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EFFECT OF MOTOR VIBRATION PROBLEMS ON POWER QUALITY OF WATER PUMPING AT RESIDENCY

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Abstract. Water pumping system is an essential machinery for residential usage. Around 150 litres of water are used by a person in India daily for their daily usage. For this reason the water pumping is used regularly. Due to dynamic performance of the pumping unit pump can be operated in both no load and load condition. Though the pumping system was controlled by throttling drive in the early stage but in modern technological advancement time pumps are controlled by variable frequency drives (VFD). VFD provides the pump variable duty requirements with significant energy saving and improved reliability. In every pumping system due to dynamic forces of hydraulic and mechanical component some vibrations are seen but sometimes this vibrations may be excessive which can damage the components of the pump. The excessive vibrations indicate some problems or failures in the system. Power quality issues are one of those problems which are seen during the vibration of the pump motor and induction motor connected with pump. This paper presents the power quality issues in the pump motor in different control method like vvc+ and v/f control method.

1. Introduction

Pumps are of various categories like centrifugal, positive displacement pump etc. [1]. but most of the pumps are used for industrial and residential purposes are centrifugal pump [2]. This centrifugal pump can be controlled by VFD drives in order to save the energy. VFD drives has three controller technology like VVC+, V/f and flus sensor less. In the latest motor control technology, installation of variable frequency drive (VFD) is a cost-effective solution to achieve significant energy savings, and when the drive is applied for pumping system, it can save 10% [13] of the energy used previously. Controlling the motor speed is one way of saving energy, and 68% of the electrical energy is used to operate flow loads like fan, blowers, compressors etc. [3]. by constant speed. The adjustments are needed where output flow fluctuates most of the time. Flow can be controlled by valve control, inlet damper control, inlet valve, outlet valve control etc. VFD is a power electronic device which converts one frequency of alternating current to another frequency for running the AC motor in variable speed to save the energy. Power quality issues are the major issues in the pumping system controlled by VFD drives because of its adjustable speed drives nature and programmable controllers. Continuous operation in resonance condition also creates excessive vibration in the system. The power quality issues are sag, swell, flickering and harmonics problems [4]. Here hardware based experimental research has been done to analysis the effect of THD, flickering, 5th and 7th harmonics problems in the pumping system. Master follower cascaded pump has been used which is controlled by VLT aqua drive and flow rate will be added with same head value when all the pumps are operated in parallal. The block diagram of multistage parallal pumping system has been shown in figure 1.

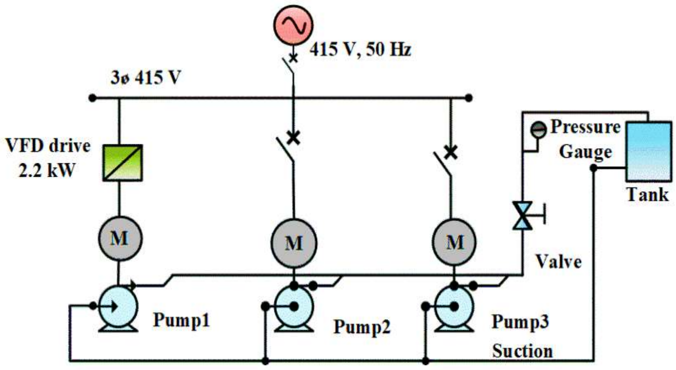

Figure 1: VFD based parallal pumping system

2. Vibration Analysis

Vibration analysis is a common technique now a days used in Industries. The vibration condition occurs due to vibration of pumps, when there is a fault in the installation of the motors or uneven grounds where motors need to be installed and it results in either mechanical or electrical imbalance of the motor. Bad motor vibrations affects the overall equipment efficiency (OEE), which is an important factor that need to be considered while performing motor operations, as it helps to prevent unexpected failures of the equipment [5].

Maximum vibration level measured at no load is less than compared at full load. Pump loading causes increase in vibration level and further causes pump bearing problems [6]. Due to unbalance moving parts within the pumping system, interaction of fluids with the pumps connecting with pipes, movements of pipelines causes vibration [7]. There are various reasons are available for unwanted vibrations like impeller unbalance, hydraulic unbalance, voltage unbalance of pump motor, bearing problems, cavitation and water hammering issues etc. This vibrational problem can be both mechanical and hydraulic problem in the pump. If impeller unbalance, bearing and seal problem creates vibration it will be categorized as mechanical failure and hydraulic failure occurs when cavitation and water hammering issues are seen [8].

Vibration problems can also occur at any time in the installation or operation of a motor. When they occur it is normally critical that one reacts quickly to solve the difficulty. If not solved quickly, one could either expect long term damage of the motor or immediate failure. To solve a vibration problem one must differentiate between cause and effect. Perhaps the support structure is just not stiff enough to minimize the displacement [10].

2.1. Power Quality Issues

The electrical system fails to meet the demand and loads are not operating properly, if any parameters of electrical supplies creates any troubleshoots all these analysis is called power system analysis. The quality of electric power is subjected to set of parameters like changes of voltage and current, continuity of service, transient voltage and current, harmonic contents of waveforms of AC power [9]. The current and voltage at various operating conditions is known as power quality. Because of unhealthy power quality, problems occur such as voltage disturbances for example voltage sags, voltage swells, voltage surges and impulse. Flickering, harmonic invasion and power factor quality. The Harmonics contents and THD can be calculated by measuring the voltage and current signal and their measured values represent the status of power quality. The harmonics have several effects like torque pulsation, acoustic noise and increased power losses. Types of harmonics present in Induction motors that is space harmonics and time harmonics. Due to the different phase windings interaction Space harmonics are generated. The power supply is sinusoidal and that can be reduced by applying a proper machine design [10].

