Sindh Univ. Res. Jour. (Sci. Ser.) Vol.49(1) 101-106 (2017)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Input/Output Current and Voltage Harmonics Analysis of Variable Frequency Drive connected Induction Machine

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Received 22nd March 2016 and Revised 18th Jauary2017

Abstract: There are several ways used to control the speed of motors depending on their applications. One of the commonly used system for speed control of motors is Variable Frequency Drive (VFD) that works on principle of constant V/Hz ratio. VFD comprises of non-linear switches and usage of non-linear load leads to the generation of harmonics which affects the power quality as well as performance of devices like motors and controllers etc. Harmonic measurement and analysis thus becomes very important task in context with increasing power quality. This paper describes the working of Variable Frequency Drive (VFD) and presents the result set for Total Harmonic Distortion (THD) produced through VFD whereas the output frequency changes from 10Hz to 100Hz in 10 equal steps. The results can be used further for a potential harmonic filter design to reduce harmonics being injected back to the power distribution network.

Keywords: Variable frequency drive (VFD), Total Harmonic Distortion (THD), Power Quality (PQ), Speed Control, Current Harmonics, and Voltage Harmonics.

1. INTRODUCTION

A variable frequency drive is an electrical adjustable speed drive which is able to change the speed and torque of the drive according to the application(Iwanciw, 1994). There are also other non-electrical types of adjustable speed drives available but the advantage of electrical adjustable speed drive is both that control and human interference are placed in control room away from process area (Al-Naseem and El-Sayed, 2013).Adjustable speed drives can be AC or DC, only AC type of adjustable speed drive is referred as variable frequency drive (Barnes, 2003). Using VFD for various industrial applications are of great deal beneficial as it has energy saving capabilities (Braun *et al.*, 2016), higher reliability factors (Burt *et al.*, 2008), smooth speed variation abilities and requires less maintenance(Narkhede and Naik, 2016) as compared to other adjustable speed drives available.

Induction motors (particularly three phase) are the heart of many industrial processes. The speed control methods earlier introduced (conventional) are inefficient as compared to variable frequency drive which change the output frequency and terminal voltage of induction motor thus controls the speed and torque of the induction motor (Al-Naseem and El-Sayed, 2013; Mohitkar and Dhend, 2014). Variable frequency drive improves productivity and saves energy in many equipment like pumps, fans, compressors etc. (Saidur *et al.*, 2012).

As VFD has increased the productivity and efficiency of the induction motors, along with that VFDs are non-linear loads that inject current harmonics back to the distribution system (Giannoutsos and Manias, 2015). Power quality issues are much concerned by the harmonic pollution generated by modern electronic switching devices such as voltage source switches (IGBTs) etc. used in variable frequency drive (Emanuel, 2004). Harmonics produced in the waveform of current or voltage leads to the non-sinusoidal signal which may cause the system failure or damage if exceeds from the limits (Mansour *et al.*, 2013). Harmonic measurement and analysis is one of the major concern in power quality studies (Karimi-Ghartemani and Iravani, 2005) thus it is pretty important worry for power system distributors as well as power quality concerned engineers.

This paper analyzes and put a light on the significance of Harmonic Measurement and analysis of power quantities. As a real case an experimental set-up is made in the Electrical Machines Laboratory and the Total Harmonic Distortion (THD) is measured using FLUKE 43B Power Quality Analyzer. Simulation is created using MATLAB and FFT results of the model are taken to compare results with the hardware results.

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Why so much concerned about Harmonics while using VFD?

In industrial applications lots of non-linear loads are used (including VFDs), due to which the importance of power system harmonics issues has increased (Mohitkar and Dhend, 2014). This is the real issue to be dealt with while applying VFDs. Harmonics produced due to these non-linear loads causes the distorted waveforms of current and voltage which has adverse effects on electrical appliances' lives and performance (Morton, 2015). Further consequences due to harmonics are given below:

A. Electrical Equipment Overheating Problem:
Heating problem in equipment is due to I^2R losses which is due to the distorted current produced as a consequence of the harmonics effect. Overheating not only increases losses but also can be the cause for failure of generators, motors, transformers and tripping of the circuit breaker.

