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Experimental analysis of PQ parameter estimation of VFD drives

Experimental analysis of PQ parameter estimation of VFD drives

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Abstract. Controlling the AC motor speed and torque changing voltage and frequency for electrical and mechanical system the adjustable speed drive system is required which is known as Variable Frequency Drive. The usage of VFD is gradually increasing every day. The 25% of the world's energy is consumed by the motor load for which the usage of VFD is responsible. The cost of VFD can be reduced and size also reduced to help the system more compatible within a very short span of space. It is based on semiconductor topologies, driver circuit, control circuit and both software and hardware devices are also used. Now power quality is the important role plays for the energy efficiency of the system. The researchers are working on various issues of power quality like voltage sag, swell, system unbalance etc. which are required to be analysed for the improvement of the efficiency of the system. In this research the VFD based induction motor faces various power quality issues which are described. The paper is concentrating on various power quality issues which affects the performance of VFD drives through various parameters. The various power quality parameters are predicted for the change in loadings with the help of MATLAB curve fitting tool. With different load variations voltage and current unbalance have been measured. The process has been done though experimental setup with the help of power quality analyser Fluke 302 and both the controller technique like VVC+ and V/F methods have been used.
Keywords: VFD, Curve fitting, Power Quality, Induction Motor, Control circuit

1. Introduction

The requirement of energy is also increasing as world also progressing. Rather than 2016 to 2030 the energy consumption also increases 30% [1]. The optimal utilization of the energy is required with the increasing demand of the energy as the resources are exhausting day by day [2].

Energy efficiency improvement is the key matter to keep the environment sustainable and the main resources of the energy comes from electric power and water. As the electric power is very important for energy supplying case and every household sectors, industries. As the electric power is the main concern therefore power quality term comes into picture. Power supply is good or bad that can be measured by power quality analysis. The differentiation is based on various parameters likewise voltage, current, frequency, harmonics and system unbalance. The change in these parameters with respect to standards shows the status of power quality [13].

The factors are various types which leads to deterioration of power quality. In this case variable frequency drives plays a significant role [14]. The power electronics modules play a significant role in the usage of VFDs and behave as a nonlinear load and draws the harmonic currents from the supply and pollution is created in the power system. This also leads to electromagnetic interfaces and in three phase system nonlinearity causes the system unbalance and significant neutral currents. As a result there is a poor power quality and reduced efficiency can be observed [15-25]. Besides harmonics power quality also deals with voltage sag, swell, power factor, system unbalance, electromagnetic interfaces, frequency variation etc. [26-35]. These parameters should be monitored in proper way and should be

maintained for the energy efficient system. Active power filters are fully commercialised and provides a unique solution for various power quality problems [5].
The various power quality parameters have to be under specified standards. These standards are governed by IEEE and IEC. IEEE Standard-519 gives the various limits for current and voltages for a power system [6]. EN 50160 gives the voltage limits for a public distribution network [7] [8]. These standards should be maintained for healthy grid conditions [9].
In this work power quality parameter estimation of VFD (variable frequency drive) is done with respect to different loadings of motor. The estimation is done using MATLAB curve fitting tool [10]. A three phase induction motor has been analysed with respect to different loadings as no load, half load and full load and parameter for other loadings are estimated [11]. The various PQ parameters are studied with the varying load and detailed analysis with respect to comparison of control techniques is made in this work. Moreover comparison between the speed control methods is also carried out [12]. The various sections of this paper consists of VFD, experimental setup, test procedure and data acquisition, standards, followed by detailed analysis and conclusions.

2. VFD (Variable Frequency Drive)

Variable frequency drive also known as adjustable speed drive system which are used for electrical and mechanical system to control the AC motor torque speed characteristics by changing voltage and frequency. VFD is very helpful for large motor system and compressor application. Few decades the usage of VFD has been increased in alarming rate, and it makes the industry energy efficient as 25% of the energy is used by motor application. VFD system helps to reduce the size of the system and it helps to improve the performance of the semiconductor devices, control circuit for both software and hardware, semiconductor devices, drive topologies. VFD is made of AC-AC and DC-DC topologies.

