A NEW METHOD FOR THE PROPOSAL OF ACOUSTIC NOISE REDUCTION IN MOTORS

Umer T.Shami[1], M.Usman Khan[1],M.Burhan Khan[3], Tahir H.Rizvi[2], Areeb Khalid[2]
[1]Dept of Electrical Engineering, U.E.T, Lahore
[2] Faculty of Engineering, University of Central Punjab, Lahore
[3]University Tunku Abdul Rahman
email: engr.usmannawab@yahoo.com

ABSTRACT—*This research paper presents a filter to reduce the acoustic noise originating from a single phase ac induction motor. Initially, a sinusoidal wave with RMS voltage of 220V is applied and the acoustic noise originating from the ac motor is recorded. At the same time a sample of the input voltage and current is also recorded. Fourier analysis is done on the input voltage, current, and the acoustic noise samples. In addition, the input voltage, current, and acoustic noise of the ac induction motor, when fed from a square wave signal is also recorded and applied to Fourier analysis. The Frequency spectrum of the acoustic noise indicates which frequency is to be eliminated. Later, similar experiments are performed with conventional filters. The acoustic noise generated when the proposed filter is connected, is presented. Lastly, a comparison is presented where the effectiveness of the proposed filter response in established.*

Keywords— ***Acoustic Noise, Harmonics, Total Harmonic Distortion (THD), passive Filter***

I. INTRODUCTION

Noise and vibrations are produced because of magnetic force acting on core of rotor and stator [1].

Remarkable work has been done over the past to mitigate the noise generated in an induction motor. Some notable works are presented as follows:

1. A solution to minimize the acoustic noise generated by the switching frequency in PWM inverter driven motors is to increase the switching frequency above the audible range of 20 kHz [2-3].However, the converter losses increase, sharply decreasing the efficiency of the whole drive.

2. Another solution is to convert the acoustic noise into white noise, which could be achieved by random pulse width modulation (RPWM)[4][5]. Besides these strategies, there are other methodologies requiring changes in the design of motor [6].

3. Another option is to use filters between electrical motor and inverter[7]. The main benefit of this method is that without changing the design of motor or inverter, the noise can be reduced.

In electric machines, the noise may be originated by three different sources;mechanical,aerodynamicand electromagnetic noise.

Some of the sources of mechanical noise are rotor unbalance, bearing and brush noise [8].

The aerodynamic noise may be caused by Air-flow, Fan, and Siren action of rotor and stator ducts. It normally lies in the range of frequencies between500-1000Hz [9].

One of the major source of electromagnetic noise is mechanical vibrations where motor's magnetic field providevibro-motive force [8].

In this research work, acoustic noise is reduced by reducing harmonics which cause the noise at minimum cost and suitable design. Different passive filter topologies are investigated to minimize the noise. First, the harmonic content of voltage and current were analysed using data acquisition tools to identify the main harmonic components causing acoustic noise. Then different filter topologies were designed to filter the identified harmonics. At the end different passive filters were compared with a new passivefilter to select the optimal filter to reduce voltage and current Total Harmonic Distortion (THD).

II. EXPERIMENTAL SETUP

The hardware setup are as follows:

- Domestic Inverter with square wave output andDC battery Source.
- Single Phase induction motor.
- Xilinx Data Acquisition Card to get the current and voltage waveform.
- Noise measurement using microphone and PC.

The specification of hardware setup is;90 watt single phase induction motor with 0.9 power factor, max no load current 0.5A, UPS of 750 watt, 90Ah battery, Xilinx Data Acquisition kit with 4 channel digital oscilloscope, noise manipulation is done on windows based MATLABplatform and microphone.The hardware setup is shown in fig 1.

