Analysis of Advanced Techniques to Eliminate Harmonics in AC Drives

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Abstract— Variable speed AC drives are finding their place in all types of industrial and commercial loads. This Work covers the current source converter technologies, including pulse width-modulated current-source inverters (CSIs) and in addition, this also addresses the present status of the direct converters & gives an overview of the commonly Used modulation schemes for VFD systems. The proposed work flow is that to work with the simulation of three phases PWM Current Source Inverter fed Induction Motor (CSI-IM) drive systems using Matlab/Simulink simulation Software. This work primarily presents a Unified approach for generating pulse width-modulated patterns for three-phase current-source rectifiers and inverters (CSR/is) that provides unconstrained selective harmonic elimination and fundamental current control. This conversion Process generates harmonics in the motor current waveform. This project deals with the analysis of motor current Harmonics using FFT analysis and use of filter for mitigating them for smooth operation of motor. The filter used for Reduction of harmonics is passive filter. The filter is such it reduces only the 5th & 7th order harmonics. Thus the Analysis of motor current harmonics is done firstly without filter & then it has been compared with the results after the Addition of filter. It is found that the 5th & 7th order harmonics has reduced considerably.

Keywords: Harmonics, Total harmonic distortion (THD), variable frequency drives (VFD), power factor, and current Source inverter (CSI), Fast Fourier Transform (FFT).

INTRODUCTION

The proposed work is based on current source inverter fed induction motor scheme. At the front end a current source Rectifier is connected which converts the 6.6Kv ac voltage into dc by rectifying it. The inverter converts the dc voltage again into ac & then supplies to induction motor. As the switches used in the rectifier & inverter are GTO's & SCR's which requires triggering pulse? The triggering pulse is given by the discrete six pulse generator which is connected to the gate of both rectifier & inverter having six switching devices in each section. Due to the switching processes Harmonics are produced in the system. The output of the inverter which is ac but not sinusoidal due to switching time Taken by the switches & is in quazi square form which is the main cause of harmonics. As six switches are used the Harmonics which are dangerous to the system are 5th & 7th. Thus main focus is to reduce this harmonic order. For doing So low pass filter is to be used so as to reduce this harmonics. An LC filter is used by selecting the values of inductor & Capacitor. Thus it is a passive filter which is used in this scheme. The output of the induction motor is given to the bus - Bar which shows the stator, rotor & mechanical quantities. As our main focus is on current on stator side we choose Stator quantities from bus-bar. A scope is connected to observe the waveforms.

METHODOLOGY

Adding a variable frequency drive (VFD) to a motor-driven system can offer potential energy savings in a system in Which the loads vary with time. The operating speed of a motor connected to a VFD is varied by changing the Frequency of the motor supply voltage. This allows continuous process speed control. Motor-driven systems are often Designed to handle peak loads that have a safety factor. This often leads to energy inefficiency in systems that operate For extended periods at reduced load. The ability to adjust motor speed enables closer matching of motor output to load And often results in energy savings. The VFD basically consist of a rectifier section which converts the ac supply into Dc, a dc choke which is used to smooth the dc output current & an inverter section which converts dc into ac supply Which is fed to induction motor? The VFD consists of a switching devices such as Diodes, IGBT, GTO, SCR etc.[1]

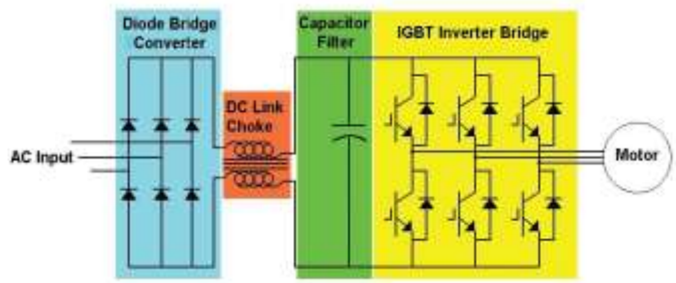

Fig.1: Generalized Variable Frequency Drive

A VFD can be divided into two main sections:

A. Rectifier stage: A full-wave, solid-state rectifier converts three-phase 50 Hz power from a standard 208, 460, 575 or higher utility supply to either fixed or adjustable DC voltage.

B. Inverter stage: Electronic switches power transistors or thyristor switch the rectified dc voltage on and off, And produce a current or voltage waveform at the desired new frequency. The amount of distortion depends On the design of the inverter and filter.