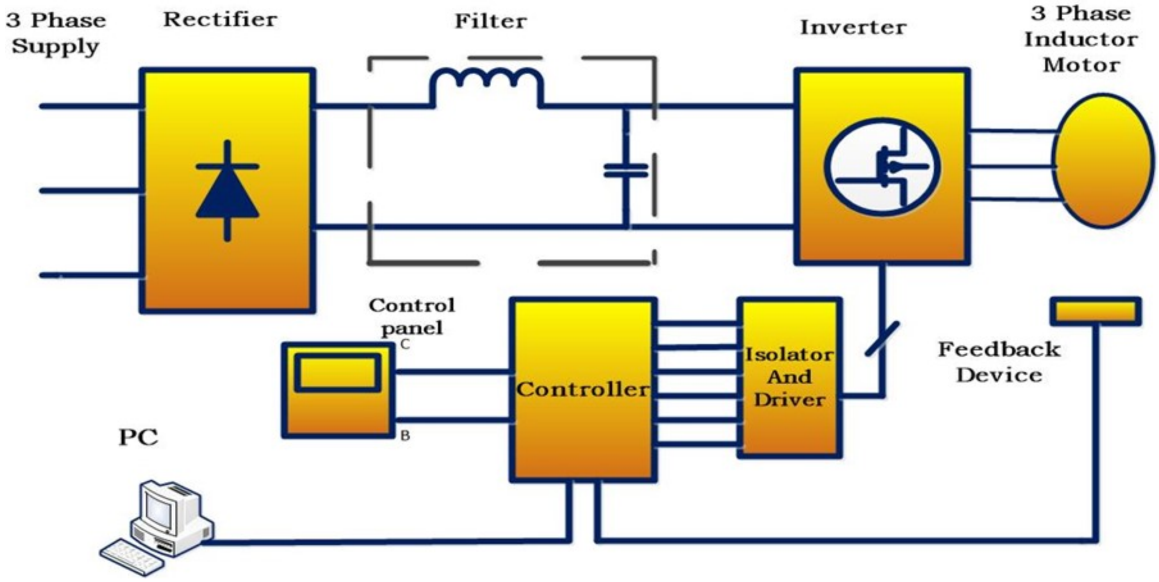

Figure 1: Block diagram of VFD drives

3. Experimental Setup

The circuit diagram of the experimental setup used for the analysis is shown in Figure 2. The circuit diagram consists of supply, measuring clamps, and VFD which is connected to the motor. The various electrical parameters are measured at the input to the VFD with a power quality analyser as shown in Figure 2. In this experiment the analysis of voltage, current, frequency unbalance, voltage unbalance, power consumed, power factor and efficiency factor, power factor and efficiency factor, energy consumed and harmonic spectrum etc.

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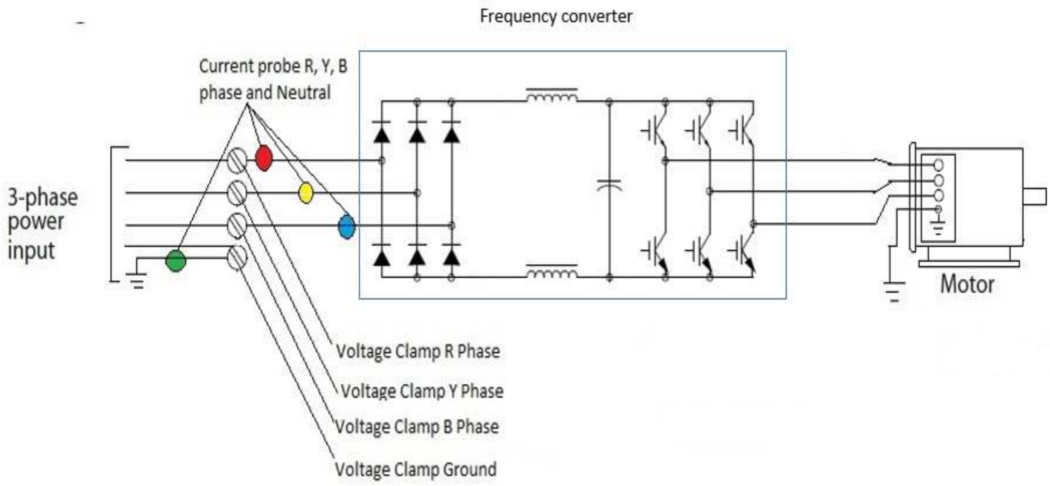

