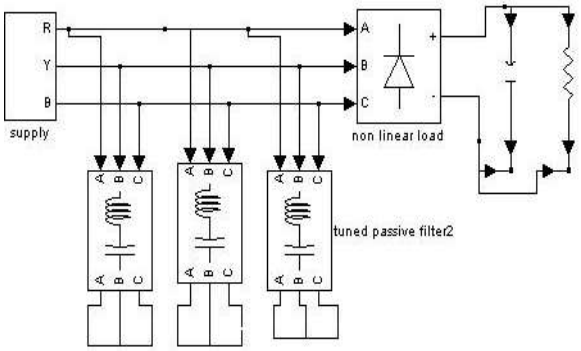
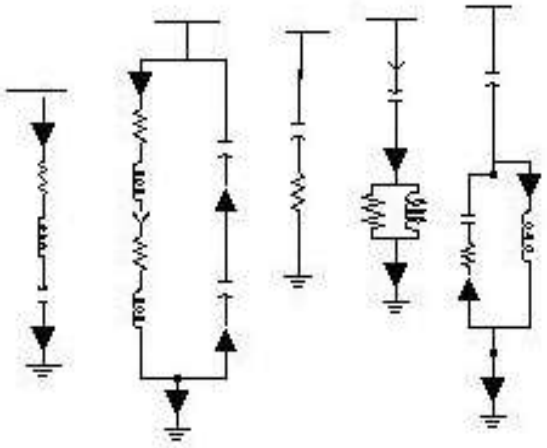


Fig 1(a): Passive filter



(I) (ii) (iii) (iv) (v)

Fig 1(b): Different configuration of passive filters, (i) series tuned (ii) double tuned (iii), (iv) and (v) 1st, 2nd and 3rd- order damped

Active Filter: Fig 2 shows the active filter which consists of the Voltage source inverter has been developed for reducing the total harmonic distortion of the supply current and also controls the reactive power. The classification of the active filters is the Series active filter and shunt active filter. The shunt active filter acts as a current source and it provides reactive power compensation where as the series active filter acts as a voltage source and it provides ac voltage regulation [2, 11, 13, 15,16, 20-22].

Due to some drawbacks of the active filter, the new filter was developed in 1988 [3]. Fig 3 shows the Shunt active filter which is used to compensate the reactive power and harmonic current generated by the three phase diode rectifier [3]. The shunt active filter is connected to the supply mains through the transformer. The instantaneous reactive power theory is used to control the Shunt active filter. The supply current is sinusoidal and power factor reaches to unity. In this Shunt active filter, Passive filters are connected to the supply mains to compensate the voltage fluctuation and voltage distortion due to the DC drives.. This filter is the combination of Active and passive filter. The Shunt passive filter acts as low impedance at the harmonic frequency and the source impedance acts as low impedance at the fundamental frequency. This can be possible only by inserting the active filter in series with the ac source. PWM converter is used as an active filter.

Fig 4 shows the active filter which consists of a Current source inverter. The active filter consists of a current source PWM converter connected in parallel with the Controlled rectifier load [8]. The LC filters of the active filter reduce the carrier harmonics but it affects the

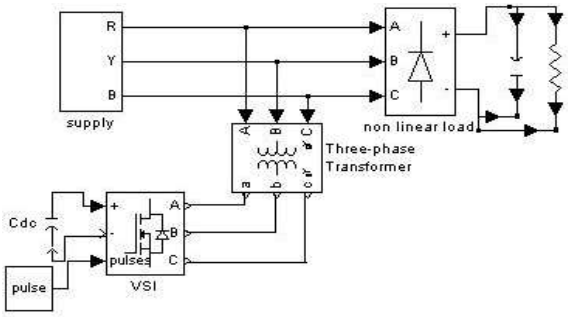


Fig 2: Active filter

transient response of the supply current. So the PWM converter is controlled by the feedback loop of the supply current and its derivatives. This gives the good dynamic response of the system. It has the advantages of quick response, high reliability, easy protection and better current controlling capability. If Super conductor coils are used, it provides the lossless dc reactor [5, 23].

