A Thorough Analysis on Harmonic Elimination Techniques

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Abstract— The study of harmonics has become eminent due to the exponential growth of usage of electronics equipment in one way or other. Harmonics cause increase in losses, instability of the system and distortion of waveforms. There are number of methods employed in industries and power system to eliminate harmonics. This paper focuses on a thorough analysis of each and every method known to eliminate harmonics. The target audience for this paper can be anyone related to the field of electrical and electronics engineering. After reading this paper, the reader will gain the knowledge of various mentioned harmonic elimination techniques. This paper will help a reader to determine the best harmonic elimination technique which can be employed for any particular purpose.

Key words: Active Filter, Harmonics, Hybrid Filter, Passive Filter, Transformer, Total Harmonic Distortion

I. INTRODUCTION

According to the IEEE definition, "Harmonics are sinusoidal voltages or currents having frequencies which are whole multiples of frequency at which a supply system is designed to operate". In layman language we can say that harmonics are the bad frequency component which needs to be avoided at any cost. Harmonics are introduced due to the fast switching of solid-state power electronics based device which are used to operate the present day electric machinery. Due to the fast switching of power electronic devices, the load becomes responsible in the phase shifting (to and fro) of current. This doesn't sound like a problem when it happens a few times. It actually creates a problem when this phenomena occurs at time which is the integer multiple of fundamental frequency of the device. It simply means that phase shifting of current becomes occurs more frequently as compared to regularly. Due to this process of current shifting its phase multiple times in a single second the problems in machines start arising. Such problems are premature failing, wires being overheated, frequent tripping of protective equipment and sometimes false measurement on power meters.

Consider an electrical equipment which operates on fundamental frequency 50Hz. With the introduction of harmonics in the equipment the same machine continuously phase shifts the current 150 times a second if we are particularly talking about 3rd harmonic. Similarly during 5th harmonic the current phase shifting of current becomes 250 times a second and so on.

In more general manner, we can state that any waveform can be broke in to many series of sine waves which are added together. Such type of analysis is what we call Fourier analysis (for repeating original waveform) or Fourier transform (for any other waveform). For a square wave waveform one can notice that all the sine wave combine to form a waveform that has frequency which is an integer multiple of the frequency of fundamental waveform.

Hence it means that harmonics are nothing but the distortions in a perfect sine wave.

A. Total Harmonics Distortion

THD is the summation of all harmonic components of the voltage or current waveform compared against fundamental components of the voltage or current wave

In audio system, lower distortion means the components in a loudspeaker, amplifier or microphone or other equipment produce a more accurate reproduction of an audio recording

In radio communications lower THD means pure signal emission without causing interference to other electronic devices Moreover, the problem of distorted and not eco-friendly radio emission appear to be also very important in the context of spectrum sharing and spectrum sensing

In power system, lower THD means reduction in peak current, heating, emission, and core loss in motor.[1]

$$THD = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2)}}{V_1} * 100\% \quad (1)$$

B. Impact of Harmonics on a 3 Phase induction motor

Let us consider a 3 Phase induction motor which operates at 50Hz fundamental frequency. Hence the first harmonic is 50Hz itself. The impact of further (2n+1) harmonics is shown in a tabular form below.

From the table we can deduce that at fundamental frequency the motor phase sequence is ABC. When the 3rd harmonic is introduced and the phase sequence of each phase reaches 2nπ due to which there exists no phase difference and hence no RMF so motor doesn't rotate. With the 5th harmonic, the phase difference gets inverted and the phase sequence also gets inverted which results in the anti-clockwise rotation of motor. 7th and 9th harmonics' effect can also be understood in the similar manner from the table.

C. Impact of harmonics on a 3-Phase transformer

When the electrical system is re-configured after the introduction of variable frequency drive, electronic choke, arc furnace etc.