2.2. Total Harmonic Distortion

The measurement of harmonic distortion present in the signal and the distortion is defined by the ratio of sum of the powers of all harmonic components and the power of fundamental frequency. This is called total harmonic distortion (THD) [11]. The series of harmonic components that represent a distorted waveform are often described by the total harmonic distortion (THD). THD can be calculated from the following equations;

$$\text{THD} = \sqrt{\frac{\sum_{n=2} V_n}{V_1}} \quad (1)$$

Where n is the order of harmonic, V_1 is the rms value of fundamental voltage and V_n is the rms value of voltage harmonic with order n. The voltage distortion limits in IEEE 519 are fairly straight forward, as shown in Table 1. There are only three levels recommended, depending on the voltage level.

Table 1. Voltage distortion limits (IEEE STD 519_2014)

Bus voltage V at PCC	Individual harmonic (%)	Total Harmonic distortion (%)
V ≤ 1.0 kV	5.0	8.0
1 kV ≤ V ≤ 69 kV	3.0	5.0
69 kV ≤ V ≤161 kV	1.5	2.5
161 kV < V	1.0	1.5

2.3. Flicker Problem

The network voltage power supply varies with respect to time due to perturbations. Electrical power quality can be decorated due to interaction of electrical loads with the networks. High power loads can varies and fluctuating in any cases. High power load can draw fluctuating current like large motor drives, arc furnaces, low, variations of voltage with low frequency etc.

The electrical instability can be seen in the system during flickering. Flicker is expressed in terms of two parameters like short term flicker who's PST for severity is 10 min and short term severity is possible to assess and for long term severity time requires 2 h in which time long term severity PLT is assessed. The equations will show the process of calculation of flicker [12].

$$P_{ST} = \sqrt{0.0314P_{0.1} + 0.0525P_{1Ss} + 0.0657P_{3s} + 0.28P_{10s+0.08}P_{50s}} \quad (2)$$

$$P_{LT} = \sqrt[3]{\frac{\sum_{i=1}^{N} P_{ST_i}^3}{N}} \quad (3)$$

P_{ST} period number within P_{LT} observations is N. Measurements would be required for calculation of P_{LT}.

3. Hardware setup:

Using VLT AQUA Drive FC 202, the experiment has been carried out and the readings have taken at PCC (Point of Common Coupling)[Figure 2]. The pressure is set in the drive and the mode of control is selected and the valve position is changed starting with fully open, semi open or semi closed and fully closed [16] [18] [20]. The motor chosen here is Induction motor. VLT Aqua drive is connected with the system for the higher performance of AC motor for wastewater applications [14] [15]. The device has a wide range of standard features, which help to improve the performance of the system [21-33]. Freely programmable warnings and alerts help the adaptation to the application of perfect system integration. Hardware results also shown in figure 3.

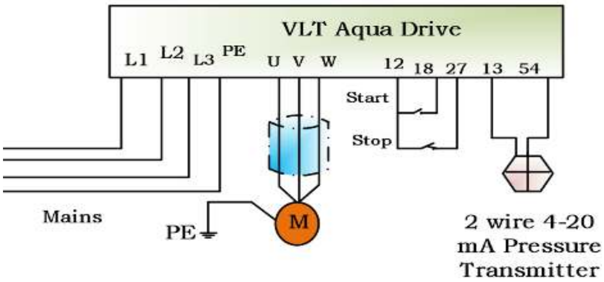

Figure 2: VLT Aqua drive schematic diagram

Figure 3: Hardware Test Bed setup

4. Vibration analysis in case of bad motor vibration

For the vibration analysis purpose two condition taken i.e., motor running under tightly and loosely connected condition with its base plate. To control the motor speed Danfoss aqua drive is used [17]. Motor is run at different pressure bar (0.3, 0.6, 1, 1.6 bar) under different value conditions (fully open, semi-closed, fully closed) at different control scheme such as VVC+ and V/F control scheme. For more analysis vibration level is increase by again loosening base plate of motor also more reading taken as taken previously taken for low vibration level. The experiment has been done in three case studies like valve fully open, semi closed and fully closed condition. In three conditions 3rd, 5th, 7th and 11th harmonics, voltage and current THD, flickering, frequency values are measured [19].

4.1. Electrical power quality analysis in case of VVC+ control scheme used when motor running Vibration condition

The measurements were analysed and represented in results and observation shows the THD, 5th, 7th,11th and instantaneous flicker values under VVC+ control scheme in case of bad motor vibration operations. It is shown that the THD value is changed depending on the number of units operation its values change between 3 and 4.5%, however these values are nearest to the permissible limits which are shown in Table 1 but there values are not exceed these limits. Also the 5th and 7th harmonic contents

are higher. The instantaneous flicker values are high which means variable fluctuation of the supply voltage due to unbalance of torque operation which results from bad motor vibration.
In the first case valve is fully closed then the changes of voltage THD, current THD, flickering and frequency will be shown by the figures [Figure 4-7].