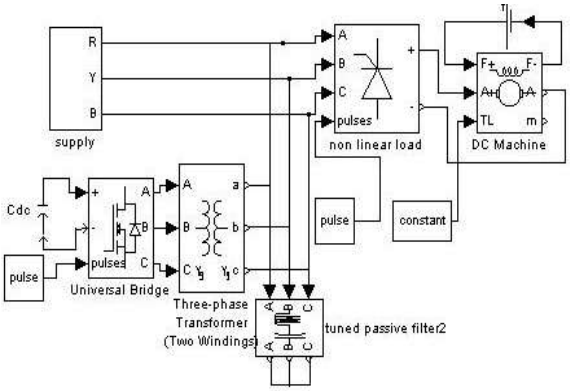


Fig. 3: Shunt active filter and shunt passive filter for DC drive

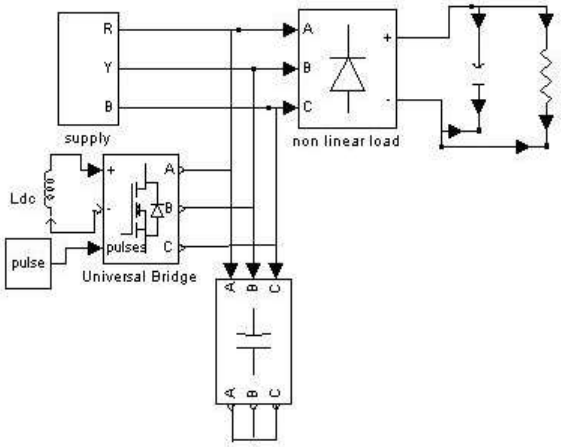


Fig 4: Current source active filter

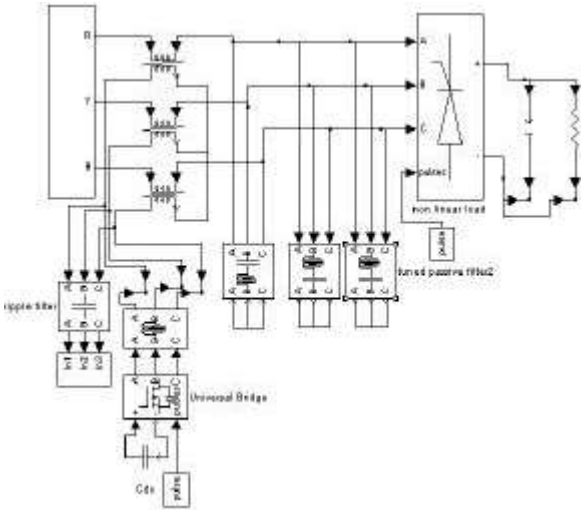


Fig 5: Series active filter with tuned passive filter

In practical case, the cost of the active filter is very high and constructing the active filter with large VA rating of low loss and rapid current response [4].