III. SYSTEM SIMULATION

The proposed work is based on current source inverter fed induction motor scheme. At the front end a current source Rectifier is connected which converts the 6.6Kv ac voltage into dc by rectifying it. For smoothing this voltage before Applying it to inverter a DC choke coil is used this removes the ripples. The inverter converts the dc voltage again into Ac & then supplies to induction motor. As the switches used in the rectifier & inverter are GTO's & SCR's which Requires triggering pulse. The triggering pulse is given by the discrete six pulse generator which is connected to the gate Of both rectifier & inverter. Six switching devices in each section. Due to the switching processes harmonics are Produced in the system. The output of the inverter which is ac but not sinusoidal due to switching time taken by the Switches & is in quazi square form which is the main cause of harmonics. As six switches are used the harmonics Which are dangerous to the system are 5th & 7th. Thus main focus is to reduce this harmonic order. For doing so low pass filter is to be used so as to reduce this harmonics. An LC filter is used by selecting the values of inductor & Capacitor. Thus it is a passive filter which is used in this scheme. The output of the induction motor is given to the bus - Bar which shows the stator, rotor &

mechanical quantities. As our main focus is on current on stator side we choose Stator quantities from bus-bar. A scope is connected to observe the waveforms. An FFT block is connected to the motor Current of any one phase whose order of harmonic is to be found out. To this FFT block an FFT spectrum window is connected which displays the order of harmonics from 0 to 19th order of harmonic. Also a bar graph is displayed which shows the order of harmonics which is shown by the FFT spectrum. Thus the work is divided into two sections one before use of filter and after the use of filter. After running the simulation it is observed that the 5th & 7th harmonic components are reduced than that without filter which is shown by the FFT spectrum block.

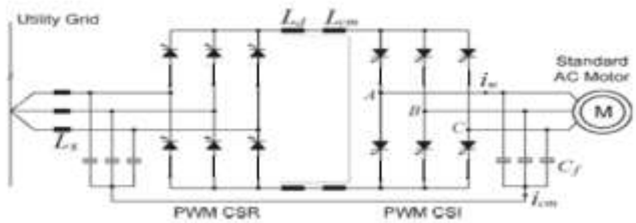

Fig.2: Simulation Diagram of CSI Fed Induction.

Table: Induction Motor Specifications

Motor Supply Voltage	6600V
Horse Power Rating of Motor	200 HP
Supply Frequency	50 Hz
Stator resistance [Rs] , Stator inductance [Ls]	1.485Ω, 0.03027 H
Pole Pairs	2

IV.HARMONICS

Harmonics are the major problems in any industrial drives. They cause serious problems in the motor which is connected as a load fed from the VFD. The VFD is a current source inverter fed (CSI) .At the front end a current source rectifier is connected which converts the 6.6Kv ac voltage into dc by rectifying it. For smoothing this voltage before applying it to inverter a DC choke coil is used this removes the ripples. The inverter converts the dc voltage again into ac & then supplies to induction motor. As the switches used in the rectifier & inverter are GTO's & SCR's which requires triggering pulse. The triggering pulse is given by the discrete six pulse generator which is connected to the gate of both rectifier & inverter. Six switching devices in each section. Due to the switching processes harmonics are produced in the system. The output of the inverter which is ac but not sinusoidal due to switching time taken by the switches & is in quazi square form which is the main cause of harmonics. As six switches are used the harmonics which are dangerous to the system are 5th & 7th . Thus main focus is to reduce this harmonic order. For doing so low pass filter is to be used so as to reduce this harmonics. Total harmonic distortion is the contribution of all the harmonic frequency currents to the fundamental.

Table 3.2.1: Harmonics & Multiples of Fundamental Frequencies

Harmonic	Frequency
1st	50 Hz
2nd	100 Hz
3rd	150 Hz
4th	200 Hz
5th	250 Hz
6th	300 Hz
7th	350 Hz
8th	400 Hz
9th	450 Hz
10th	500 Hz
11th	550 Hz
13th	650 Hz

The characteristic harmonics are based on the number of rectifiers (pulse number) used in a circuit and can be determined by the following equation:

$$h = (n \times p) \pm 1$$

where: n = an integer (1, 2, 3, 4, 5 ....)
p = number of pulses or rectifiers

For example, using a 6 pulse rectifier, the characteristic harmonics will be:

$h = (1 \times 6) \pm 1 \Rightarrow$ **5th & 7th harmonics**
$h = (2 \times 6) \pm 1 \Rightarrow$ **11th & 13th harmonics**
$h = (3 \times 6) \pm 1 \Rightarrow$ **17th & 19th harmonics**
$h = (4 \times 6) \pm 1 \Rightarrow$ **23rd & 25th harmonics**