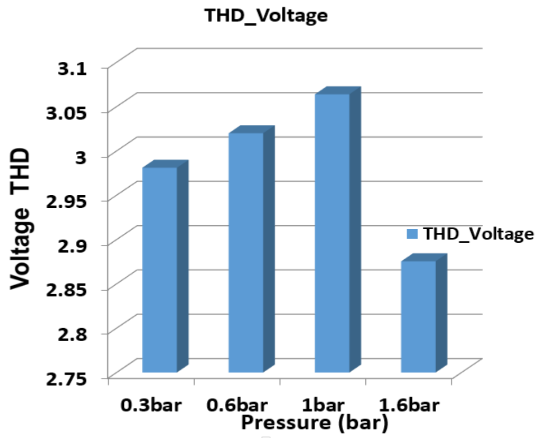

Figure 4: Voltage THD at fully closed condition

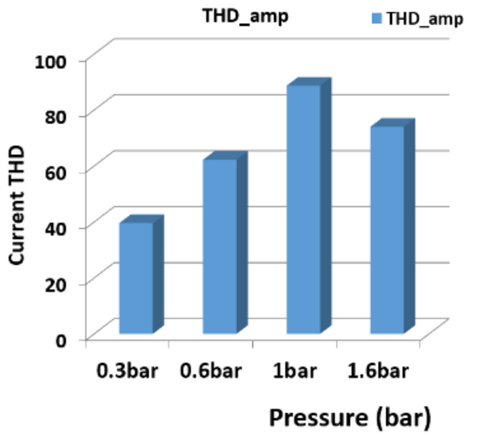

Figure 5: Current THD at fully closed condition

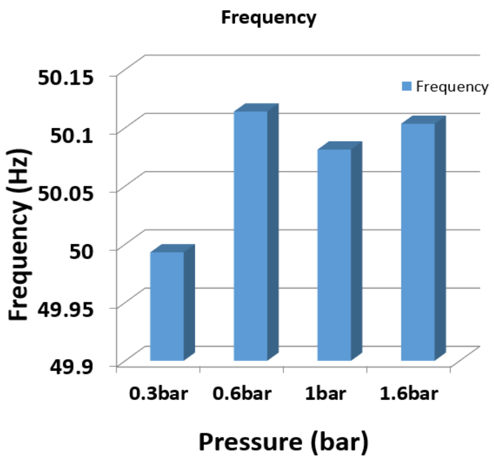

Figure 6: Frequency at fully closed condition

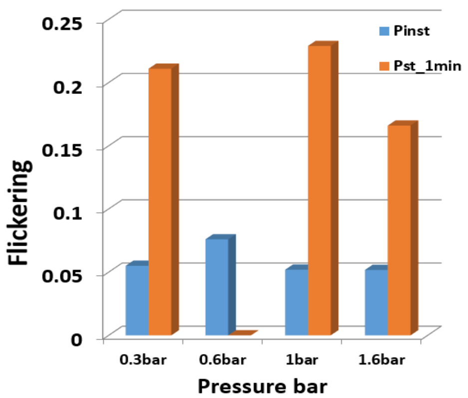

Figure 7: Flickering at fully closed condition

The second case is when valves are semi closed values are collected for voltage and current THD, frequency and flickering [Figure 8-11].

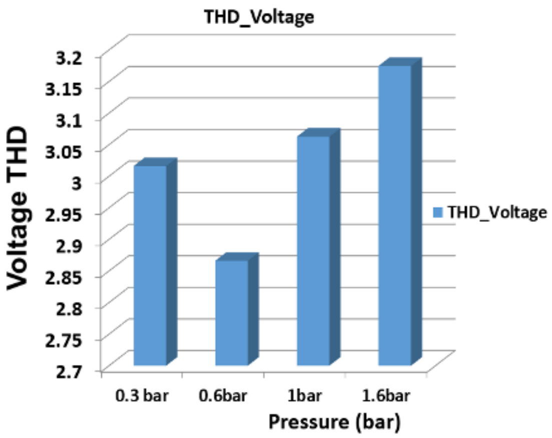

Figure 8: Voltage THD at semi closed condition

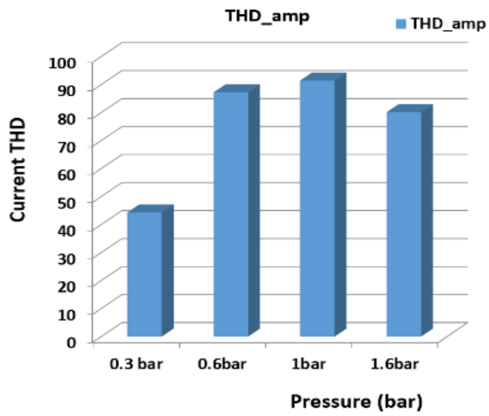

Figure 9: Current THD at semi closed condition

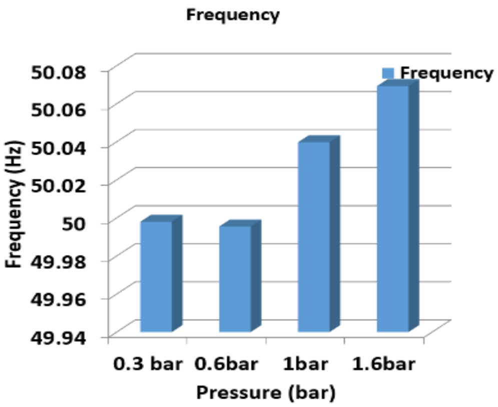

Figure 10: Frequency at semi closed option condition

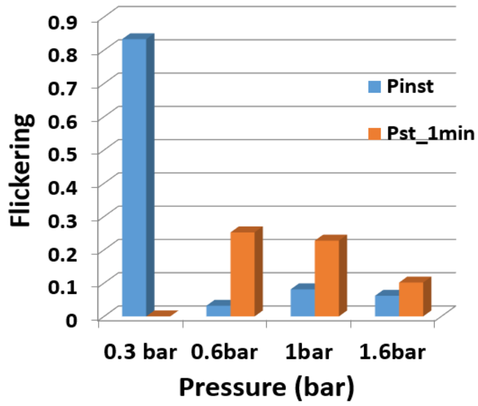

Figure 11: Flickering at semi closed

Now in case 3 the value of voltage and current THD, frequency and flickering values are collected when valves are fully open [Figure 12-15].