Fundamental	A 0°	B 120°	C 240°	A-B-C
3rd harmonic	A' 3 x 0° (0°)	B' 3 x 120° (360° = 0°)	C' 3 x 240° (720° = 0°)	*no rotation*
5th harmonic	A'' 5 x 0° (0°)	B'' 5 x 120° (600° = 720° - 120°) (-120°)	C'' 5 x 240° (1200° = 1440° - 240°) (-240°)	C-B-A
7th harmonic	A''' 7 x 0° (0°)	B''' 7 x 120° (840° = 720° + 120°) (120°)	C''' 7 x 240° (1680° = 1440° + 240°) (240°)	A-B-C
9th harmonic	A'''' 9 x 0° (0°)	B'''' 9 x 120° (1080° = 0°)	C'''' 9 x 240° (2160° = 0°)	*no rotation*

Fig. 1: harmonics on a 3-Phase transformer

The harmonics are introduced along with voltage input to the transformer. Harmonics do have an ill effect on transformers but they cannot be noticed until a failure occurs. From the above mentioned definition of harmonics we have come to understand that due to the addition of harmonics a sine wave becomes distorted. When such distorted voltage wave is applied to the transformer primary it increases the iron losses in the iron core of the transformer just like an induction motor. Due to the introduction of harmonics the eddy currents in the windings increase. These eddy currents accumulations are higher near the end of transformer winding and it happens due to accumulation of leakage magnetic fields near coil extremity. Due to the eddy currents the temperature of the transformer increases at a considerable extent. If this is not taken care of, the major failure of transformer may occur.[2]

II. HARMONICS ELIMINATION METHODS

In this paper, we are focusing basically on harmonic elimination techniques, namely, active filter, passive filter and hybrid filter.

A. Active Power Filter

The concept of active power filter was developed by L.Gyugyi in 1970s. The control strategy for active power filter was concluded by H.Akagi as three modes Load current detection, supply current detection and voltage detection for different applications. Active power filter contains active elements which are produce power. Active power filter work on the principle of the generation of the opposite voltage of harmonics voltage generated in the power system. For elimination of the voltage and current different type of active power filters are used .For elimination of the voltage harmonics series active power filters are used and for the elimination of the current harmonic shunt active power filters are used. There are many advantages of shunt active power filters over the series shunt power filters.

Now, active power filters are having mainly two types

- Shunt Active Power Filters
- Series Active Power Filter

1) Shunt Active Power Filters

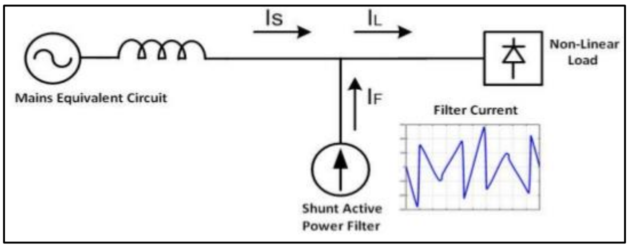

Fig 1: Shunt Active Power Filter

Shunt active power filters have a numbers of advantages over the passive filters .Shunt active harmonics filters (SHAF) are power electronic based device used as controlled current sources Modem active filters are microprocessors controlled which gives them high flexibility and versatility. The In configuration of a PF a VSI founded It comprises of a DC-bus capacitor, power electrical devices swaps and interfacing inductors. Shunt APF acts as a current source, reimbursing the harmonics current due to nonlinear loads. The procedure of shunt APF is founded on injection of compensation present which is equals to the distortion current, therefore eradicating the initial distortion current. This is achieved by "SHAPING" the reimbursement present waveform, utilizing the VSI swaps. The shape of reimbursement present is got by measuring the load present and subtraction it from a sinusoidal quotation. The aim of shunt APF is to obtain a sinusoidal source current utilizing the equation

$$i_s = i_l - i_f \quad (2)$$

a) Principles configuration of a VSI based shunt SAPF:

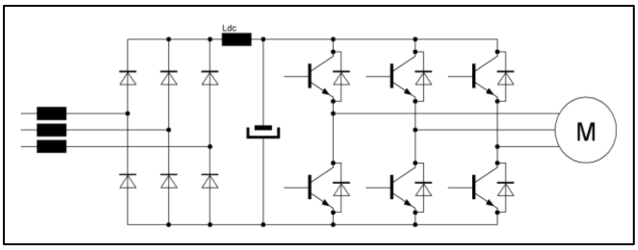

Fig. 2: VSI based series APF

In SAPF the ideal source present when shunt active power filter presents harmonics filtering of a diode rectifier. The injected SAPF current completely cancelled the current harmonics from the non-linear burden, resulting in a harmonics free source current. From the nonlinear load current point of outlook, the shunt APF can be considered as a varying shunt impedance. The impedance is none or at least small for the harmonics frequencies and infinite in the period of the basic frequency. As a result, decrease in the voltage distortion happens because the harmonics current flow through the source impedance is decreased.