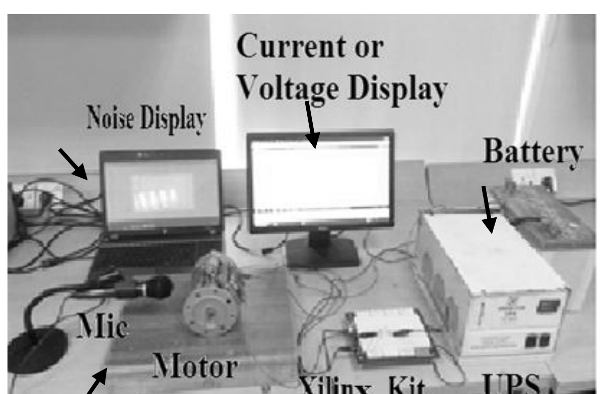


Fig 1: Experimental Setup of Hardware

To avoid turbulent behaviour of hardware setup, following assumption are made like microphone is placed with 5cm distance in between motor and microphone. Distance should be maintain throughout the iterations. Other things which should beunder consideration are both bearing noise and ambient noise kept zero.

III. TESTING AND RESULTS

The experimentation comprised of following phases.

A. MOTOR SUPPLIED BY UTILITY

When the motor is connected with pure sinusoidal input,the voltage spectrum shows that there is no harmonics and only fundamental component appear on 50Hz as shown in fig 2. The motor introduced odd harmonics in current waveform spectrum, as shown in the fig 3. Apparently with pure sinusoidal source the motor gave minimum audible noise. The Fast Fourier Transform (FFT) of noise is shown in fig 4 which also indicating that fundamental component is dominant.

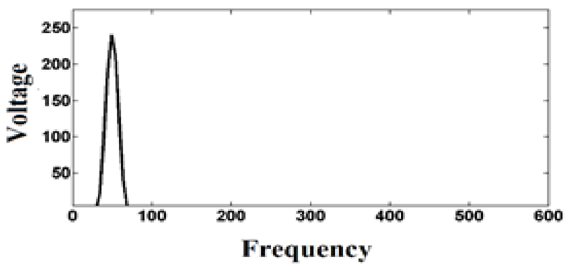


Fig 2: Voltage Waveform Spectrum of sine wave

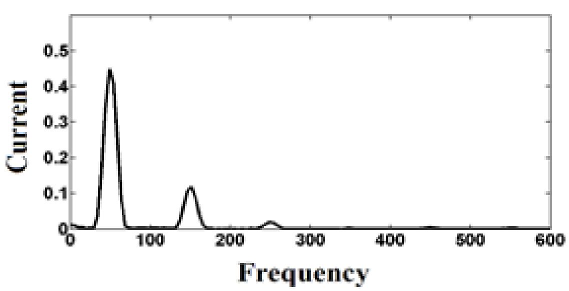


Fig 3: Current Waveform Spectrum of sine wave

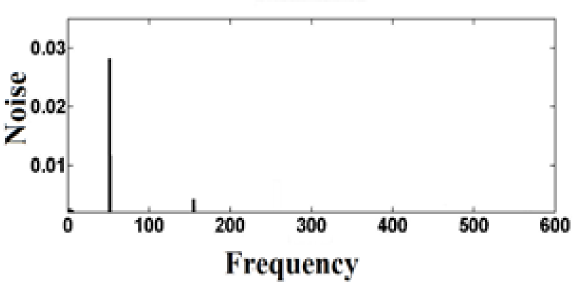


Fig 4: Noise Waveform Spectrum of Utility

B. MOTOR SUPPLIED BY SQUARE WAVE INVERTER

In this phase first of all, output voltage waveform of the domestic inverter was recorded as shown in fig 5. It is observed that magnitude of fundamental component is three time greater than third harmonic. Current spectrum is shown in fig 6, which indicates that third and fifth are dominating harmonics.The recorded THD is approximately 60%.

The FFT of acoustic noise is shown in fig 7, which indicates that there are some harmonic components common with current spectrum.