B. Communication interference:
Current has magnetic effect which means distorted current creates distorted magnetic and electric field of different frequencies (due to harmonics) which can be the cause for communication interference. Interference generated can induce line noise and can disturb the nearby communication devices.

C. Resonance:
Harmonics are the integer multiples of the fundamental frequency; resonance befalls when the harmonic frequency concurs with the system's natural frequency. Resonance can setup large circulating current which may cause the malfunctioning of the electronic devices, inaccurate meter readings and false operation of protective relays.

Circuit configuration of Variable frequency drive

Block diagram of the VFD along with three-phase induction motor is given below in **(Fig 1).** VFD has three main stage; Rectifier, DC link and inverter.

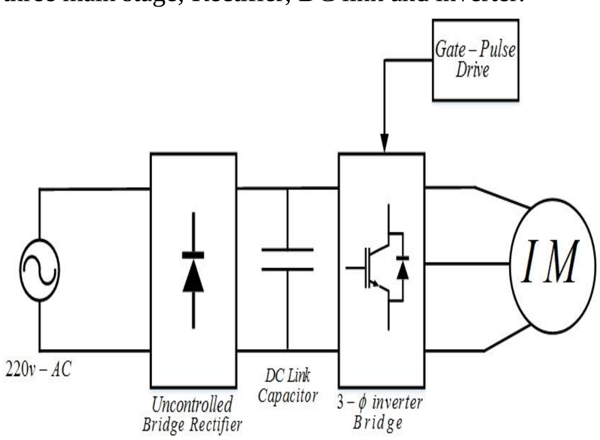


Fig 1. Circuit configuration of Variable Frequency Drive connected Induction Motor (IM)

Rectifier converts the 220V, 50Hz constant supply to fixed DC supple. Output of the rectifier has ripples in voltage waveforms that are smoothened using DC link capacitors. For high load currents DC link inductor is also used to smoothen the current waveform as well. Fixed DC from the terminals of the capacitor is the input of voltage source inverter. IGBTs are used as the switching components in inverter. Various parameters for simulation are given in the **(Table 1).**

Table 1. Circuit and Machine parameters used in simulation

Various Simulation Parameter		
S#	**Parameter**	**Value**
1	AC Supply Profile	220V, 50Hz
2	Rotor Type	Squirrel Cage
3	Motor Rating	4 kW
4	Number of poles	4
5	Nominal Speed	1430 rpm
6	Capacitance (dc-link)	5mF
7	Stator 'R' and 'L'	1.4Ω, 0.005H
8	Rotor 'R' and 'L'	1.3Ω, 0.005H

To alter the output frequency of the inverter, IGBTs are switched at different angles (time). Gate pulse driving circuit uses Sinusoidal Pulse Width Modulation Technique (SPWM) to trigger the IGBTs.

2. RESULTS AND DISCUSSION

Results of hardware and software are given below where as total results comparison and analysis at each output frequency is discussed in bar charts.

Input current harmonics are observed to be independent of output drive frequency as the results **(Fig. 2 and. 3)** are taken, whereas the current harmonics are much greater than the IEEE standard.

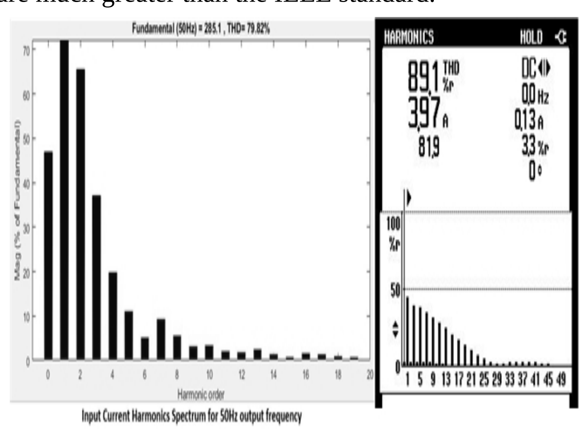


Fig 2. Input current harmonics of Simulated and Hardware model at 50Hz output frequency.