In the shunt active power filter as frequency increase the impedance is also increase , due to this a current of same magnitude of the harmonics but in opposite polarity generates ,this cancelled the harmonics and give pure power.

b) Series Active Power Filter

This filter is connected in series with the distribution line through an equivalent transformer. Here, VSI is used as the controlled source; therefore the principle configuration of series APF is alike to shunt APF, except that the interfacing inductor of shunt APF is restored with the interfacing transformer. Due to this I^2R losses are increase. By increasing the voltage, the SAFs are able to present high impedance for the harmonics current, resulting the blockage of the unwanted harmonics and preventing them from flowing to the source. The major benefit of sequence APFs over shunt is that are ideal for voltage harmonics elimination.

1) Operation

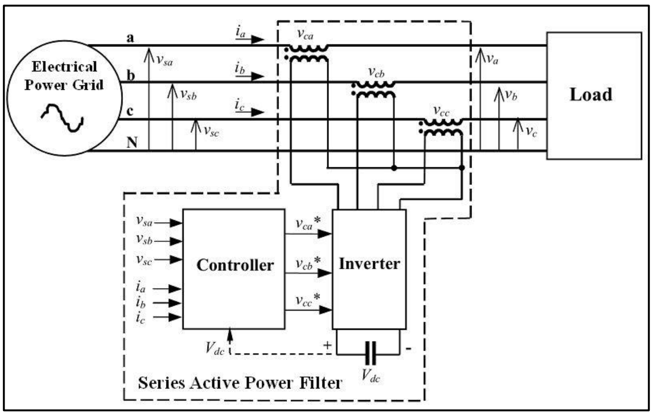

Fig. 3: Series Active Power Filter

The operation of series APF is based on isolation of the harmonics in between the nonlinear burden and source. This is got by the injection of harmonic voltage (V_f) across the interfacing transformer. The injected harmonics voltage are added/ subtracted, to/from the source voltage to maintain an untainted sinusoidal voltage waveform across the nonlinear burden. The sequence APF can be considered as a harmonics isolator. It is controlled in such a way that it presents non impedance for the fundamental constituent, but appears as a resistor with high impedance for harmonics frequencies components. That is, no current harmonics can flow from nonlinear load to source and vice-versa. Series APFs are not widespread compare to shunt APFs because they have to handle high burden currents.[3]

2) Disadvantages of series APFs compared to shunt APFS

Series APF is the principal that series injection transformer needs to be used to interface with the system in order to inject the active filter's voltage. The transformer requires a special design so the cost is more

The transformer must provide very low voltage for line frequency load current circulation

The Series APF is much complex for the protection system for the active filter converter which must be design to withstand load's short circuit. During a short circuit event, the high load current will reflect on the secondary of the injection transformer generation dangerous voltage and potentially damaging the active filter converter.

Typical protection schemes consider a thyristor based bypass that closes to bypass the converter when the load suffers high current fault condition and consequently protect the converter from failure.

B. Passive Harmonics Filter

Passive harmonics filter are most common method used to control the flow of harmonics current. They are built using a series of capacitors and reactors forming an LC circuit in parallel with the power source. More complex design may involve multiple LC circuit, some of which may also include a resistor. The passive harmonic filter is also referred to as a trap because it absorbs the harmonics current to which it is used.

1) Basic Design and Operation Principle

The basic combination of capacitors and inductors forms a tank circuit, which provides a low impedance path for the targeted harmonics frequency. The idea is to properly size the LC circuit with respect to its location in the system to achieve e the same resonance frequency of the harmonics to be eliminated, the harmonics current is dissipated as heat by the utility system. This heat is not consider as the loss