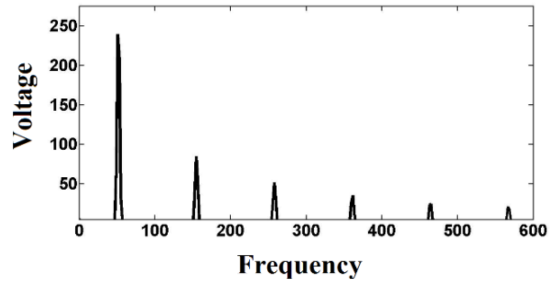


Fig 5: Voltage spectrum of Motor fed by Inverter

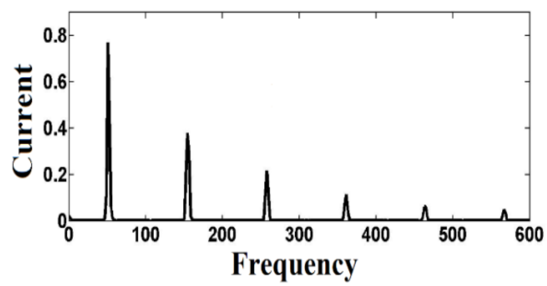


Fig 6: Harmonic Spectrum of Current Waveform by Inverter

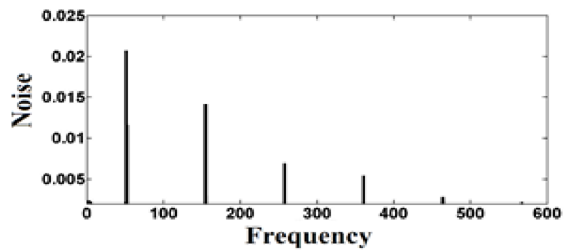


Fig 7: Noise Spectrum of directly connected motor

C. FILTERS BETWEEN INVERTER AND MOTOR

In this research work the THD and hence acoustic noise is reduced by using different passive filters i-e CLC and LCL and later results are compared with new proposed filter.

1) DESIGN AND IMPLEMENTATION OF CLC FILTER:

First of all CLC filter is designed using state space technique. The third degree filter would be used, represented by three state variables. The filter circuit is shown in fig 8.

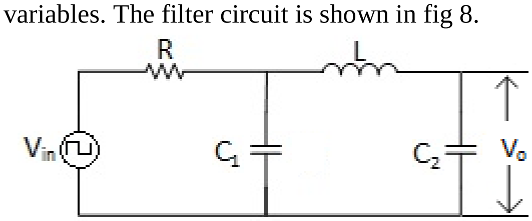


Fig 8:Noise cancellation CLC Filter

State equations and state matrices of CLC filter are given below:

$$\dot{x}_1 = \frac{V_{in}}{C_1} - \frac{x_3}{C_1} - \frac{x_1}{C_1 R} \quad (1)$$

$$\dot{x}_2 = \frac{x_3}{C_2} \quad (2)$$

$$\dot{x}_3 = \frac{x_1}{L} - \frac{x_2}{L} \quad (3)$$

$$y = x_2 \quad (4)$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x} \end{bmatrix} = \begin{bmatrix} -\frac{1}{C_1R} & 0 & -\frac{1}{C_1} \\ 0 & 0 & \frac{1}{C_2} \\ \frac{1}{L} & -\frac{1}{L} & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} \frac{1}{C_1R} \\ 0 \\ 0 \end{bmatrix} u \quad (5)$$

$$y = [\,0\ 1\ 0] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (6)$$

For tuning of the filter, state matrix is converted into transfer function by using C1=4.7µF, C2=32.9µF, R=1Ω, L=350mH and following equation

$$G = C[SI - A]^{-1}B + D \quad (7)$$

Transfer function of CLC filter would be

$$G = \frac{-3.83e^{-8}s + 1.848e^{10}}{s^3 + 2.128e^5 s^2 + 6.947e^5 s + 1.848e^{10}} \quad (8)$$

2) DESIGN AND IMPLEMENTATION OF LCL FILTER:

For reduction of harmonics another passive filter LCL is designed and implemented this filter have two inductors and a capacitor as shown in fig 9.