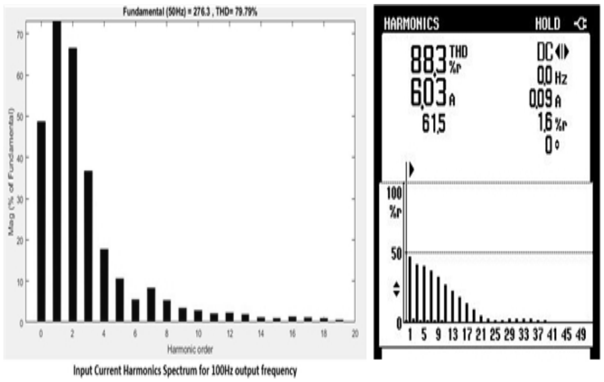


Fig 3. Input current harmonics of Simulated and Hardware model at 100Hz output frequency.

There is no harmonic distortion at the input side of the voltage waveform in the simulated model as the input supply voltages are pure sinusoidal but the hardware results have got minor harmonic distortion (1.2% to 1.3%) which is due to minor distortion in voltage waveform at the experimental setup side.

Either waveforms of current or voltage at the input side, they appear to be totally independent of the output frequency of the drive which is just because output frequency is generated at the third stage of VFD that is inverter. Inverter has no effect over the first stage rectifier that leaves no adverse effect at the input side.

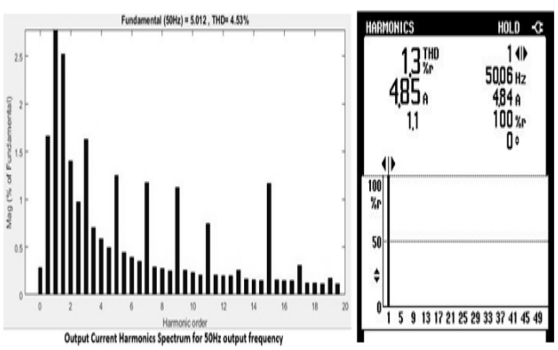


Fig 4. Input voltage harmonics of Simulated and Hardware model at 10Hz-100Hz output frequency.

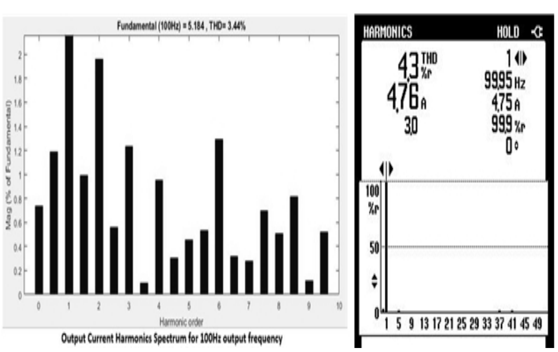


Fig 5. Output current harmonics of Simulated and Hardware model at 50Hz output frequency

Output current harmonics results reveals that current harmonics at the output side are not of much concern as they remain under the allowable limit of 5% but the minor changes suggest that current harmonics minutely increases as output frequency of the drive increases.