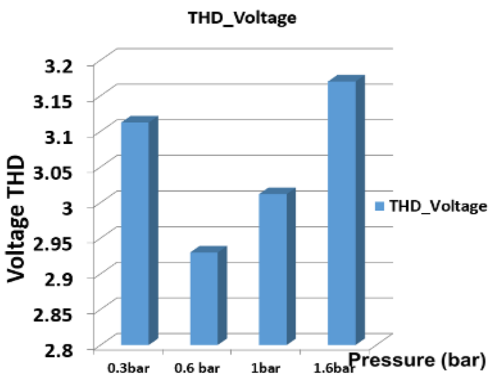

Figure 12: Voltage THD at fully open condition

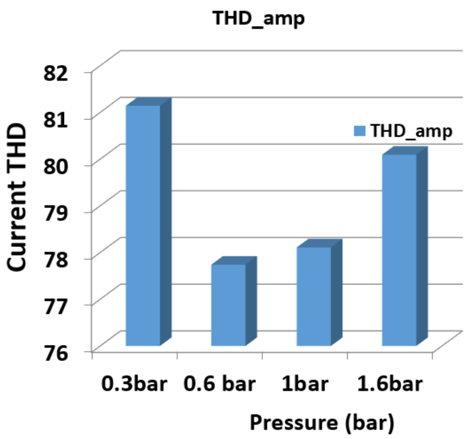

Figure 13: Current THD at fully open condition

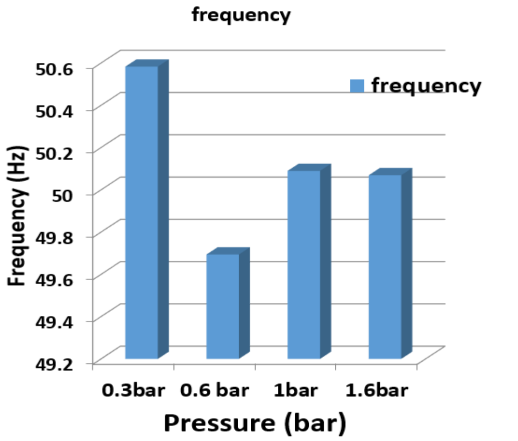

Figure 14: Frequency at fully open condition

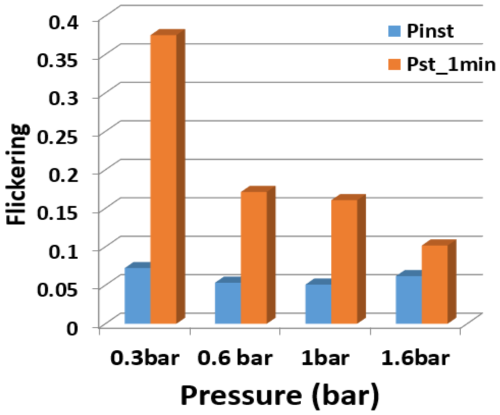

Figure 15: Flickering at fully open condition

4.2. Electrical power quality analysis in case of V/F control scheme used when motor running Vibration condition

The measurements were analysed and represented in results and observation shows the THD, 3rd, 5th, 7th,11th and instantaneous flicker values under V/F control scheme in case of bad motor vibration operations. It is shown that the THD value is more than the THD value when motor run during VVC+ control scheme. Also the 5th and 7th harmonic contents are higher. The instantaneous flicker values are also high which means variable fluctuation of the supply voltage due to unbalance of torque operation which results from bad motor vibration. The VVC+ and V/F control are the two major controller technique for VFD based pump. Here the characteristics of VVC + and V/F are compared for power quality issues. Here also three cases have been investigated like fully closed, semi closed and fully open condition.

Here case 1 is when vales are fully closed that times the nature of voltage, current THD, flickering and frequency values are collected for V/F control [Figure 16-19].

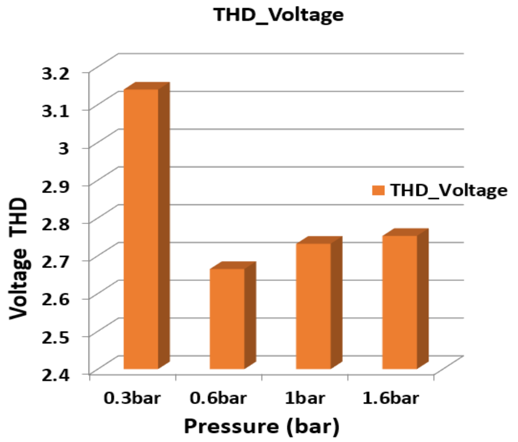

Figure 16: Voltage THD at fully closed condition

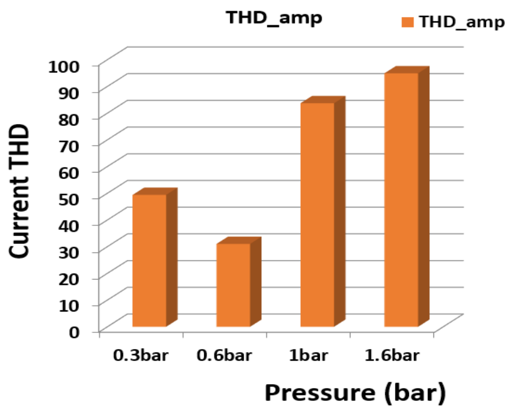

Figure 17: Current THD at fully closed condition

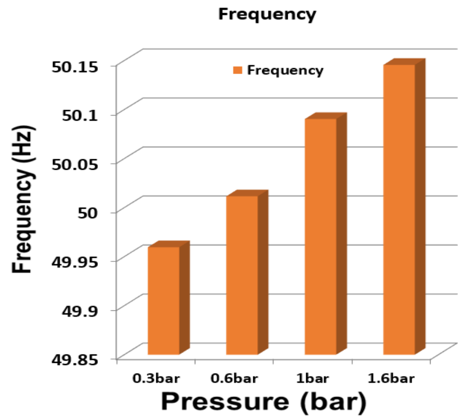

Figure 18: Frequency at fully closed condition

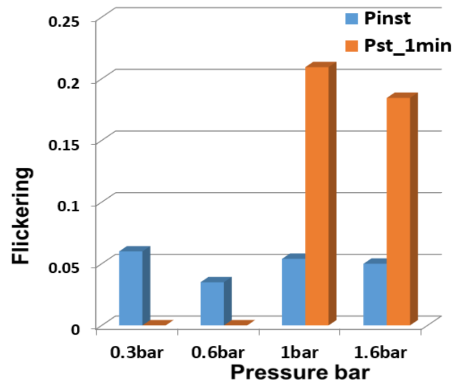

Figure 19: Flickering at fully closed condition

In case 2 when valves are semi closed the voltage, current THD, flickering, frequency values are collected [Figure 20-23].