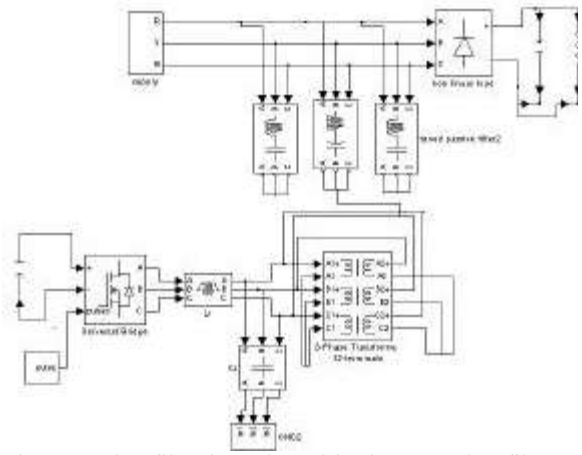


Fig 6: Active filter in series with Shunt passive filter

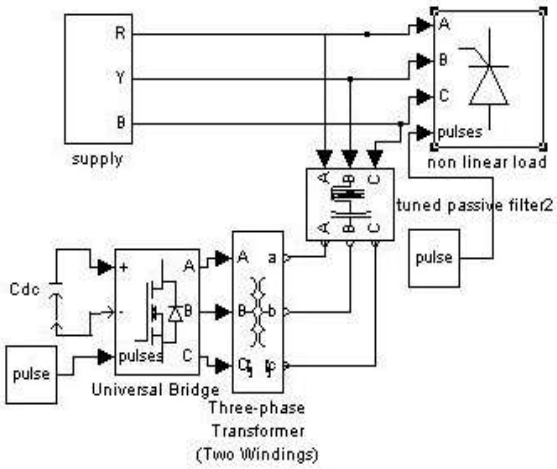


Fig 7: Parallel hybrid filter

Hybrid filter: In 1988, the new filter was developed which is the combination of Active and Passive filter shown in Fig 5. The PWM converter acts as zero impedance at the dominant harmonic so it eliminates the limitations of the passive filters. The active filter are connected the supply mains through the current transformer and the LC filter. The LC filter is used to suppress the voltage spikes due the switching of the PWM converter. The low pass and high pass filters are connected to eliminate the dominant harmonics and high order harmonics. This filter eliminates the supply harmonics of the thyristor rectifier load. The PWM converter is protected against the over voltage and over current by turning off the upper leg switches and turning on the lower leg switches. The secondary are shorted with the dc capacitor so the converter is released from the secondary of current transformer. The instantaneous reactive power theory is used to control the active filter. The current flowing

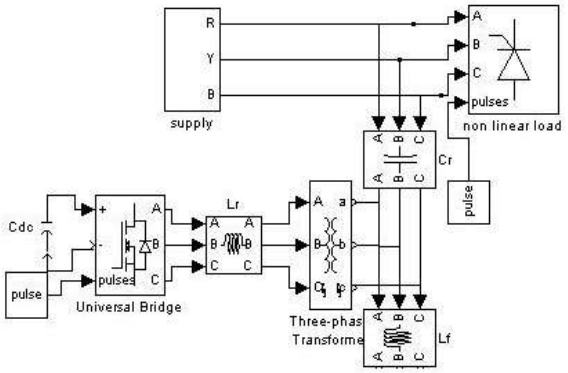


Fig. 8: Parallel hybrid filter with two inductor parallel to a capacitor

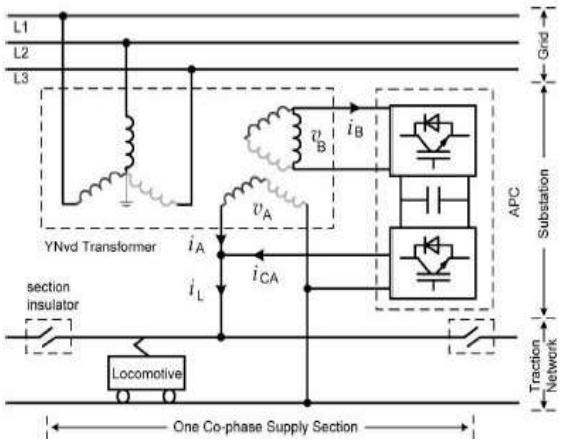


Fig. 9: Single phase back to back connection of active filter

through the active filter is leading current of the passive filter and the fundamental of the load current. This filter reducing the harmonics from the supply and the characteristics of the passive filters are also improved. For high power application this filter is considerably suitable to compensate the harmonics. But it is difficult to protect against a short circuit fault. The Q factor of the passive filter decides the VA rating of the active filter [4]. The VA rating of this active filter is reduced by the combination of active filter in series with the shunt passive filter which is shown in Fig 6. This filter eliminates the problem when passive filter alone used in the supply system. The current flowing through the active filter is harmonic current and the leading current of the passive filter. It is easy to protect and isolate from the supply system. This type of filters is series hybrid filter.