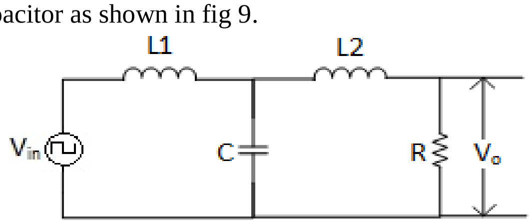


Fig 9: Noise cancellation LCL Filter

State equations of LCL filter are given below:

$$\dot{x}_1 = \frac{x_2}{C} - \frac{x_3}{C} \quad (9)$$

$$\dot{x}_2 = \frac{V_{in}}{L_1} - \frac{x_1}{L_1} \quad (10)$$

$$\dot{x}_3 = \frac{x_1}{L_2} - \frac{x_3R}{L_2} \quad (11)$$

$$y = x_3R \quad (12)$$

These state equations is used to obtain following state matrices:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{C} & -\frac{1}{C} \\ -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{L_2} & 0 & -\frac{R}{L_2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L_1} \\ 0 \end{bmatrix} u \quad (13)$$

$$y = [\,0\ 0\ R] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (14)$$

Transfer function of LCL filter is obtained by using L1=230 mH, L2=20 mH, R=1 MΩ and C =28.2 µF for state matrices,and using following state space to transfer function converting equation

$$G = C[SI - A]^{-1}B + D \quad (15)$$

Transfer function of LCLfilter would be

$$G = \frac{9.313e^{-10}s^2 + 0.0005453s + 7.709e^{11}}{s^3 + 5e^6 s^2 + 1.927e^6 s + 7.709e^{11}} \quad (16)$$

3) DESIGN AND IMPLEMENTATION OF PROPOSED PASSIVE FILTER:

A new passive filter is proposed for reduction of harmonics and noise. The proposed filter is shown below

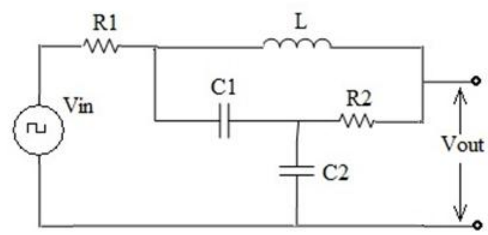


Fig 10: Proposed Filter for noise cancellation

State equations and state matrices are as follows:

$$\dot{x}_1 = \frac{V_{in}}{C_1R_1} - \frac{x_1}{C_1R_1} - \frac{x_2}{C_1R_1} - \frac{x_3}{C_1} \quad (17)$$

$$\dot{x}_2 = \frac{V_{in}}{C_2R_1} - \frac{x_1}{C_2R_1} - \frac{x_2}{C_2R_1} \quad (18)$$

$$\dot{x}_3 = \frac{x_1}{L} - \frac{x_3R_2}{L} \quad (19)$$

$$y = x_2 + x_3R_2 \quad (20)$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -\frac{1}{C_1R_1} & -\frac{1}{C_1R_1} & -\frac{1}{C} \\ -\frac{1}{C_2R_1} & -\frac{1}{C_2R_1} & 0 \\ \frac{1}{L} & 0 & -\frac{R_2}{L} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} \frac{1}{C_1R_1} \\ \frac{1}{C_2R_1} \\ 0 \end{bmatrix} u \quad (21)$$

$$y = [\,0\ 1\ R_2] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (22)$$

The above state matrix is converted into transfer function by using C1=9.4 µF, C2=9.4 µF, R1=1Ω, R2=1 Ω,L=100mH and following equation which is used to convert state space into transfer function

$$G = C[SI - A]^{-1}B + D \quad (23)$$

The transfer function would be:

$$G = \frac{2.128e^5s^2+2.128e^6s+2.263e^{11}}{s^3+4.255e^5s^2+3.191e^6s+2.263e^{11}} \quad (24)$$

4) COMPARISON AND DISCUSSION OF IMPLEMENTED FILTERS:

Three passive filters have been implemented. From the analysis of voltage waveform of CLC filter it is observed that the response is very close to sinusoidal waveform.The voltage output of CLC filter is shown in fig 11, it is observed that wave form is symmetric about zero crossing so only odd harmonics is appeared. The Voltage spectrum is shown in fig 12. The voltage THD of CLC filter is recorded approximately 22%.