Figure. 2. Circuit diagram of the experimental setup used

Pictorially the test bench setup looks like Figure 3. The various parts are shown and labelled in Fig. 3.

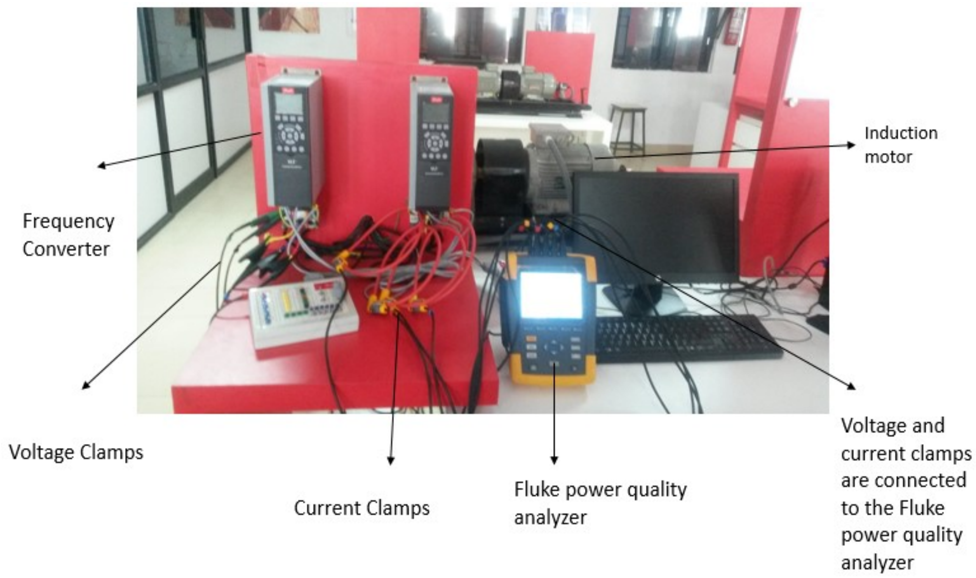

Fig. 3. Pictorial view of the Test Bench

4. Test Procedure and Data Acquisition

The below steps represent the step by step procedure involved in the analysis of frequency converter fed IM. First step is one end of the voltage and current clamps are connected on the input side of the converter and the other end is connected to the fluke meter. Second step is the frequency converter will be initialized and required settings should be done. Third step is the machine should be turned on and loaded. Fourth step is fluke power analyser is turned on and data acquisition has been started and recorded for 5 minutes. Fifth step is data is stored in fluke power analyser SD card. Sixth step is to connect the PC and SD card also connected through PC. Seventh step is to use power log software to use the fluke power analyser to analysis the data. Eighth step is to obtain the data and interfaces to be analysed.

The various PQ parameter’s standard values are given in Table 1.

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Table 1. Standards

S.NO	Parameters	Value
1	Voltage variation	<±10%
2	THD	Voltage (<8%) and current (<5%)
3	Unbalance	<±3%
4	Frequency variation	< ± 0.1%

5. Estimation of Power Quality parameter and comparison of control methods

The various power quality parameters are predicted for the change in loadings with the help of MATLAB curve fitting tool. The different plots are estimated for two control methods namely VVC+ and V/F method which are used for induction motor speed control.