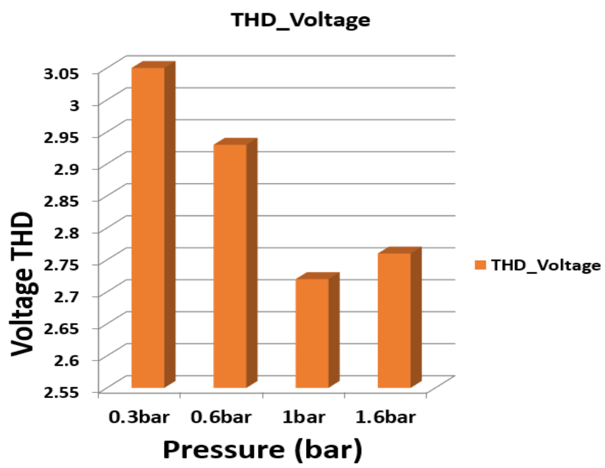

Figure 20: Voltage THD at semi closed condition

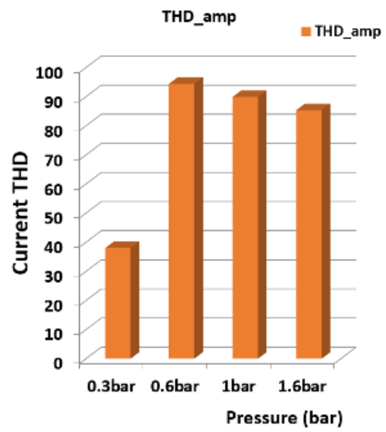

Figure 21: Current THD at semi closed condition

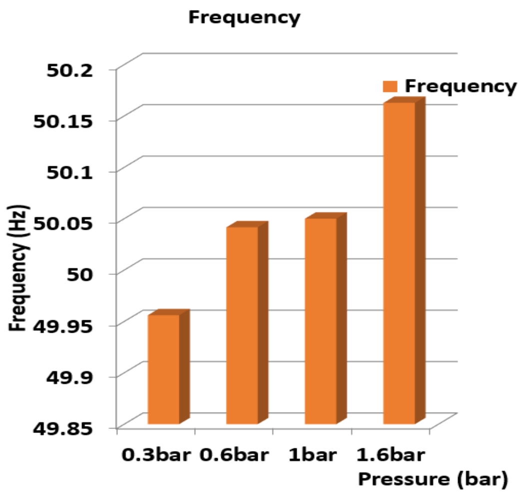

Figure 22: Frequency at semi closed condition

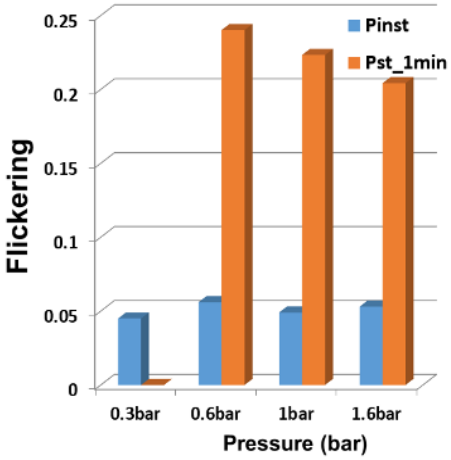

Figure 23: Flickering at semi closed condition

In the 3rd case when all the valves are open then voltage, current THD, frequency, flickering values are collected [Figure 24- 27].

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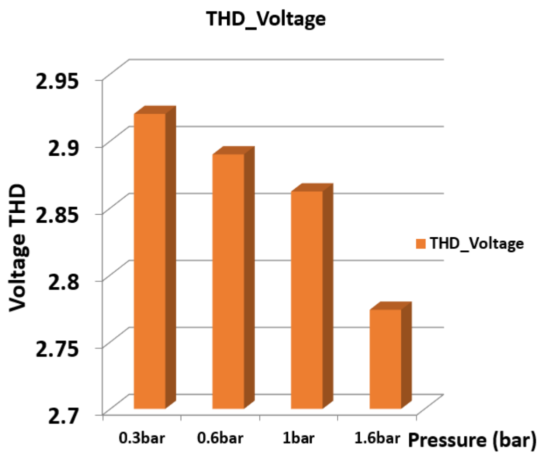