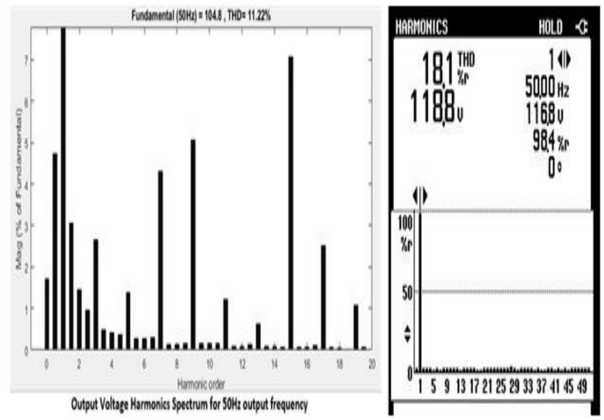
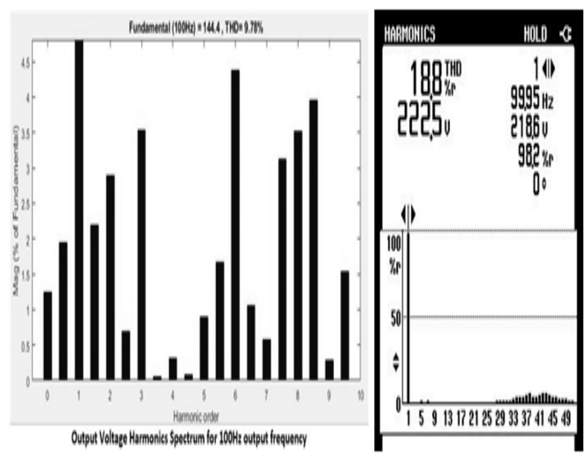


Fig 6. Output current harmonics of Simulated and Hardware



model at 100Hz output frequency.

Fig 7. Output voltage harmonics of Simulated and Hardware model at 50Hz output frequency.

Output voltage harmonics at the output side of the drive are increased from the allowable IEEE standards. **(Fig 7 and Fig 8)** suggests that voltage harmonics are not much effected from the output frequency 50Hz to 100Hz but harmonic content in voltage waveform decreases as the drive's output frequency increases.

Total simulation and hardware results are compared and bar charts are given for input voltage, input current, output voltage and output current comparison. **(Fig 10 and 11)** shows the results of input voltage and input current at various output drive frequencies. Fig 10 shows that input voltage in simulation has no harmonics whereas the hardware model has some harmonics due to distorted supply at experiment site.

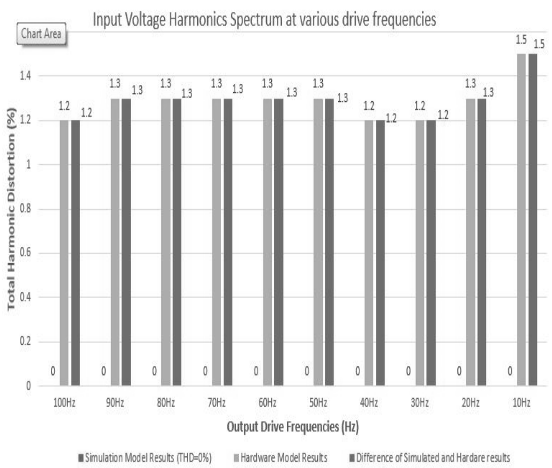


Fig 10. Input Voltage Harmonics

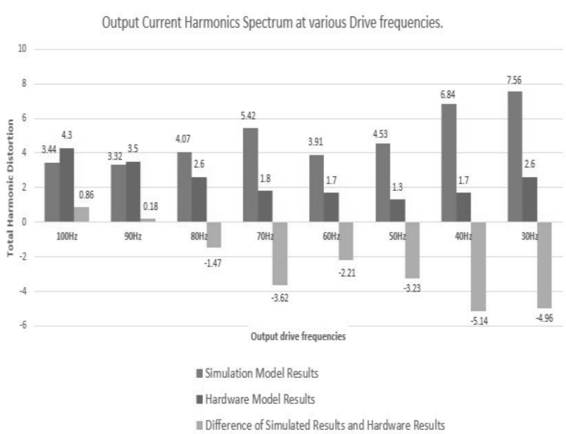


Fig 11. Input Current Harmonics

Fig 11 shows that at input side of the VFD, current waveform has high content of harmonics because of the rectifier. High current harmonics can be further mitigated by applying harmonic filter at input side. Input current harmonics are not dependent on the output frequency of VFD.