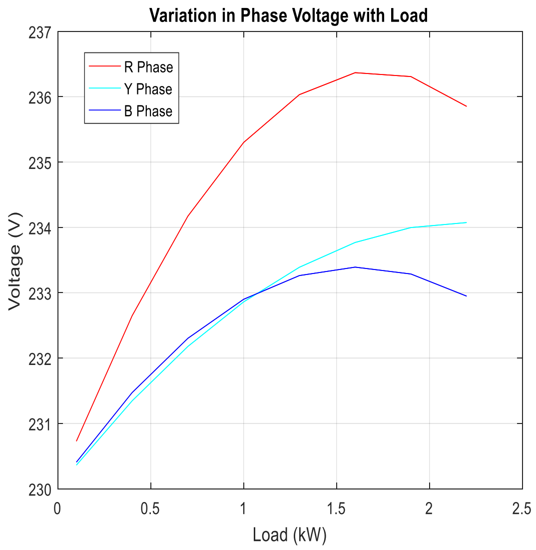


Figure.4 Variation of Phase Voltage (VVC+)

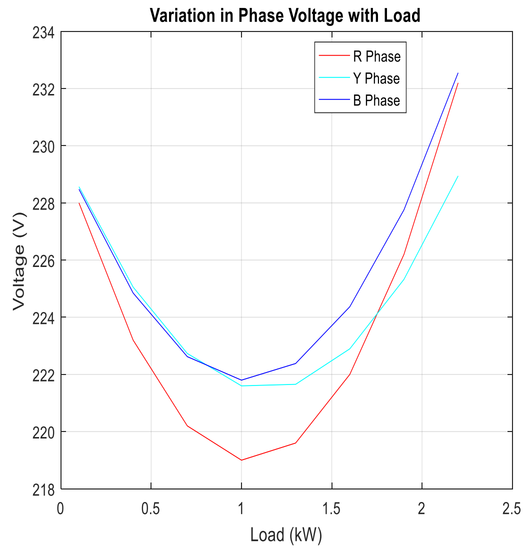


Figure.5 Variation of Phase Voltage (V/F)

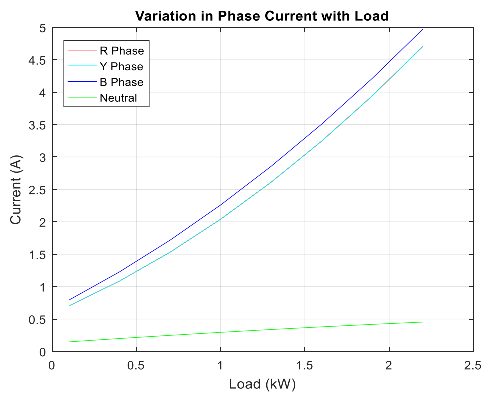


Figure. 6 Variation of Phase Current (VVC+)

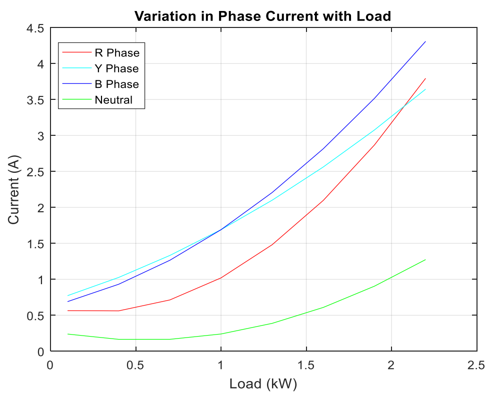


Figure. 7 Variation of Phase Current (V/F)