Figure 24: Voltage THD at fully open condition

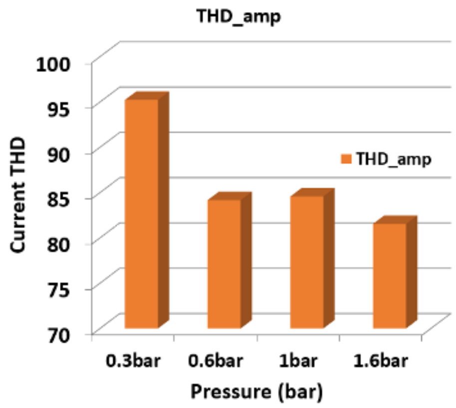

Figure 25: Current THD at fully open condition

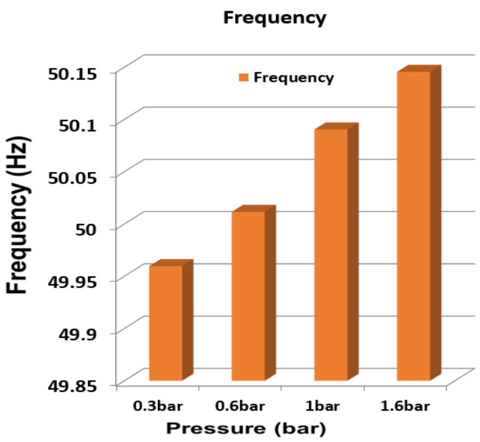

Figure 26: Frequency at fully open condition

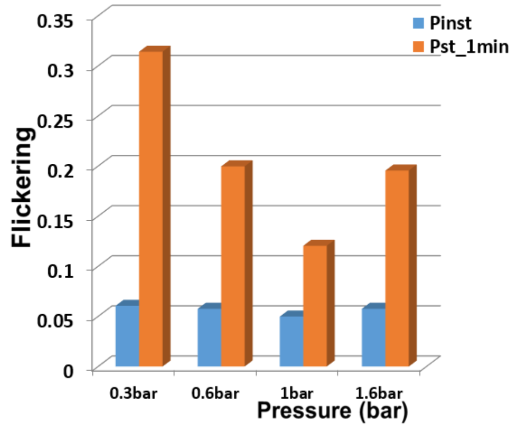

Figure 27: Flickering at fully open condition

Table 2: Valve operations condition for VVC+ control

	VVC + Control											
	Valve fully closed				Valve semi closed				Valve fully open			
	0.3 bar	0.6 bar	1 bar	1.6 bar	0.3 bar	0.6 bar	1 bar	1.6 bar	0.3 bar	0.6 bar	1 bar	1.6 bar
THD voltage	2.9811 volt	3.02 volt	3.064 volt	2.8755 volt	3.016 volt	2.866 volt	3.0625 volt	3.1746 Volt	3.11 volt	2.93 volt	3.01 volt	3.17 volt
THD Current	39.57 amp	62.2 amp	88.6782 amp	74.02 amp	44.29 amp	87.222 amp	91.4113 amp	80.094 amp	81.15 amp	77.74 amp	78.11 amp	80.1 amp
Frequency	49.9931 Hz	50.114 Hz	50.0814 Hz	50.1035 Hz	49.998 Hz	49.9955 Hz	50.0398 Hz	50.0693 Hz	50.58 Hz	49.7 Hz	50.09 Hz	50.1 Hz
Flickering												
Pinst	0.0551	0.076	0.052	0.518	0.833	0.032	0.0814	0.062	0.07	0.053	0.05	0.06
Pst_1 min	0.211	0	0.229	0.166	0	0.2525	0.2277	0.102	0.38	0.17	0.16	0.11

Table 3: Valve operations condition for V/F control

	V/F Control											
	Valve fully closed				Valve semi closed				Valve fully open			
	0.3 bar	0.6 bar	1 bar	1.6 bar	0.3 bar	0.6 bar	1 bar	1.6 bar	0.3 bar	0.6 bar	1 bar	1.6 bar
THD voltage	3.14 volt	2.665 volt	2.73 volt	2.75 volt	3.05 volt	2.93 volt	2.72 volt	2.76 volt	2.92 volt	2.89 volt	2.86 volt	2.77 volt
THD Current	49.38 amp	31.03 amp	87.11 amp	94.92 amp	37.98 amp	94.37 amp	89.89 amp	85.36 amp	95.2 amp	84.2 amp	84.6 amp	81.54 amp
Frequency	49.93 Hz	49.96 Hz	49.98 Hz	50.09 Hz	49.96 Hz	50.04 Hz	50.05 Hz	50.16 Hz	49.9 Hz	50.0 Hz	50.1 Hz	50.2 Hz
Flickering												
Pinst	0.06	0.035	0.054	0.05	0.045	0.056	0.049	0.053	0.06	0.06	0.05	0.05
Pst_1 min	0	0	0.2094	0.1845	0	0.2401	0.2233	0.240	0.31	0.19	0.12	0.19

From Table 2 and Table 3 it has been concluded that in the case of valve fully closed condition except in 1.6 bar the voltage THD is lower when the motor is running in VVC+ control rather than V/F control. Current THD also lower most of the cases in VVC+ control expect in 0.6 bar pressure condition. Average Flicker are more dominant when motor run under V/F method. Similarly when valve is fully open condition voltage and current THD is more in V/F control. Average flicker is more dominant when the motor run under V/F control. In valve semi closed condition voltage THD is higher in VVC+ control in 1 bar pressure and current THD is higher in VVC+ control most of the cases. Average Flicker are more dominant when motor run under VVC+ method.

The harmonics values of the system like voltage harmonics and current harmonics are collected to analysis the power quality issues in water pumping system. Here also in both VVC+ and V/F control method the process have been done [Figure 28-39].