Fig 7 shows the parallel hybrid filter where active filter connected with the tuned passive filter through the three phase transformer. The active filter provides the low impedance path so that the entire harmonic current is flow into the passive filter. This filter needs a small active filter but there is a large voltage drop at the fundamental frequency across the capacitor. This causes large current to flow in the inverter through the transformer. So the transformer is designed for high turns ratio which leads to high insulation voltage [10]. To reduce the VA rating of the active filter new structure of parallel hybrid filter was developed by S.Park in 1999 [10, 16]. The fundamental component of the supply current to the passive capacitor filter is controlled by the inductor L_r connected in parallel with L_f. The active filter is controlled by the supply current detection method. The fundamental component of the active filter is extracted by synchronous reference frame and PI controller is used to regulate the DC bus voltage of the active filter .

The KVA rating of the three phase active filter is obtained from the equation $kVA = 3.|V_{inv}|.|I_{co}+I_{Ch}|$.

Where V_{inv}, I_{Co} and I_{Ch} denotes the inverter output voltage, fundamental currents of the inverter and filter capacitor harmonic current. Further reduction in the cost of the active filter is achieved by removing the isolation transformer between the passive and active filter. This reduces the rating of the inverter to less than 10% compared to shunt active filter [14, 15]. The reactive current is flowing in the passive filter and a small size of active filter is used to reduce the current harmonics.

Multilevel inverters are used as the active filter to reduce the supply current harmonics. Two or three single phase inverter are connected in series forms a multi level inverter [24]. Fig 9 shows the a single phase back to back active filter for traction application. This filter provides the harmonic compensation and reactive power compensation. Measurement of Active power and reactive power are done by Phase locked loop (PLL) in phase A and phase B [17]. The control strategy needs many low pass filter, PLL, arthimetic and logical operators. This forms the control circuit very complex. In order to reduce the complexity of the control circuit of active filter, ANN techniques are used

In this paper, a single phase hybrid filter using artificial neural network is designed to control the harmonics without a transformer. The artificial neural network reduces the complexity of the control circuit and reduces the rating of the active filter control circuit. The modified Widrow - Hoff algorithm is used to calculate the weight matrix (W) [25].

$$\text{The supply voltage } V_s = V_m \sin w_1 t \qquad (1)$$

The supply current is given by

$$i_L(t) = \sum_{k=1}^{\infty} I_k \sin(k\omega_1 t + \Phi_k) \quad (2)$$

This current contains fundamental current and harmonic current.

$$i_L(t) = I_1 \sin(\omega_1 t + \phi_1) + \sum_{k=2}^{\infty} I_k \sin(k\omega_1 t + \Phi_k) \quad (3)$$

$$i_L(t) = i_f(t) + i_h(t) \quad (4)$$

$$i_h(t) = i_L(t) - i_f(t) \quad (5)$$

$$i_f(t) = I_1 \sin(\omega_1 t) \quad (6)$$

Where I_1 is the amplitude of the fundamental component of the load current and ω_1 is the supply frequency (50Hz).

From equation (1)

$$\sin \omega_1 t = \frac{V_s}{V_m} \quad (7)$$

Uing equation (7) in (6)

$$i_f(t) = \frac{I_1}{V_m} \times V_s \quad (8)$$

So, $i_h(t) = i_L(t) - \frac{I_1}{V_m} \times V_s$ (9)

In the ANN, the error is calculated by

$$e_n = d_n - y_n \quad (10)$$

The output matrix is given by

$$y_n = \sum_{l=0}^{L} x_{n-1} w_{\ln} \quad (11)$$

Where d_n is the desired output, y_n is the actual output, x_n is the input variable.

The weight matrix $w_n = w_{n-1} + \eta X_n e_n$ (12)

Where w is the weight matrix, η is the learning rate, x_n is the input variable and e_n error.