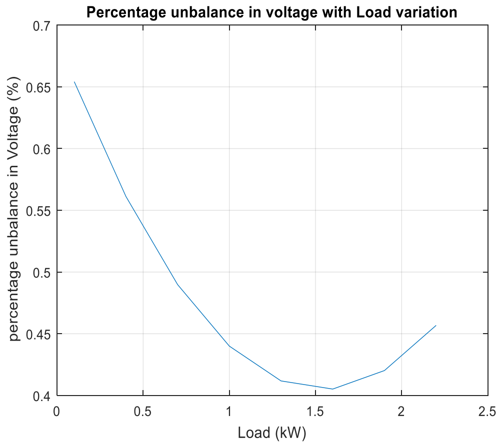


Figure.8 Voltage unbalance v/s load variation (VVC+)

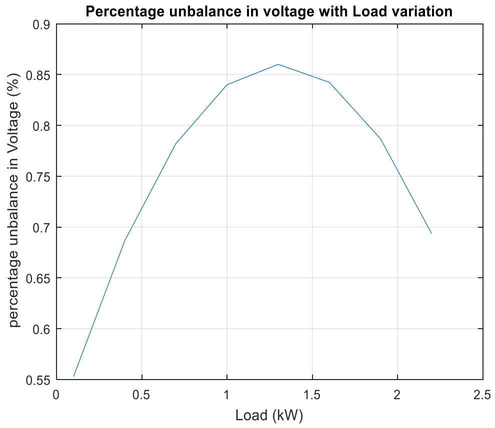


Figure 9 Voltage unbalance v/s load variation (V/F)

5.1. *Phase Voltage*

Using plotting tool of MATLAB, the phase voltage is estimated for VVC+ as shown in Fig. 4 and for V/F as shown in Fig. 5. The voltage increases in the case of VVC+ and decreases in the case of V/F. As the load further increases in the case of VVC+ the voltage comes to a saturation point while in V/F case the voltage increases.

5.2. *Line Current*

Line current variation for VVC+ is shown in Fig. 6 and for V/F is shown in Fig. 7. It can be seen that there is an increase in the value of line current with the increase in the loading for both the cases of VVC+ and V/F respectively. The difference is in the magnitude of neutral current. The neutral current is more with the increase in the loading for the case of V/F as compared to VVC+.

5.3. *Voltage Unbalance*

The unbalance in voltage for the case of VVC+ is shown in Fig. 8 and for the case of V/F is shown in Fig. 9. For the case of VVC+ the unbalance in voltage decreases with the increase in the load while in the case of V/F, the voltage unbalance increases with the increase in the load. After 1.5 kW, the nature changes, for VVC+ the unbalance increases while for V/F the unbalance decreases.

5.4. *Current Unbalance*

Unbalance in current for VVC+ is shown in Fig. 10 and unbalance in current for V/F is shown in fig. 11. It can be seen that with the increase in loading current unbalance for both the cases decreases. For the case of VVC+, the decrease is sudden while for V/F the decrease is gradual. Moreover, for VVC+, when the loading is reaching near the full load, there is an increase in current unbalance.

5.5. *Frequency*

Frequency variation is shown in fig. 12 for VVC+ and for V/F is shown in fig.13. For VVC+, the frequency first increases and then decreases. Similar graph is obtained for V/F also. The difference is that in the case of V/F method, the frequency never jumps below 50 Hz while for the case of VVC+, the frequency comes below 50 Hz with the increase in loading.

5.6. *Active Power*

Fig. 14 and Fig. 15 shows the active power variation for VVC+ and V/F respectively. In both the cases with the increase in loading of the motor the active power requirement increases as shown in fig. 14 and fig. 15.

5.7. Reactive Power

Fig. 16 and Fig. 17 shows the reactive power requirement for VVC+ and V/F control strategies respectively. The reactive power requirement in the case of VVC+ is more as compared to V/F. For same loading in both the cases of VVC+ and V/F, there is less reactive power requirement in the case of V/F which is also the cause of improved power factor in the case of V/F speed control method

5.8. Apparent Power

Apparent power demand for VVC+ and V/F method are shown in fig. 18 and fig. 19 respectively. It can be seen that apparent power is more in the case of VVC+ as compared to V/F.

