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DESIGN AND IMPLEMENTATION OF PASSIVE HARMONIC FILTER FOR VFD fed INDUCTION MOTOR

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ABSTRACT

Power quality issues are becoming critical with the growing use of industrial drives. The most of power quality problems are caused due to non-linear loads such as induction furnace and power electronic devices. The non-linear load produces harmonics which destroy the sinusoidal nature of supply. The best method of mitigating harmonics is by using by filter. However single tuned or high pass filters are generally used in industries. They have been used to improve power factor and to absorb harmonics in power systems. In this paper, harmonics produced due to variable frequency drive in induction motor system is analysed using Fluke 435 seriesII and design calculations for the filter is performed. The hardware results of VFD fed induction motor along with filter circuit are presented and it shows that harmonic content in the system is reduced after the installation of filter.

INDEX TERMS: *Harmonics, VFD, Passive filter*

I. INTRODUCTION

In recent years both power engineers and consumers have been giving focus on the degradation of voltage and current due to harmonics, low power factor etc. The most of power quality problems are caused due to non-linear loads such as induction furnace and power electronic devices. Thus Harmonics play significant role in deteriorating power quality, called harmonic distortion. IEEE standards have defined limits for harmonic voltages and harmonic currents. So that it is important to mitigate this harmonics. The filter is design to minimize harmonic distortion caused by source such as drives. Several types of passive filters are effective in minimizing voltage distortion caused by non-linear loads in industrial power systems. Harmonic filters function by providing a low impedance path for harmonic currents generated by non-linear loads.

Different types of passive filters are single tuned, high pass filters, third order filters and C type filters. However single tuned or high pass filters are generally used in industries. They have been used to improve Power factor and to absorb harmonics in Power Systems because of its low cost, simplicity and efficiency. Passive filter offers very low impedance in the network at a tuned frequency to divert all the related current and at given tuned frequency.

Design of passive shunt filter take place for the two purpose one is the filtering purpose and another one is to provide reactive compensation purpose of correcting power factor in the circuit at desired level. The shunt passive filter is also capable of filtering specific tuned harmonic frequencies such as 5th, 7th, 11th etc. They have also been used extensively in HVDC systems, arc-furnace installations, and static VAR compensators installation. Superimposition of harmonics with fundamental waveform will distort the original waveform as shown in figure 1.

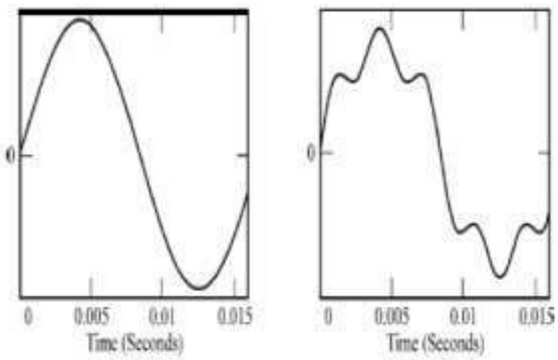

Fig 1 SUPERIMPOSITION OF HARMONICS WITH FUNDAMENTAL WAVEFORM

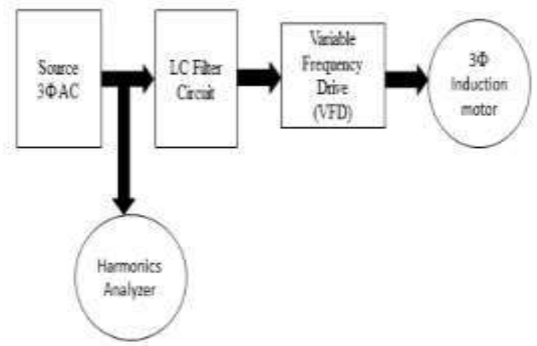

Fig 2 BLOCK DIAGRAM OF HARMONIC FILTER FOR VFD fed INDUCTION MOTOR

Table 1 SPECIFICATIONS OF VFD

Model	VFD022E43A
Input	2.2Kw,380-480V,7.1A
Output	2.2Kw,0-480V,5.5A
Frequency	0.1-599 Hz
Make	Delta Electronics

Table 2 SPECIFICATIONS OF AC MACHINE

Machine	Squirrel Cage I.M
Power	3 HP/2.2Kw
Voltage	400Volt
Current	4.3 Amps
Frequency	50 Hz
Speed	1440 rpm
Make	G.D Electricals

II. FILTER SELECTION

Harmonic filters are shunt elements that are used in power systems for reducing the voltage distortion and power factor correction. Harmonic filters are broadly classified into two types:

1. Active harmonic filter
2. Passive harmonic filter

1. Active harmonic filter

An active filter is something like a boost regulator. The concept used in an active filter is the introduction of current components using power electronics to remove the harmonic distortions produced by the nonlinear load. Active harmonic filters are mostly used for low voltage networks. The types of active filters are,

a) Series filter
b) Parallel filter
c) Hybrid filter

2. Passive harmonic filter

Passive filters are build using capacitors, inductors and resistors. They are series along or parallel resonating electrical circuits which offer very high or low impedance at tuning frequency. The filters are resistive at tuning frequency, capacitive below tuning frequency and inductive beyond tuning frequency

a) Single tuned filter
b) High pass filter
c) Double tuned filter
d) Double tuned high pass filter

a) Single Tuned Filter

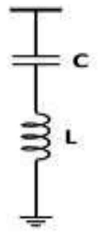

Fig 3 SINGLE TUNED FILTER

The most common type of passive filter is the single-tuned "notch" filter. This is the most economical type and is frequently sufficient for the application. The notch filter is series-tuned to present a low impedance to a particular harmonic current and is connected in shunt with the power system. Thus, harmonic currents are diverted from their normal flow path on the line through the filter.

b) High pass filter

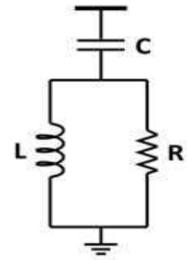

Fig 4 HIGHPASS FILTER

Low order high pass filters are realized using third order filter or c type filter .The filter is designed such that L and CL are tuned to fundamental frequency to offer a low impedance path for fundamental current thereby allowing very little amount of current to flow through the damping resistor. The major drawback of this filter is that it requires larger installed MVAR rating than multiple single tuned Filters in order to meet same specified performance.

c) Double tuned filter

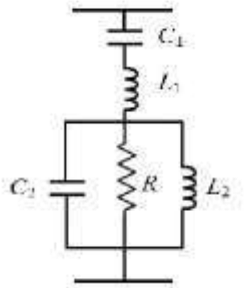

Fig 5 DOUBLE TUNED FILTER

Double tuned filter are equivalent to two single tuned filters connected in parallel. These filters use series as well as parallel resonating circuits, which makes it complex. C&L corresponds to first tuning frequency and high voltage section whereas C2&L2 corresponds to second tuning frequency and low voltage section. Accurate tuning is required at site because of which provision of taps on the reactor is essential. This increases the cost of the reactor.

d) Double tuned high pass filters

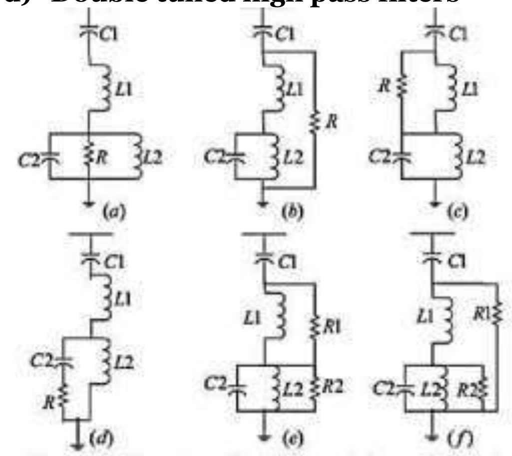

Fig 6 DIFFERENT CONFIGURATION OF DOUBLE TUNED HIGH PASS FILTER

Double tuned high pass filters are similar to double tuned filters except that damping resistors are added as shown in the figure according to the requirements. This filter is also equivalent to two second order high pass filters connected in parallel. RH corresponds to first tuning frequency and high voltage section whereas CL, LL and RL corresponds to second tuning frequency and low voltage section.

III. EXPERIMENTAL RESULTS

3.1 Direct Motor load

It's below shown in the fig 7 block diagram of motor load without variable frequency drive. The three phase induction motor is connected to a 3phase supply without VFD in delta connection and the observations are tabulated.

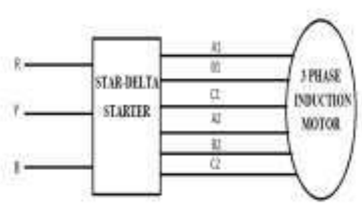

Fig 7 BLOCK DIAGRAM OF DIRECT INDUCTION MOTOR LOAD

The individual spectrum for different order of harmonic THD is shown in table 3 and it is observed that 5^{th} and 7^{th} order voltage harmonic are high.