Then from the above equation, the weight matrix for the system is

$$w_n = w_{n-1} + \eta V_s i_h \quad (13)$$

From equation (9),(10) and (11), the weight w is given by

$$w = \frac{I_1}{V_m} \quad (14)$$

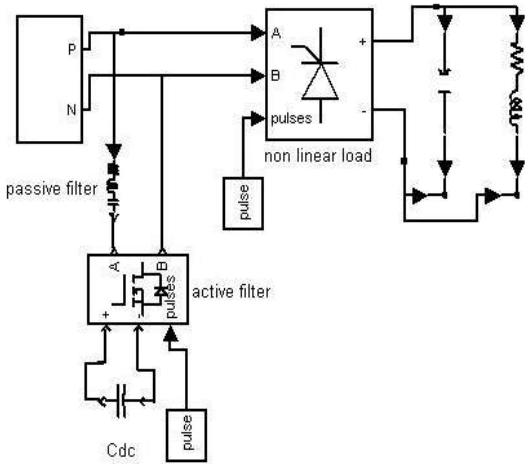


Fig. 10: Single phase Shunt hybrid Active filter

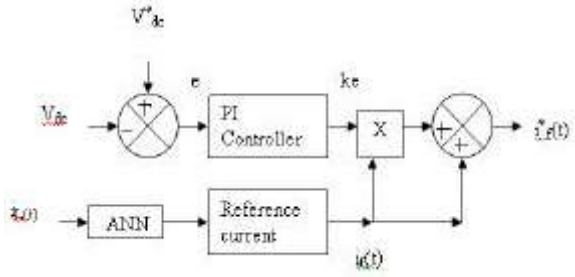


Fig. 11: Reference current extraction using ANN

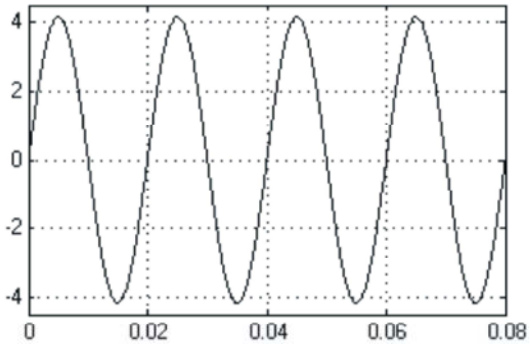


Fig. 12: Reference current waveform

Where I_1 and V_m is the fundamental component of load current and the maximum supply voltage.

The new control strategy was developed to extract the fundamental component of the supply current which is the reference current for the hysteresis controller shown in Fig 11. Fig 12 shows the fundamental component of the supply current extracted by modified widrow hoff algorithm and it is compared with the actual supply current using hysteresis current controller [26]. This control design is very simple and it reduces the complexity of the control circuit where the instantaneous

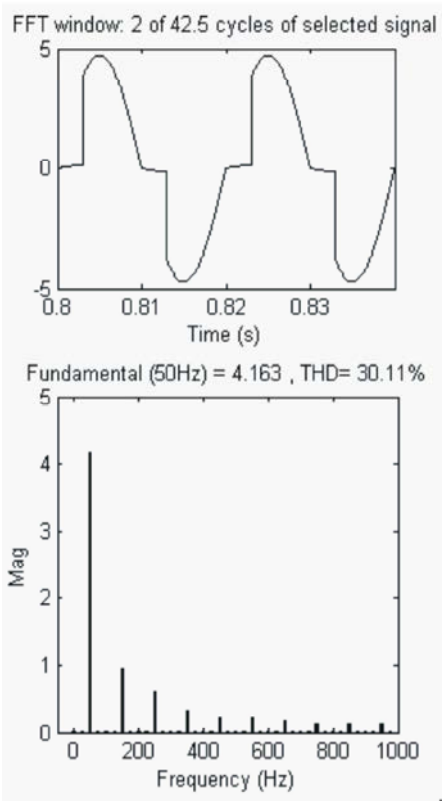


Fig. 13: Supply current waveform and Frequency spectrum of the supply current without filter for α=54°

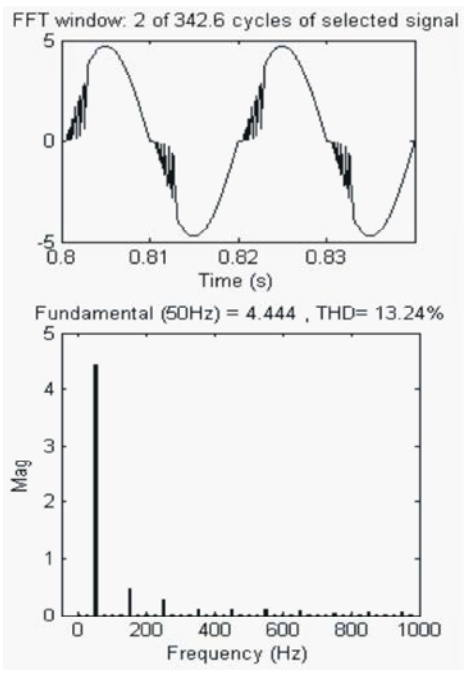


Fig. 14: Supply current and frequency spectrum of supply current with filter α = 54°