5.9. Power factor

Power factor for both the control methods are shown in fig. 20 and fig. 21 respectively. It is noticed that power factor profile for V/F method is superior as compared to the VVC+ method.

5.10. Voltage THD

Voltage THD profile is shown in fig. 22 and fig. 23 respectively for VVC+ and V/F speed control methods. It can be seen that the THD in voltage increases in the case of VVC+ with the increase in load while in the case of V/F method, the voltage THD decreases with the increase in load.

5.11. Current THD

Current THD for VVC+ and V/F control methods are shown in fig. 24 and fig. 25 respectively. It can be noticed that current THD are greater in magnitude in the case of V/F method as compared to VVC+. Moreover, neutral current have huge THD in V/F method as compared to VVC+ method. For both the cases with the increase in load, there is an increase in current THD and then there is a decrease with the further increase in load. Only for the case of neutral current in V/F method, there is a increase in THD with an increase in load.

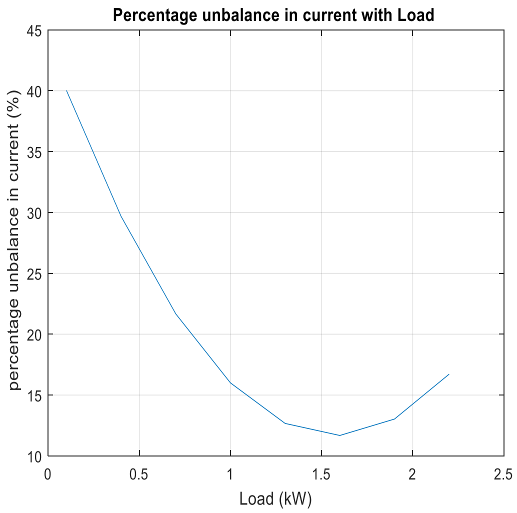


Figure. 10 Current unbalance v/s load variation (VVC+)

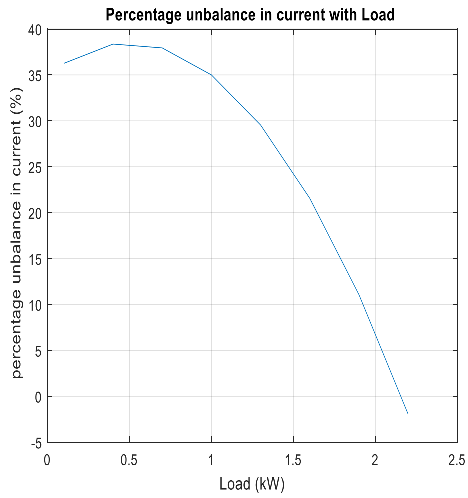


Figure. 11 Current unbalance v/s load variation (V/F)

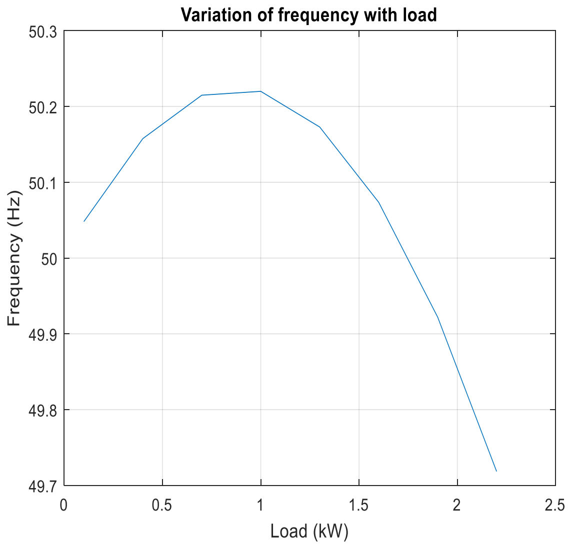


Figure.12 Frequency v/s load variation (VVC+)

