Harmonics and THD analysis of Five phase Inverter Drive with Single Tuned Filter using Simulink/MATLAB

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Abstract— This paper aims at the reduction of harmonics in Five phase inverter drive using Single tuned filter. This filter eliminates most of the harmonic content at the output AC voltage/current before connecting to any load or grid. Inverter designs performance will be improved by minimizing fewer harmonics accurately by connecting a single tuned filter. Five phase inverter drive is more useful design, gives better performance than the conventional three phase inverter. This method is verified by constructing five phase PWM Five phase inverter drive with and without single tuned filter using Simulink/MATLAB, the results obtained are compared and same is presented. The harmonic content and Total Harmonic Distortion is compared with normal Five Phase Inverter drive with Single tuned filter connected at the output of the inverter.

Keywords- five phase; harmonics; inverter drive; THD; filters; single tuned filter;

I. INTRODUCTION

Industries use induction motors abundantly due to its various advantages. As the technology is developing the new motor drive designs have been introduced according to the user requirements. Recent technological advancement brings the new ideas in the industries to choose the best designs for their choices. The present scenario shows that increased use of three phase induction motor in the industries all over the world. As researchers working on various drive designs in ASD (Adjustable Speed Drives) using VSI (Voltage Source Inverter) and CSI (Current Source Inverter), performance is the key role that satisfy the user, harmonics are major effects in PWM inverters, this become challenge for the researchers to eliminate or suppress the harmonics at the output of the inverter drive that cause many problems to the load as well as the inverter drive.

Advancement in the power electronics leads to the introduction of Multi/poly phase induction motors in the mechanical world. As the number of phases are increased the advantages increases gradually, three phase induction motor is the most used device but five phase induction motor is preferred over the conventional three phase induction motor due to its various advantages such as reducing the amplitude and increasing the frequency of torque pulsation, reducing the rotor harmonic current per phase without increasing the

voltage per phase, lowering the dc-link current harmonics and higher reliability, high fault tolerance [1].

The Application oriented research increased these days, the main application areas of multi/poly phase induction motor drives are ship propulsion, traction (including electric and hybrid electric vehicles) and the concept of more-electric aircraft, locomotive traction, aerospace and high power applications [2-7].

In all inverter drives the major problem occurs when the harmonic arises, Harmonic contents are both in current and voltages. Inverter consists of non-linear elements such as switches, which produces odd harmonics and it is superimposed on the fundamental harmonic frequency. The harmonics in any power systems cause heating in the device and conductors, misfiring in adjustable speed drives, poor power factor and torque pulsations in motors. Most of the researchers worked on harmonics to eliminate or suppress the content of the harmonics also incorporated many design techniques, used many types of filters to mitigate the harmonics in the inverter. In five phase inverter drive the leading harmonic content is the 3rd harmonic order. The 5th and every 5th multiples harmonic order is absent in the five phase inverter drive. The concern now is that to reduce the harmonics effectively before connecting to the load or to the grid.

To reduce the harmonics filters are efficiently used, filters changes amplitude and phase of a voltage with frequency, filters have wide applications in power electronic system to reject and allow certain range of frequencies. The passive elements give drastic reduction of harmonic content and THD. A harmonic filter is a circuit used to block the content of different harmonic orders from coupling source to the load. The harmonics will affect to the low impedance devices. Many of the harmonic filters designs are available today and it consists of parallel connected capacitor and inductor circuits to create a low impedance device. These filters will be considered as passive devices. The passive devices attract harmonic current from the sources connected to the system. Most of the designer use passive filters to mitigate the harmonics, in this paper a passive shunt filter a single tuned filter are used. Advantage of this filter is that it

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is simple to design and less expensive to implement. A single-tuned filter consists of a capacitor in series with an inductor. The capacitor and inductor values are designed such that the branch impedance becomes zero nearby harmonic order frequency, which bypasses that harmonic order. The capacitor provides reactive power compensation accordance with total power. A resistor used to adjust the tunings sharpness maintaining the bandwidth [8-12].

A. Design of the single tuned filter:

Single tuned filter can be designed by considering the quality factor Q . The quality factor can be calculated using the formula (1).

$$Q = \frac{\sqrt{L/C}}{R} \quad (1)$$

Where L , C and R represents inductor, capacitor and resistor respectively. While designing the single tuned filter the inductive X_L and capacitive reactance X_C should be equal for resonance as shown in equation (2).

$$X_L = X_C \quad (2)$$

$X_C = \frac{1}{\omega C}$ and $X_L = \omega L$, where $\omega = 2\pi f$. f =fundamental frequency.

II. FIVE PHASE INVERTER DRIVE

Five phase inverter drive constructed using 10 IGBT switches as shown in Fig. 1. Five Phase signals generated by pulse generator P1-P10, the switches S1-S10 are turned on for a period of 180° conduction mode with 72° out of phase with each phase leg. Inverter output voltage can be obtained by proper switching on and off of IGBT's.

Fig.1. Circuit diagram of five phase inverter drive

Fig. 2. Switching sequence of inverter switches

Two switch from the upper group and three switches from the lower group is on, or two from the lower group and three from the upper group is on. The switching sequence of the five phase inverter is as shown in Fig. 2.