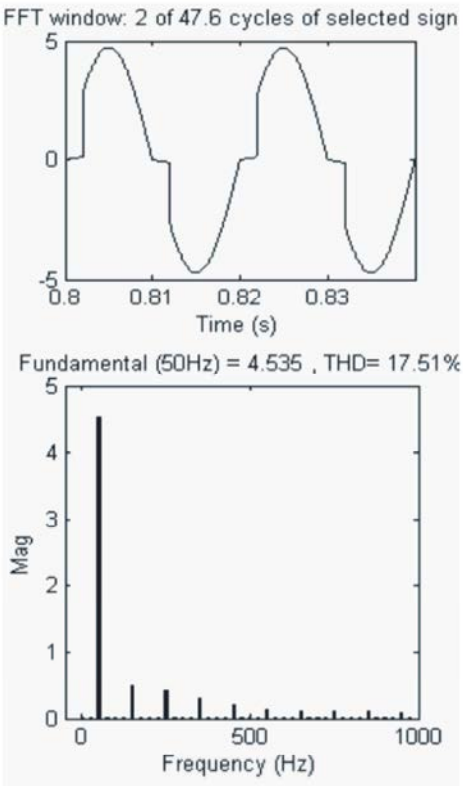


Fig. 15: Supply current and frequency spectrum of supply current with out filter α = 36°

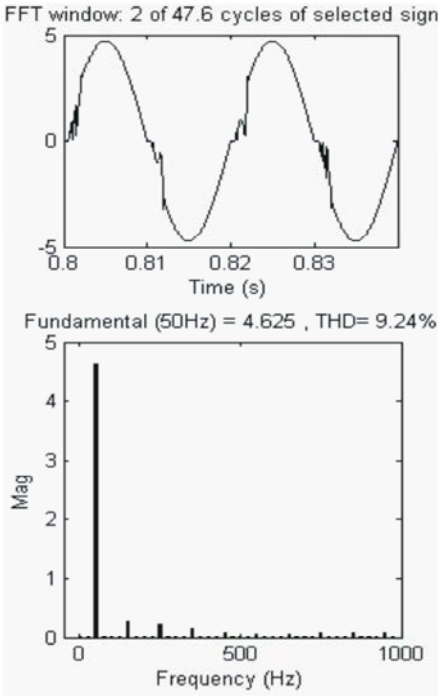


Fig. 16: Supply current and frequency spectrum of supply current with filter α =36°

reactive power theory is used to extract the reference current in the paper [27]. Fig 13 & Fig 15 shows the current waveform and frequency spectrum of the supply current with out filter for the firing angle 54° and 36°. The Total harmonic distortion of the supply current is 30.7% and 17%. When the Shunt active filter is connected to the supply mains the THD is reduced to 13% and 9% respectively. Fig 14 & Fig 16 shows the waveform of the supply current with filter. The supply current is nearly sinusoidal and power factor reaches near to unity.

CONCLUSIONS

Various types of filters are studied in this paper. The active filter overcomes the drawbacks of the passive filter. But the cost of the active filter is high so the passive and active filter are combined together, forms a hybrid filter. Different configuration of hybrid filter is also studied. In the parallel hybrid filter the cost of the active filter is very much reduced. If the isolation transformer is removed from the supply, the cost of the active filter is reduced to 10%. In traction system, single phase back to back shunt active filter is connected to reduce the current harmonics. The control circuit is very complex so ANN based control of Shunt active filter is analyzed using Matlab simulink and waveforms shows that the supply current is near to sinusoidal. The control strategy used in this paper is very simple and it can be implemented for any configuration of the active and hybrid filter.

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