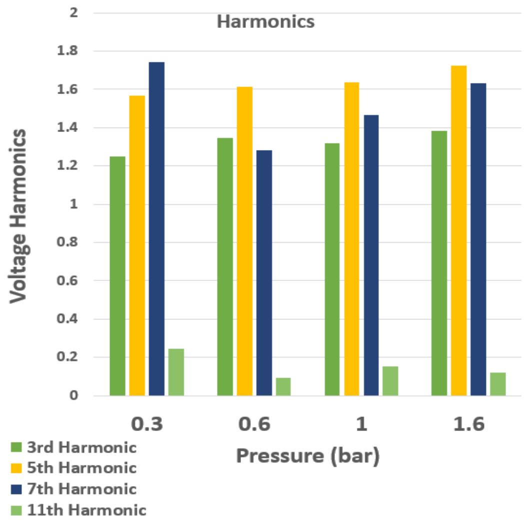

Figure 28: Voltage harmonics for fully open condition (VVC+)

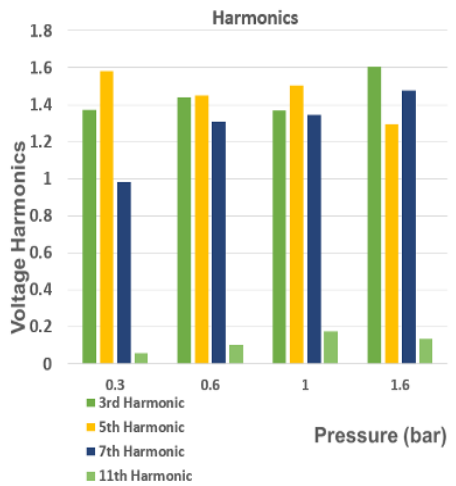

Figure 29: Voltage harmonics for fully open condition (V/F)

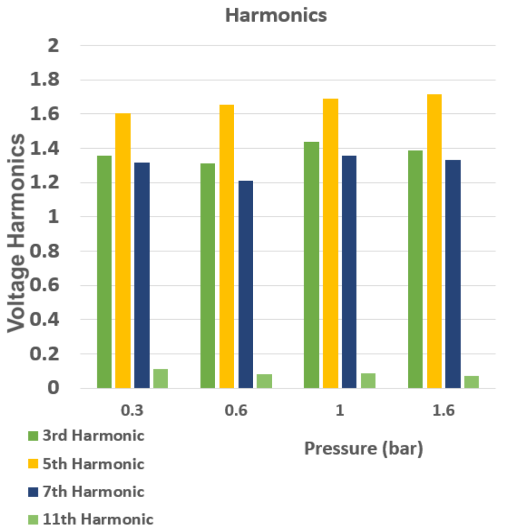

Figure 30: Voltage harmonics for semi closed condition (VVC+)

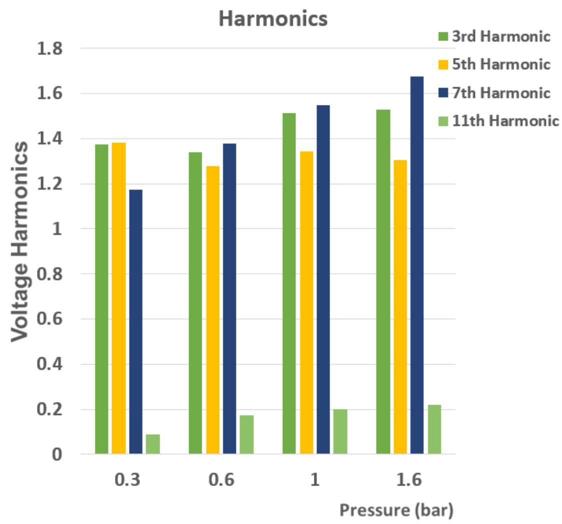

Figure 31: Voltage harmonics for semi closed condition (V/F)

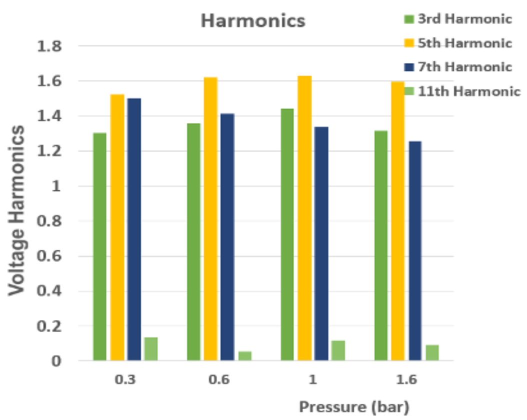

Figure 32: Voltage harmonics for fully closed condition (VVC+)

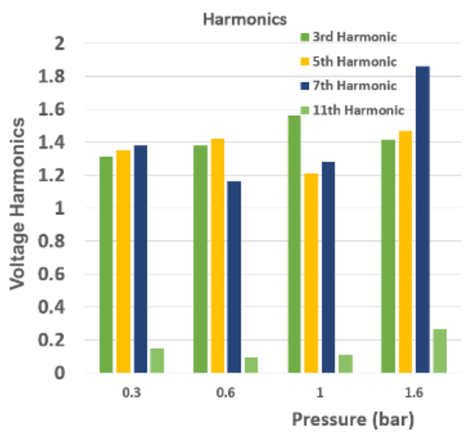

Figure 33: Voltage harmonics for fully closed condition (V/F)

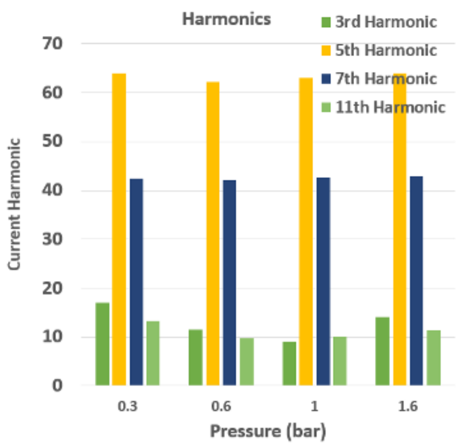

Figure 34: Current harmonics for fully open condition (VVC+)

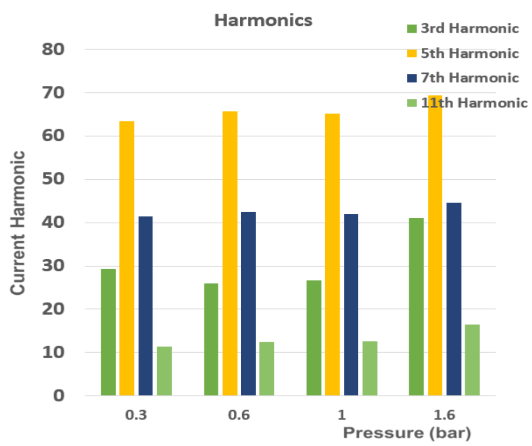

Figure 35: Current harmonics for fully open condition (V/F)