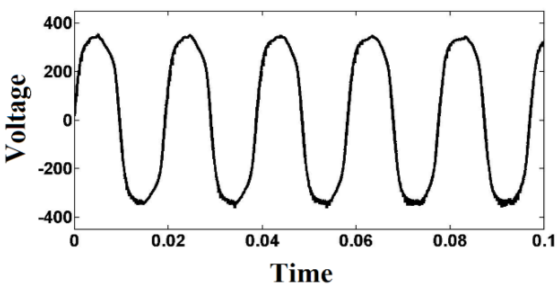


Fig 11: Voltage Output of CLC Filter

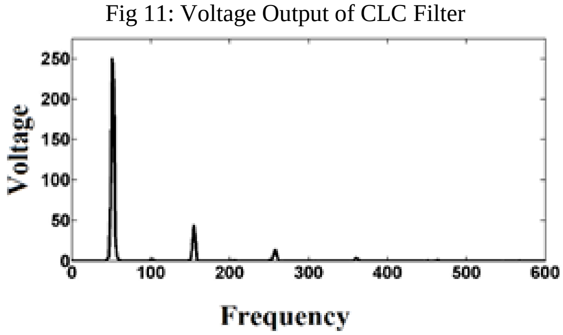


Fig 12: Voltage Spectrum of CLC Filter

Next current spectrum of CLC filter is measured which is shown in fig 13.The THD of the current spectrum is 35% which is comparatively less than the THD of directly connected inverter method.

By comparing current and voltage THD's ofCLC filter it is observed that this filter is effective on voltage harmonics. The noise spectrum is shown in fig 14.It is observed that noise spectrum is following current spectrum more than voltage spectrum.

The voltage waveform of LCL in time domain is shown in fig 15. Which indicate that LCL is also making sinusoidal waveform with some distortion. The voltage spectrum of LCL filter is shown in fig 16. The calculated THD of filter is approximately 26% which is higher than CLC.

In case of current the THD of LCL filter is reduced to 19% which is less than CLC filter. It is indicating that this filter is more effective on current harmonics as shown in fig 17. Noise spectrum is also reduced compared to CLC filter and it is also following current spectrum of LCL filter which is evident from fig 18.The output voltage of proposed noise cancellation filter in time domain is again close to sine wave as shown in fig 19.The THD of this filter is reduced to 20%, voltage in frequency domain is shown in fig 20.

The current spectrum of new proposed filter is shown in fig 21, its THD is approximately 22%.It is observed that proposed filter is very effective on third harmonic which was contributing most towards the noise in direct method.

Noise spectrum in fig 22 is also indicating that third harmonic is reduced in case of proposed filter.

The proposed filter is optimum for voltage harmonics because of low THD, low cost, low weight and low values of capacitors and inductors etc. Although the THD of LCL filter for current harmonics is reduced to 19% which is 3% less than proposed filter. The proposed filter is still preferred over LCL filter because of smallvalues of C, L, and cost factor.