The selection of the capacitor and reactor ratings are depend upon,

- Harmonic order to be removed
- Harmonic profile of the load current
- KVA requirements of the load
- Harmonics factor of neutral current
- System data and configuration

a) Passive Series Filter

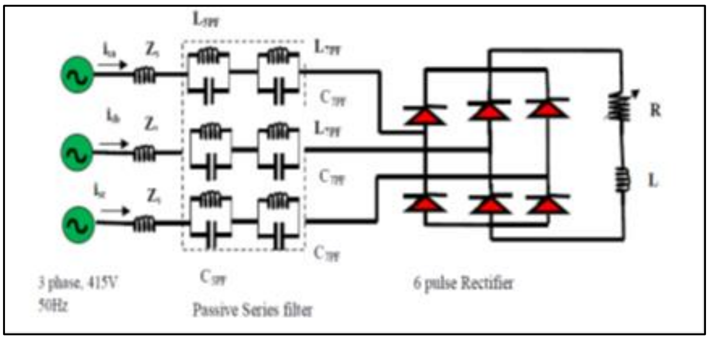

Fig. 4: Passive Series Filter

The series passive filter is connected in series with the load. The inductor and capacitor are connected in parallel and are tuned to provide high impedance at a selected harmonics frequency. The high impedance then blocks the flow of harmonics current at the tuned frequency only. At fundamental frequency, the filter would be designed to yield low impedance, thereby allowing the fundamental current to flow with only minor additional impedance and losses. Series filter are used to block a single harmonics current and are much useful in single phase circuit where it is not possible to have advantage of zero-sequence characteristic. The use of the series filter is limited in blocking multiple harmonic current. Each harmonic current requires a series filter tuned to that harmonic. This arrangement can create losses at the fundamental frequency. The systems which come with the voltage source type harmonics which are the bi product of diode rectifier with R-C connects load. A passive type series filter has property of purely inductive type or LC tuned characteristics. The main components of passive series filter are AC line reactor and DC link filter.

The operating principle of passive filter is that AC line reactor improves system magnitude of inductance in the system that alters the path of current drawn in the rectifier circuit. Due to this in system the current wave form become more continuous as compared to previous. The merit of this filter is in its low cost, small size and provides n system resonance condition.

The value of the inductor is set to a voltage drop of between 3% and 5% of the nominal voltage of the network. Series harmonic filter lack upgrade ability, monitoring and redundancy, meaning that, if the filter fails, the drive fails. The last series-passive solution in multi-pulse ,a multi-winding transformer with phase shift in the winding , because every secondary winding has its own rectifier, an 18-pulse configuration can target and effectively cancel out the 18^{th} ,19^{th} ,35^{th} and 37^{th} harmonics. The downside of using multi-pulse is that it's very sensitive to voltage unbalance.

In 18 pulse drive under 50% load, when unbalance is increase 0%-3%, the current THD increase from 10%-35%. At less than 100% load, the current THD doubles from 8%-16%. When using multi-pulse, planning the drive system and deployment a unit are often large, heavy and difficult to retrofits.[5]

b) Passive Shunt Filter

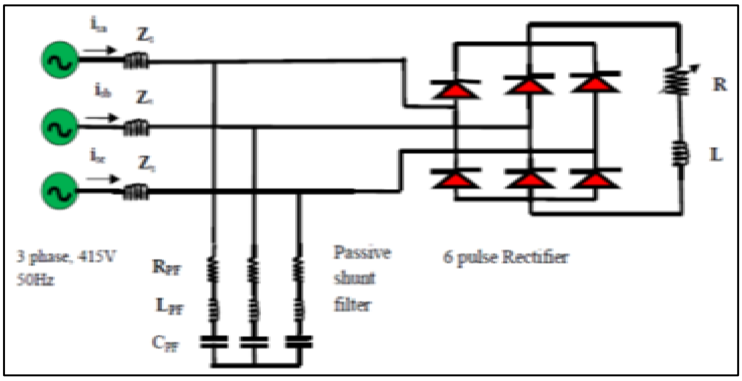

Fig. 5: Shunt Passive Filter

In the distribution system, this is a very common method for the reduction of harmonics current. The principle of design of Passive harmonics filter is either single tuned or band pass filter technology. Here, shunt type filter are connected in system parallel with load. Passive filter gives very low impedance in the network at the tuned frequency to divert all the related current at given tuned frequency.

Because of passive filter always have tendency of offering some reactive power in the circuit so the design of passive shunt filter take place for the main two purpose, first is to filtering purpose and second is to provide reactive compensation of correcting power factor in the circuit.