The nonlinear loads such as AC to DC rectifiers produce distorted waveforms. Harmonics are present in waveforms that are not perfect sine waves due to distortion from nonlinear loads Around the 1830's a French mathematician named Fourier discovered that a distorted waveform can be represented as a series of sine waves each an integer number multiple of the fundamental frequency and each with a specific magnitude. For example, the 5th harmonic on a system with a 50 Hertz fundamental waveform would have a frequency of 5 times 50 Hertz, or 2500Hertz. These higher order waveforms are called "harmonics". The collective sum of the fundamental and each harmonic is called a Fourier series. This series can be viewed as a spectrum analysis where the fundamental frequency and each harmonic component are displayed. [8] Graphically in pu is shown in a bar chart in Figure 3.4.1

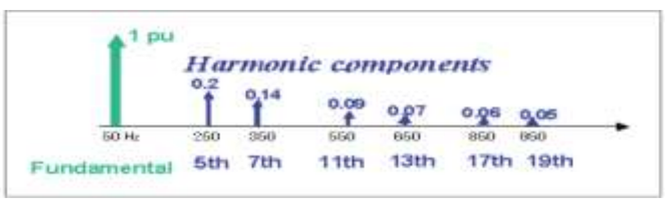

Figure 3: Harmonics order in per unit with respect to fundamental

From above study it is clear that harmonic currents flow in an AC drive with a 6-pulse front end, let's address what, if any, problems this may cause. Power is only transferred through a distribution line when current is in phase with voltage. This is the very reason for concerns about input "power factor". Displacement power factor in a motor running across the line can be explained as the cosine of the phase angle between the current and voltage. Since a motor is an inductive load, current lags voltage by about 30 to 40 degrees when loaded, making the power factor about 0.75 to 0.8 as opposed to about 0.95 for many PWM AC drives? In the case of a resistive load, the power factor would be 1 or "unity". In such a case all of the current flowing results in power being transferred. Poor power factor (less than 1 or "unity") means reactive current that does not contribute power is flowing.

CONTROL STRATEGIES

The induction motor control can be done with the help variable frequency drives. The high power drives can be divided into subparts depending upon the areas of applications. Following chart shows the high frequency drives with different schemes.

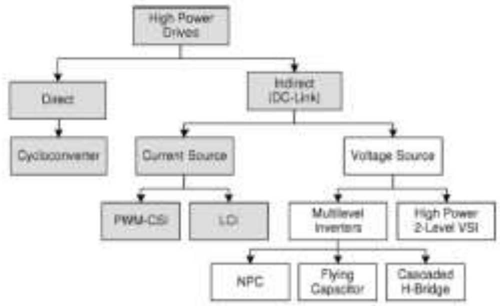

Figure 4. Chart showing types of VFD schemes

Adding a variable frequency drive (VFD) to a motor-driven system can offer potential energy savings in a system in which the loads vary with time. VFDs belong to a group of equipment called adjustable speed drives or variable speed drives. (Variable speed drives can be electrical or mechanical, whereas VFDs are electrical.) The operating speed of a motor connected to a VFD is varied by changing the frequency of the motor supply voltage. This allows continuous process speed control. Motor-driven systems are often designed to handle peak loads that have a safety factor. This often leads to energy inefficiency in systems that operate for extended periods at reduced load. The ability to adjust motor speed enables closer matching of motor output to load and often results in energy savings

OVERALL WORKING OF MODEL

The proposed work is based on current source inverter fed induction motor scheme. At the front end a current source rectifier is connected which converts the 6.6Kv ac voltage into dc by rectifying it. For smoothing this voltage before applying it to inverter a DC choke coil is used which removes the ripples. The inverter converts the dc voltage again into ac & then supplies to induction motor. As the switches used in the rectifier & inverter are GTO's & SCR's which requires triggering pulse. The triggering pulse is given by the discrete six pulse generator which is connected to the gate of both rectifier & inverter. Six switching devices in each section. Due to the switching processes harmonics are produced in the system. The output of the inverter which is ac but not sinusoidal due to switching time taken by the switches & is in quazi square form which is the main cause of harmonics. As six switches are used the harmonics which are dangerous to the system are 5th & 7th . Thus main focus is to reduce this harmonic order. For doing so low pass filter is to be used so as to reduce this harmonics. An LC filter is used by selecting the values of inductor & capacitor. Thus it is a passive filter which is used in this scheme. The output of the induction motor is given to the bus -bar which shows the stator ,rotor & mechanical quantities. As our main focus is on current on stator side we choose stator quantities from bus-bar. A scope is connected to observe the waveforms. An FFT block is connected to the motor current of any one phase whose order of harmonic is to be found out. To this FFT block an FFT spectrum window is connected which displays the order of harmonics from 0 to 19th order of harmonic. Also a bar graph is displayed which shows the order of harmonics which is shown by the FFT spectrum. Thus the work is divided into two sections one before use of filter and after the use of filter. After running the simulation it is observed that the 5th & 7th harmonic components are reduced than that without filter which is shown by the FFT spectrum block. The Total harmonic distortion is also found out by connecting a THD block available in simulink library. It is found that the THD is also reduced after the use of filter. Also a single tuned filter can be used to reduce the harmonics which takes care of only one frequency harmonic component which is to be reduced. The FFT analysis can also be done by using powergui which contains FFT tool. The motor current signal is imported in work space by connecting a simout block to the scope & by selecting structure with time option. Further the proposed work deals with the Wavelet analysis of motor current signal. The Wavelet analysis is performed by two methods. The first one by doing programming in M-file. The program is written so that the motor current without & with filter are compared. The Wavelet analysis uses the time scaling technique. Thus the Low & high frequency components of motor current are compared. It is observed that higher frequency components become zero after filter is used.