III. FIVE PHASE INVERTER WITH SINGLE TUNED FILTER

Five phase inverter drive is connected with single tuned filter as shown in Fig 3. The single tuned filter designed values are $C=22\mu F$, $L=0.86$ and $R=87\Omega$. Table I shows the RLC values are used in the experiment.

TABLE I. R, L AND C DESIGNED VALUES FOR SINGLE TUNE FREQUENCY OF 50 HZ

Components	Values
Resistor R_1 - R_5	87Ω
Capacitor C_1 , C_5	$22\mu F$
Inductor L_1 - L_5	0.86

Fig. 3. Circuit Diagram of five phase inverter with single tuned filter

IV. SIMULATION RESULTS

Simulation has been done for the two input frequency of 50Hz for rated speed applications and 7 Hz for lower speed applications, with RL load with $R=1.7 \Omega$ and $L=1.3mH$. The line output voltage is measured and plotted for five phase PWM inverter without filter and with single tuned filter. THD is measured for both normal inverters without filter and with single tuned filter.

A. For Input frequency 50 Hz:

The line voltage waveforms of five phase PWM inverter for 50 Hz are as shown in Fig. 4. The line voltage waveforms five phase inverter with single tuned filter for 5 Hz is as shown in Fig. 5.

The THD (Total Harmonic Distortion) in Five phase inverter drive without and with filter is as shown in table II. The FFT analysis has been done for the inverter output voltage with and without filter modes and these are presented in Fig. 6 and Fig. 7 respectively.

Fig. 4. Line voltage and line current waveforms of a phase in normal Five phase PWM inverter for 50 Hz

Fig. 5. Line voltage and line current waveforms of an individual phase in Five phase PWM inverter with single tuned filter for 50 Hz.

TABLE II. THD COMPARISON OF FIVE PHASE INVERTER DRIVE WITH AND WITHOUT FILTER FOR F=50 Hz

Modes	THD in %
Five phase inverter Drive (Without Filter)	42.7
Five Phase Inverter Drive With Single Tuned filter	26.19

Fig. 6. FFT sequence of normal five phase inverter drive for $f_{in}=50\text{Hz}$

Fig. 7. FFT sequence of Five phase inverter drive with single tuned filter for $f_{in}=50\text{Hz}$

Using Simulink/MATLAB the individual harmonic order voltage can be calculated for the inverter with and without filter, the same are presented in Table III.

TABLE III. INDIVIDUAL VOLTAGE HARMONIC ORDER AT THE OUTPUT OF AN INVERTER WITH AND WITHOUT FILTER FOR F= 50 Hz

Harmonic Order	Five Phase Inverter Drive (V)	Five Phase inverter Drive with filter (V)
1	248.28	243.37
2	0	0
3	82.76	58.13
4	0	0
5	0	3.13
6	0	0
7	35.47	20.31
8	0	0
9	27.59	17.09
10	0	0
11	22.57	13.66
12	0	0
13	19.1	10.13
14	0	0
15	0	0.94
16	0	0
17	14.6	7.61
18	0	0
19	13.06	7.60

B. For Input Frequency 7 Hz:

The FFT analysis of Five phase inverter drive without and with filter for an input frequency of $f_{in}=7\text{ Hz}$ and $V_{in}=28\text{V}$ are used to study the Individual harmonics and THD as shown in Fig. 8 and Fig 9 respectively, the results have been presented shown in table IV.

TABLE IV. THD COMPARISON OF FIVE PHASE INVERTER DRIVE WITH AND WITHOUT FILTER FOR $F = 7$ HZ

Modes	THD in %
Five phase inverter Drive (Without Filter)	43.29
Five Phase Inverter Drive With Single Tuned filter	23.73

Fig. 8. FFT sequence of normal five phase inverter drive for $f_{in} = 7$ Hz Fig. 9. FFT sequence of Five phase inverter drive with single tuned filter for $f_{in} = 7$ Hz

Percentage of Individual harmonic order is obtained for the inverter with and without filter the same are presented in Table V.

TABLE V. INDIVIDUAL HARMONIC ORDER PERCENTAGE IN THE OUTPUT VOLTAGE WITH AND WITHOUT FILTER FOR $F_{in} = 7$ HZ

Harmonic Order	Five Phase Inverter Drive (%)	Five Phase inverter Drive with filter (%)
1	100	100
2	3.28	0
3	32.94	20.82
4	2.56	0
5	2.53	0
6	2.48	0

7	14.87	6.51
8	1.85	0
9	9.77	4.83
10	1.03	0
11	9.64	3.85
12	0.46	0
13	8.89	3.12
14	0.79	0
15	0.77	0
16	0.75	0

V. CONCLUSION

The Five phase PWM drive is constructed using Simulink/MATLAB. The single tuned filter is designed and connected at the output of the inverter to study the harmonics and Total Harmonic Distortion of Five phase Inverter drive. The results have been compared with five phase inverter drive without filter and with tuned filter, from the results it found that the harmonic reduction and THD is found to be less with tuned filter five phase inverter drive.

This simulation work is implemented practically to study the temperature of the five phase induction motor for future work.

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