The advantage with the passive shunt type filter is that it only carry fraction of current so that the whole system AC power losses are reduces compare to series type filter. In the schematic diagram of system connected to shunt passive type filter which are used in distribution system have R-C load in system

The designing of filter component should be good so they will precisely employ for each specific harmonic frequency which it has to be tuned. Sometime shunt passive filter use fixed capacitor bank, tuned and detuned contactor based units, thyristor capacitor bank and fine-tuned passive filter for correction of power factor.

This methods were develops on the principal of resolve reactive power not on specially harmonics mitigation. So a weakness inherent in passive solution is the inability to control the load. The grid loading along with filter impedance can cause fine-tuned shunt filter to interact, result in resonance with other equipment.[3]

Active and Passive filters are explained above. There is another elimination technique which is more advanced and efficient then active filter and passive filter. This technique is referred as Hybrid Filter Technique.

C. Hybrid Filters

1) Block diagram using Hybrid Filter

There are two types of hybrid filter, namely hybrid active filter and hybrid passive filter. The term hybrid is introduced because both these filters employ series and shunt type of active and passive filters respectively. We will discuss both hybrid active and hybrid passive filter in this paper. At first, we will discuss about hybrid passive filter.

a) Hybrid Passive Filter

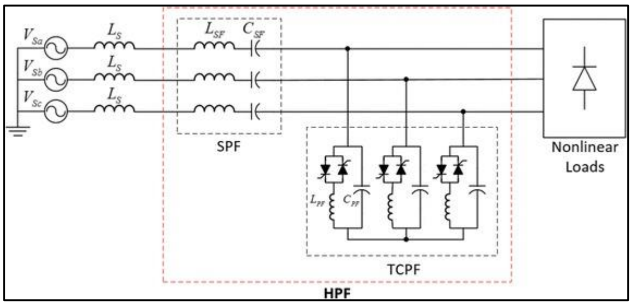

Fig. 6: Hybrid Passive Filter

Figure 6 shows passive hybrid filter. Passive shunt filter seems problematic for voltage regulations at light loads. During the operation the passive filter increases dc voltage ripple and ac peak current of the rectifier. In the case of passive series filter, it bears lagging power factor during operation. Moreover, there is voltage drop in the filter components at both fundamental and harmonic frequencies. Both these drawbacks are overcome by using a combination of passive shunt filter and passive series filter which is termed as passive hybrid filter. This type of combinational network provides the benefits of both passive shunt and passive series filter. This combination improves harmonic compensation under varying load conditions for taut and misshaped AC voltage input.[3]

b) Hybrid Active Filter

The below mentioned figures show active hybrid filters.

In Figure 7 there is an active hybrid filter in which series active power filter is connected to line through a transformer whereas a passive filter is connected in parallel to the load. The shunt passive filters might contain a single unit or might contain multiple units which are single-tuned passive filters. The series active hybrid filter is operated such that its operation is like a harmonic isolator between source and non-linear load.

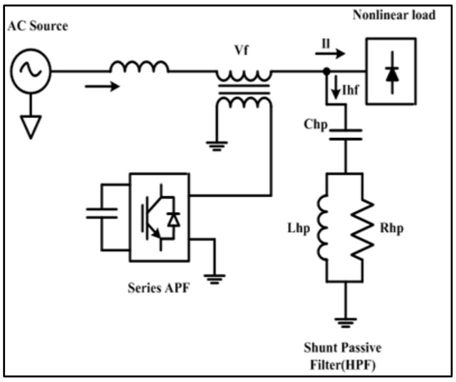

Fig. 7: Hybrid Active Filter configuration 1

A controlled harmonic voltage is introduced in the system which eliminates harmonic voltages. Its operation is such that at fundamental frequency there is zero impedance offered whilst at all unwanted harmonic frequencies a high impedance is offered. With this all the load current harmonics are prevented from entering in to the passive filter. With this effect the source and non-linear load are isolated at all frequencies except fundamental frequency.

There is only one limitation of this system because a transformer with high current rating due to which the system becomes bulky and costly. Due to these drawback this method is rarely used.

Figure 8 shows an active hybrid filter which is a combination of shunt active filter and shunt passive filter. This combination of hybrid active power filter has two functions: firstly the passive high pass filter by passes all the harmonics of higher order and the shunt active filter supplies for low order harmonics present in the load current (I_L).