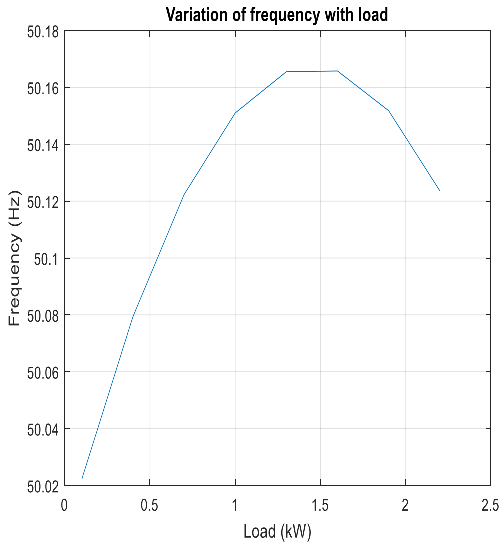


Figure. 13 Frequency v/s load variation (V/F)

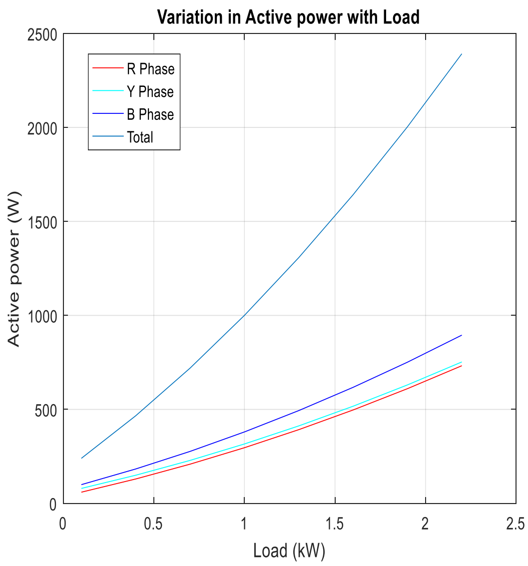


Figure. 14 Active Power v/s load variation (VVC+)

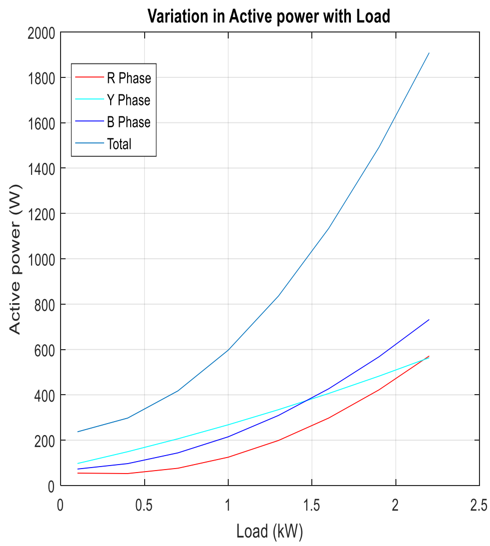


Figure. 15 Active Power v/s load variation (V/F)

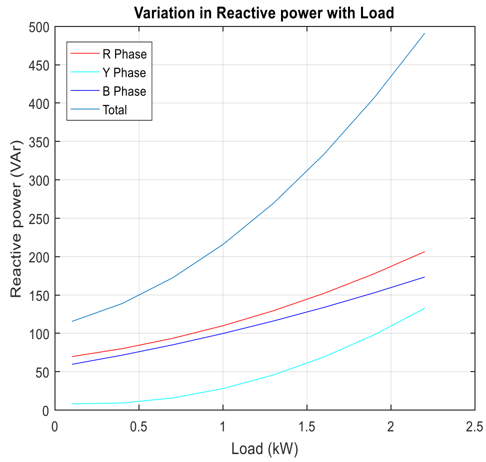


Figure. 16 Reactive power v/s load variation (VVC+)