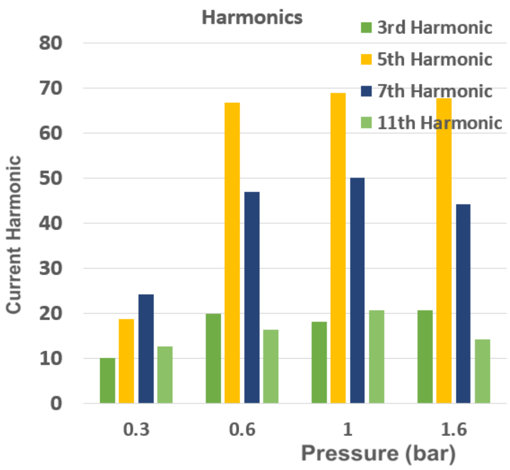

Figure 36: Current harmonics for semi closed condition (VVC+)

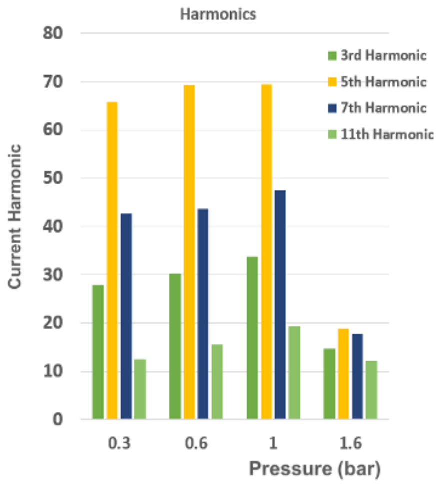

Figure 37: Current harmonics for semi closed condition (V/F)

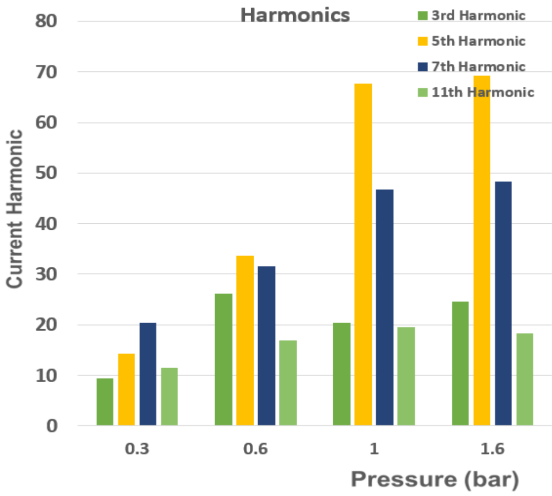

Figure 38: Current harmonics for fully closed condition (VVC+)

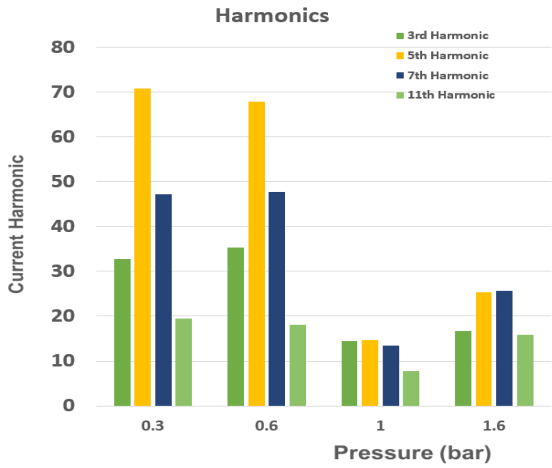

Figure 39: Current harmonics for fully closed condition (V/F)

5. Comparison among VVC+ and V/F method

The overall experimental results shows that the voltage THD and current THD is almost high in the case of V/F control in three cases than VVC+ control in different pressure bar. The flicker is dominant in most of the time for V/F control method. In the case of harmonics also it is seen from the figures and table 3 that in percentage of harmonic in VVC+ control is lesser than V/F control in three cases in different pressure bar for both voltage and current harmonics. When value is at open condition overall performance of motor is good under V/F method even though vibration level is high. So VVC+ method is this case when power quality issues taken in consideration. When value is at fully -Closed condition overall performance of motor is good under VVC+ method (Except 0.6pressure bar) even though vibration level is high. While V/F method is suitable only for 0.6 pressure bar. So overall VVC+ method is preferable when value is at Fully-Closed condition under vibrating condition (Table 4).

Table 4: Comparison between Normal condition and under vibrating condition

Case	Normal	VVC+	V/F
THD	About 4.5%	Less than7%	About 9%
3th harmonics	3.2%	Less than 5.4%	More than 6.8%
5th harmonics	2-2.5%	Less than 3.2%	More than4.3%
7th harmonics	About1.3-1.4%	Less 2.1%	More than 3.2%
11th harmonics	About 1.2%	Less 1.8%	More than2.1%
Flicker (at 1min)	Less	Small flicker value	Large flicker value

Conclusion

The analysis of the dynamic measurements and power quality showed that; as motor vibration level is increase it affects not only dynamic performance but also electrical power quality. Here a comparison between electrical power quality analysis and dynamic performance of motor under vibration condition has been done and result shows that under poor fixing or weakness of baseplate or foundation leads to high levels of vibration. The THD level is more in V/f method than VVC+ method also the harmonics content of 3rd,5th,7th,11th is more in V/F control than VVC+ method .The results also show that VVC+ control method is best suitable under vibration condition than V/F control method.

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