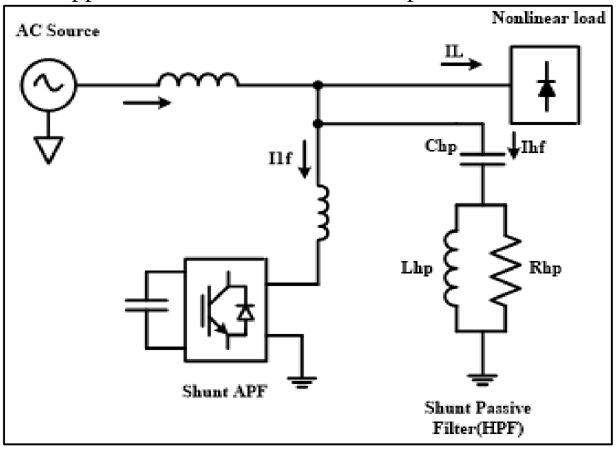

Fig. 8: Hybrid Active Filter configuration 2.

This combination has a tendency to adjust its practice with active power filter and it is suitable for elimination of harmonics and reactive currents. Such type of combination of hybrid active filter has wide scope of implementation in low voltage distribution system. This type of connection basically helps to lower the switching noise and interference at a time.[3]

c) Advantages of Active and Passive Filter

Active Filter	Passive Filter
No inductors are used.	Requires no power supply.
High internal impedance and low output impedance for minimal loading.	Capable to handle large voltage and large current.
Easier designs.	Accurately Reliable.
High gains can be produced.	Requires less number of components to design a filter.
It is easier to tune.	Noise is due to resistances only.
Size and weight are smaller.	Bandwidth unlimited.

Table 1: Advantages of Active and Passive Filter

d) Disadvantage of Active and Passive Filters:

Active Filter	Passive Filter
Requires power supply.	For low frequencies large inductors needed.
Prone to inter-modulated oscillations.	Non-toroidal inductors may require shielding.
Op-amp gain bandwidth is constrained.	Low tolerance inductors are very expensive.
Requires many components	Design consideration according to input and output

Table 2: Disadvantage of Active and Passive Filters

III. CONCLUSION

With the possible configurations mentioned, the best is found to be hybrid filter configuration. It eliminates the disadvantages of active filters can be overcome using passive filter in series or parallel combination. After going through this paper the reader will get an idea about harmonic filtering techniques. On studying the harmonic filter it is found that the load side harmonics are completely removed as compared to the source side. Hence the input voltage applied to the system resembles the sine wave. By applying a pure sine wave on the input side the power quality is improved and hence the equipment life expectancy is not harmed. Moreover, the equipment can operate smoothly without any harmonic disturbances.

REFERENCES

[1] Power Quality Published by C. R. C Press written by C. Sankaran
[2] Komurcugil, H. & Kukrer, O., “A new control strategy for single-phase shunt active power filters using a Lyapunov function”, IEEE Transactions on Industrial Electronics, Vol. 53, No. 1, pp. 305 - 312, February, 2006.
[3] Ankit H. Patel, B. A. Shah “Harmonic compensation using different passive filter configurations”, IJSRD, Vol.2, Issue 01, 2014.
[4] Farooq, A. and Bhat, A.H., (2015),” Performance Evaluation of a Three phase Shunt Active Power Filter For power Quality Improvement.”

[5] Report by Deepak C.Bhonsle. "Design and implementation of single phase shunt active power filter for harmonic mitigation in distribution system" The M.S.University of Baroda.
[6] H. Akagi, "Active harmonic filters," Proc. IEEE, vol. 93, no.12,pp.2128–2141,Dec.2005
[7] Jacobs J,Detjen" D,-A new hybrid filter versus a shunt power filter", in European conference on pwer electronics &applications,Graz,Ausreia 2001.
[8] Prof.dr.Dobariya,Prof.P.Upadhyay,(2015),"Simulation and comparison between hybrid active power filter and shunt active power filter."
[9] Kuldeep Kumar Srivastava, SaquibShakil and AnandVardhan Pandey, "Harmonics & its mitigation technique by passive shunt filter" IJSCE, ISSN: 2231- 2307, Volume-3, Issue-2, pp.325-331, May 2013.