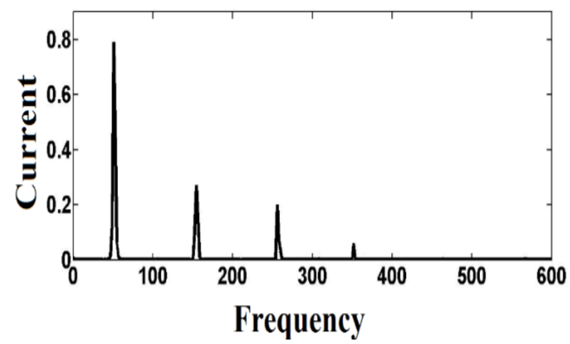


Fig 13: Current Spectrum of CLC Filter

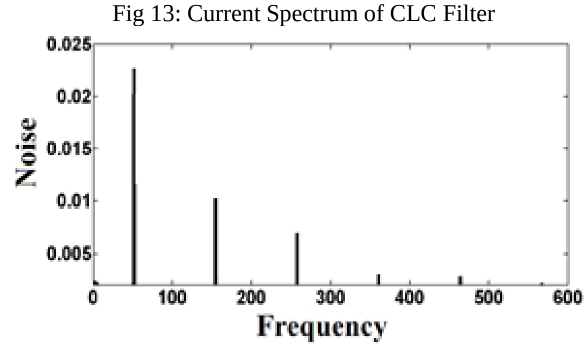


Fig 14: Noise Spectrum of CLC Filter

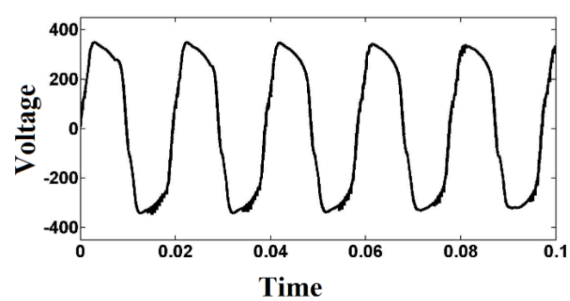


Fig 15:Voltage Output of LCL Filter

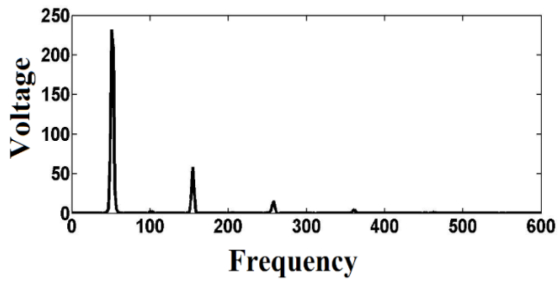


Fig 16:Voltage Spectrum of LCL Filter

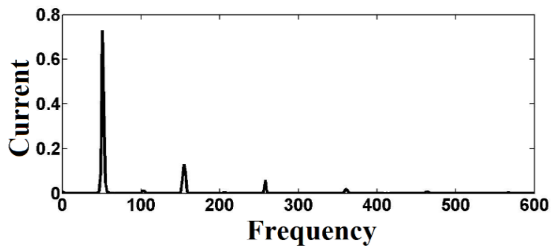
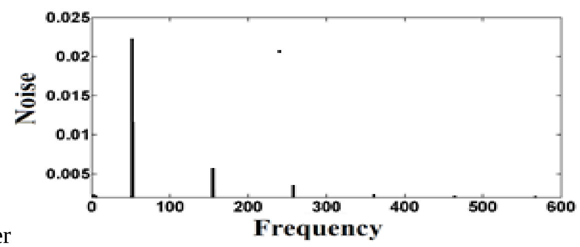
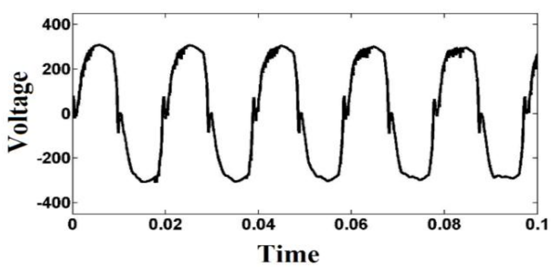