FFT ANALYSIS OF MOTOR CURRENT

The FFT analysis of motor current is done in two steps i.e without filter & after the addition of filter circuit. The output of the induction motor is given to the bus -bar which shows the stator ,rotor & mechanical quantities. As our main focus is on current on stator side we choose stator quantities from bus-bar. A scope is connected to observe the waveforms.

An FFT block is connected to the motor current of any one phase whose order of harmonic is to be found out. To this FFT block an FFT spectrum window is connected which displays the order of harmonics from 0 to 19th order of harmonic. Also a bar graph is displayed which shows the order of harmonics which is shown by the FFT spectrum. Thus the work is divided into two sections one before use of filter and after the use of filter. After running the simulation it is observed that the 5th & 7th harmonic components are reduced than that without filter which is shown by the FFT spectrum block. The Total harmonic distortion is also found out by connecting a THD block available in simulink library. It is found that the THD is also reduced after the use of filter. Also a single tuned filter can be used to reduce the harmonics which takes care of only one frequency harmonic component which is to be reduced. The FFT analysis can also be done by using powergui which contains FFT tool.

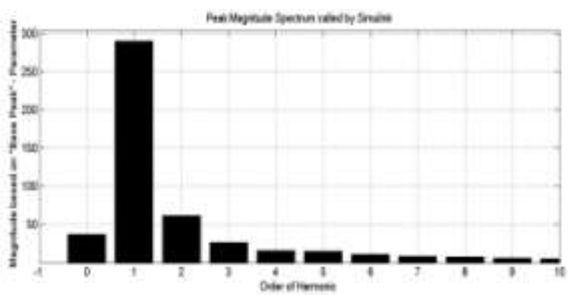

Figure 5: Bar-graph showing magnitude of harmonics without filter

FFT analysis of motor current with LC filter

The FFT analysis of motor current harmonics is done after adding filter An FFT block is connected to the motor current of any one phase whose order of harmonic is to be found out as seen in the diagram . To this FFT block an FFT spectrum window is connected which displays the order of harmonics from 0 to 19th order of harmonic. After the simulation is run the FFT spectrum displays the harmonic orders. As we are using six switches in both current source rectifier & current source inverter we are more concerned with 5th & 7th order harmonic. Also a bar graph is displayed which shows the order of harmonics which is shown by the FFT spectrum. The analysis is done for 5th & 7th harmonic components. The magnitude of this components is 6.19A & 6.18A respectively.

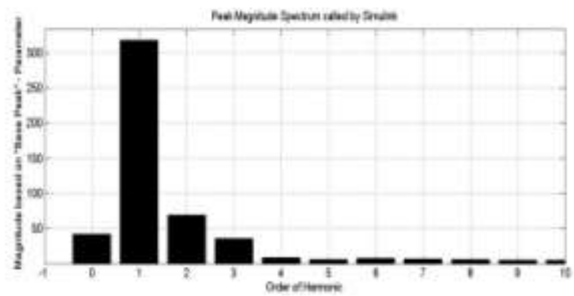

Figure 6. Bar-graph showing magnitude of harmonics with filter

VII Conclusion

The simulation of CSI fed Induction Motor drive caused harmonics in the motor current. This harmonics are the byproduct of switching devices used in rectifier & inverter section. From all the harmonic orders 5th & 7th harmonic cause problem as we use 6 pulse rectifier & Inverter Sections. For the reduction of harmonics we have used LC filter with typical values of inductor & Capacitor. Thus reduction in the 5th & 7th harmonics components is done by passive filter.

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