Table 3 TABULATION FOR DIRECT MOTOR LOAD

Frequency (Hz)	Order Of harmonic	Voltage THD	Current THD
50	3th	0.39%	75.49%
	5th	1.6%	50%
	7th	0.6%	43%
	9th	0.4%	39%

3.2 Motor load with VFD drive

In case of motor load with variable frequency drive (VFD) operating condition, the motor speed is controlled by using VFD.Here VFD act as non-linear load and inject the harmonics into the supply. The VFD connected in the circuit between the source and motor load. By connecting the power analyser across the input source Total Harmonic Distortion (THD) in the system is observed. The circuit diagram is shown in the fig 8 induction motor with drive.

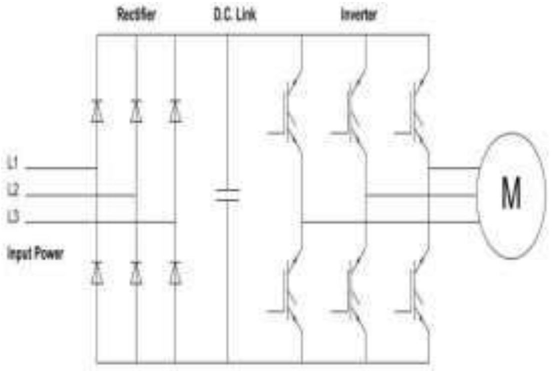

Fig. 8 MOTOR LOAD WITH VFD DRIVE

The individual spectrum for different order of harmonic THD is shown in table 4. Since VFD is non-linear load THD is increased compared to direct motor load and similarly 5th and 7th order voltage and current harmonics are high compared with other order of harmonics.

TABLE 4 TABULATION FOR VFD FED MOTOR LOAD

Frequency (Hz)	Order of harmonic	Voltage THD	Current THD
50	3th	0.3%	1.8%
	5th	1.4%	2.6%
	7th	0.5%	1.5%
	9th	0.4%	1.6%

3.2.1 Harmonic Filter

The most common type of passive filter is the single-tuned "notch" filter. This is the most economical type and is frequently sufficient for the application. The notch filter is series tuned to harmonic current and is connected in shunt with the power system. Thus, harmonic currents are diverted from their normal flow path on the line through the filter.

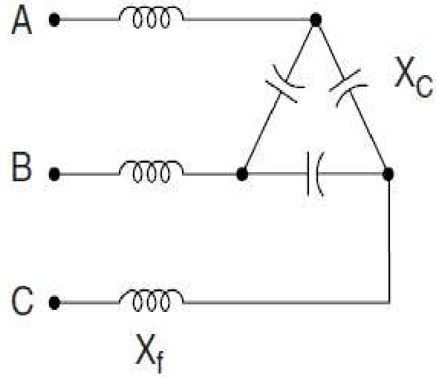

Fig 9 CIRCUIT DIAGRAM OF PASSIVE FILTER

3.2.2 Design Considerations

Consider a load consuming 2.2 kW of power at 415 V and a power factor of 0.8 to reach the system at 0.99 power factor the following parameters are to be calculated.

Calculation for (KVA)

KVA = KW / Power Factor
= 2.2 / 0.8
=2.75 KVA

Three phase current

= (KVA*1000)/ (Volts*1.73)
= 2750 / (415 *1.732)
=3.825 amps

Reactive power calculation

Present PF = 0.8
Target PF = 0.99
Tan (Cos^{-1}(0.8)) = 0.75 present Pf
Tan (Cos^{-1}(0.99)) = 0.044 Target Pf

Convolution Factor

Convolution factor =Present pf – target pf
= 0.75-0.4
= 0.31

Required KVAR at rated voltage
=KW*convolution factor
=2.2*0.31
=0.682

Capacitor Required KVAR at Design Voltage

=(Design voltage)^2*KVAR/(rated voltage)^2

$$= ((440 * 440) * (0.628)\big/(415 * 415))$$

=0.766 KVAR

KVAR formulation

For 766 VAR, 415KV

Current = VAR*1000/voltage in KV

= (((766*1000) / (415)) / (1000))

=1.845amps

C = KVAR / (2 π f V²)

= ((0.766) / (2π*50*415*415))

=28.32

Tuning frequency calculation

Assume the value of L in mh = 25

Tuning frequency = $\frac{1}{2\pi\sqrt{LC}}$

= $\frac{1}{2\pi\sqrt{(25*28.32*10^{-9})}}$

=189.148

Capacitor KVAR and Reactor selection is done considering the tuning Frequency (189.148 Hz at) Reactor 766 VAR / 25mh / 415 V/ 7%.In our case we decided to suppress the predominant harmonic 5th & 7th order in this case we choose the capacitor values as 3000var /415KV.