Fig 17:Current Spectrum of LCL



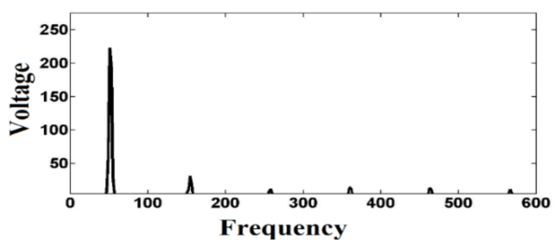
Filter

Fig 18: Noise Spectrum of LCL



Filter

Fig 19:VoltageOutput of Proposed noise cancellation



Filter

Fig 20:VoltageSpectrum of Proposed Filter

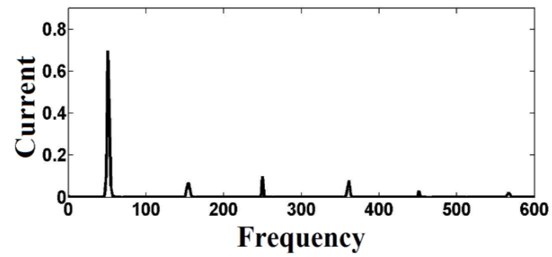


Fig 21:Current Spectrum of Proposed Filter

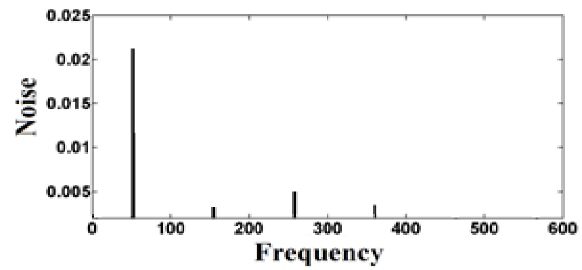


Fig 22:Noise of Proposed Filter

V. CONCLUSION

The noise spectrum has been followed by the current harmonics.Which authenticates that the main source of acoustic noise in induction motor is current harmonics.Different passive filter topologies like LCL and CLC has been designed and implemented to reduce the acoustic noise.

A new filter is proposed, designed, implemented and compared with the previous filters. The results has been validated by comparison of new proposed filter with LCL and CLC.

From the validation results, it has been concluded that theProposed Filter is the most optimum choice for acoustic noise reduction for induction motors.

REFERENCES

[1] P. Vijayraghavan and R. Krishnan, "Noise in electric machines: a review," *IEEE Transactions on Industry Applications*, vol. **35**, pp. 1007-1013, 1999.

[2] S. J. Yang, "Low-noise electrical motors," Oxford: Clarendon Press 1981.

[3] J. E. Gilliam, J. A. Houldsworth, and L. Hadley, "Variable speed induction motor with integral ultrasonic PWM inverter," Third Annual IEEE Applied Power Electronics Conference and Exposition, 1988, pp. 92-96.

[4] T. H. Nishimura and P. G. Maranesi, "Ultrasonic carrier PWM converter employing IGBT in the near future," Eleventh International Telecommunications Energy Conference, 1989, vol.2.

[5] J. T. Boys and P. G. Handley, "Spread spectrum switching: low noise modulation technique for PWM inverter drives,", IEE Proceedings B Electric Power Applications, vol. 139, pp. 252-260, 1992.

[6] Ruiz-Gonzalez, A.; Vargas-Merino, F.; Nezamalhosseini, S.; Salehi, J.; Perez-Hidalgo, F., "Application of Slope PWM Strategies to Reduce Acoustic Noise Radiated by Inverter-Fed Induction Motors," Industrial Electronics, IEEE Transactions on , vol.60, no.7, pp.2555,2563, July 2013.

[7] Boglietti, A.; Cavagnino, A.; Saied, S.; Vaschetto, S., "Experimental identification and reduction of acoustic noise in small brushed DC motors," XXth International Conference on Electrical Machines (ICEM), 2012, vol., no., pp.1679,1685, 2-5 Sept. 2012.

[8] J. A. Ferreira, P. Dorland, and F. G. de Beer, "An active in-line notch filter for reducing acoustic noise in drives," IEEE Transactions on Industry Applications, May-June 2007, vol. 43, issue 3, pp. 798-804.

[9] E. Kramer, “Dynamics of rotors and foundations”, Berlin: Springer-Verlag, 1993.