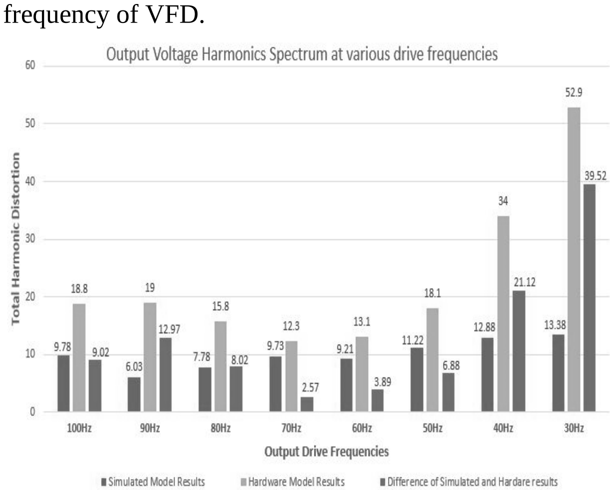


Fig 12. Output Voltage Harmonics

Fig 12 shows the output current harmonics at different output frequencies of VFD. It can be observed from the bar chart in fig 12 that THD at the output voltage side increases as output drive frequency decreases and output frequencies lower than 50Hz need to be tackled as the harmonic contents are tremendously increasing from 50Hz to 30Hz.

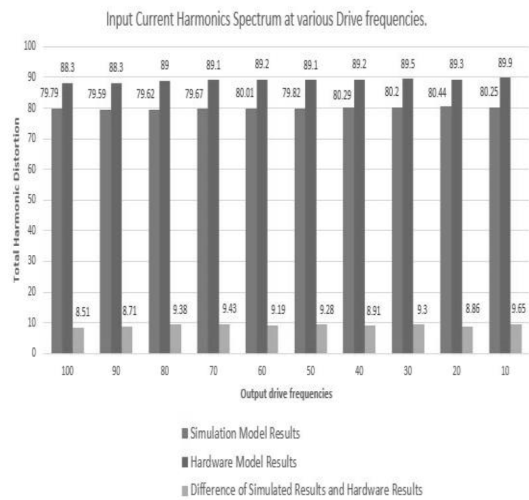


Fig 13 shows the output current harmonics contents for various output drive frequencies. It is observed from the fig 12 and 13 that at output side of the VFD, voltage harmonics are greater than the current harmonics whereas the current harmonics at the output side has minute effect of output drive frequencies.

4. DISCUSSIONS

Comparison of simulation and hardware results for Total Harmonic Distortion (THD) for the current and voltage (input side and output side of VFD) are given in fig 10 to fig 13. From the results it is clear at input side current harmonics are greater whereas at the output side voltage harmonics are greater. Difference between hardware and simulation results is also given in bar charts that shows minor difference and hence validates the results.

5. CONCLUSION

The paper presented the Harmonics Measurement and Analysis as one of the burning issue of power quality and control. From the results it is observed that current harmonic level of input current and output voltage is greater than the set international standards. Result set built during the research work is beneficial for the harmonic filter design that can be implemented further to reduce current harmonics injection into system. Special considerations must be given to the input side current harmonics filter design and output side voltage filter design. It is a potential database for the future work on harmonic measurement and analysis when the system configuration is altered.

ACKNOWLEDGMENT

Authors would like to show great gratitude to Mehran University of Engineering and Technology Jamshoro, Sindh for providing basic facilities and healthy environment for research work carried out. Authors extend thanks to Institute of Information and Technology and Electrical Machines Lab of the same university for their guidance and cooperation.

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