Current = VAR*1000/voltage in KV

= (((3000*1000) / (415)) / (1000)

=7.22amps

Capacitor C = KVAR / (2 π f V²)

= ((3500/1000) / (2π*50*415*415))

= 63.998(micro farad)

Tuning Frequency Calculation

Asumme L=11mh

Tuning frequency = $\frac{1}{2\pi\sqrt{LC}}$

= $\frac{1}{2\pi\sqrt{(63.998*11)}}$

=189.9406

Capacitor KVAR and Reactor selection is done considering the tuning frequency (189 Hz With 7%) Reactor 3000VAR /11mh / 415 V/ 7% meet the required tuning frequency hence it suppresses the harmonics in this system.

Capacitor – 3 KVAR,

Reactor – 11mh/415V

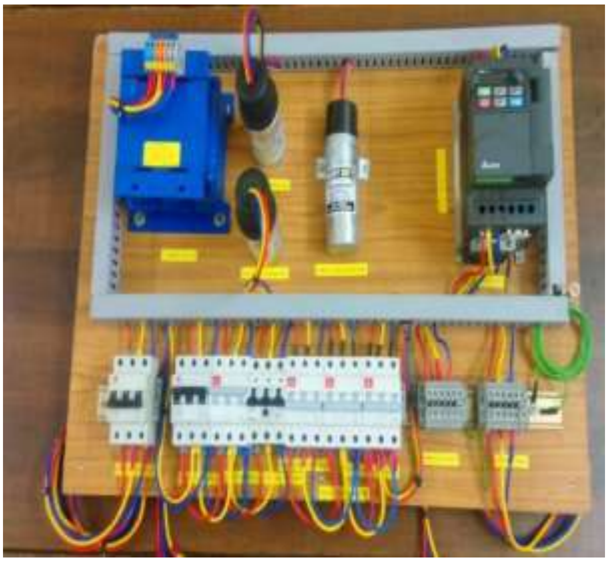

Fig 10 HARDWARE SETUP OF PASSIVE FILTER FOR HARMONIC REDUCTION

3.3 VFD fed Induction Motor load with Filter

The passive filter is connected in shunt with the system. Thus, harmonic currents are diverted from their normal flow path on the line through the filter. The individual spectrum for different order of harmonic THD is shown in table 5.After installation of passive shunt Filter harmonics due to non-linear characteristics of VFD is reduced to considerable amount. The dominant 5th and 7th order voltage and current harmonics are reduced in the system by insertion of a filter it is observed that the power factor of the circuit has improved to a great extent and the THD has reduced to a very low value compared to that of without a filter.

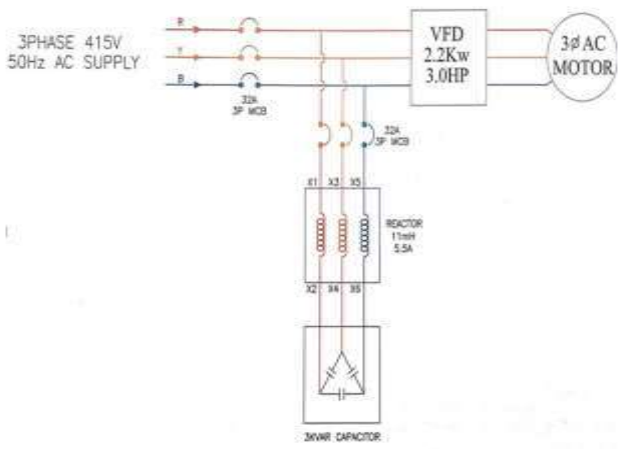

Fig 11 CIRCUIT DIAGRAM OF VFD DRIVE OPERATED MOTOR LOAD WITH FILTER

Fig 12 EXPERIMENTAL SETUP OF VFD FED INDUCTION MOTOR LOAD WITH FILTER

TABLE 5 TABULATION FOR VFD FED INDUCTION MOTOR LOAD WITH FILTER

Frequency (Hz)	Order Of harmonic	Voltage THD	Current THD
50	3th	0.4%	10%
	5th	1.2%	4.8%
	7th	0.3%	3.2%
	9th	0.3%	3.4%

IV. CONCLUSION

Passive filter are effective in minimizing voltage and current distortion caused by non-linear loads. This paper presents the proper selection of single tuned passive harmonic filter parameters (L and C) and its design to improve the system performance by suppressing the dominant 5^{th} order harmonics. The hardware implementation of the passive filter is done and analysed for VFD fed induction motor load using fluke 435 series II. The results depicts that by using passive filters the voltage distortion at main input point is reduced from **1.6 % to 1.2%** and current distortion from **50% to 4.8%.** So, it can be concluded that the designed filter suitable for performing harmonic analysis and the results obtained could meet the recommended IEEE 519 harmonic Standards.

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