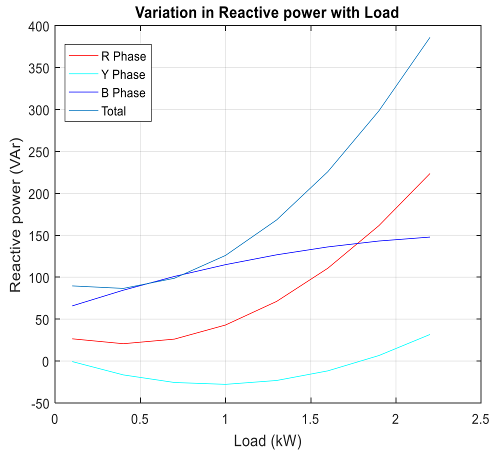


Figure. 17 Reactive power v/s load variation (V/F)

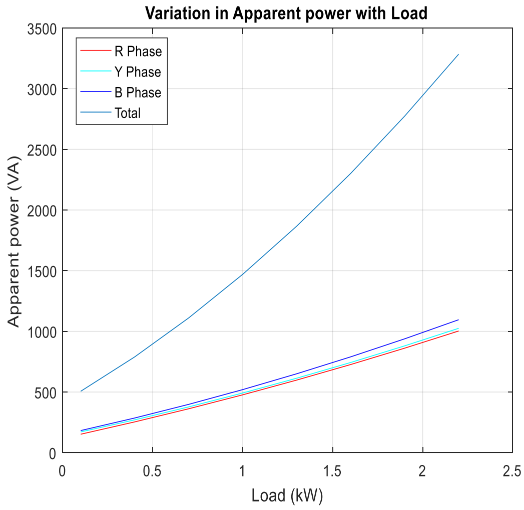


Figure. 18 Apparent power v/s load variation (VVC+)

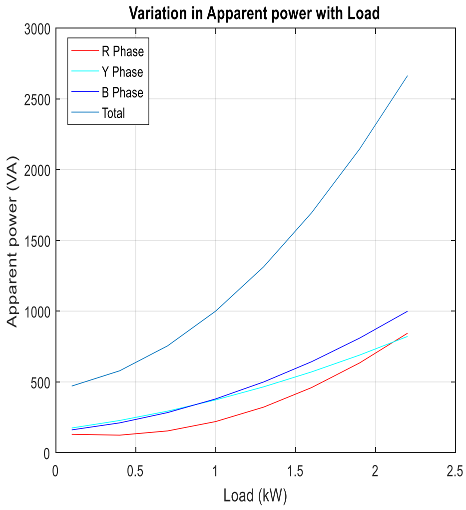


Figure. 19 Apparent power v/s load variation (V/F)

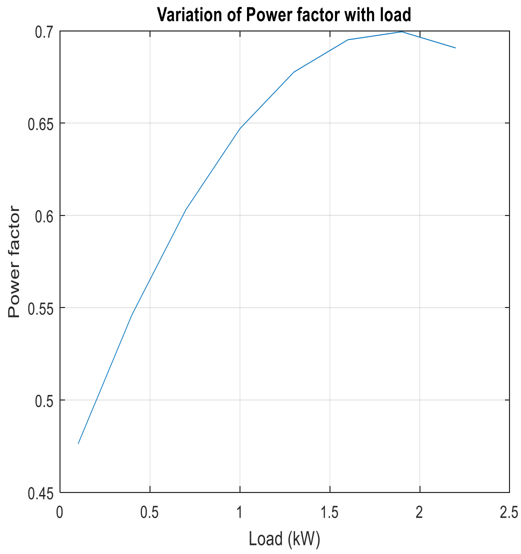


Figure. 20 Power Factor v/s load variation (VVC+)

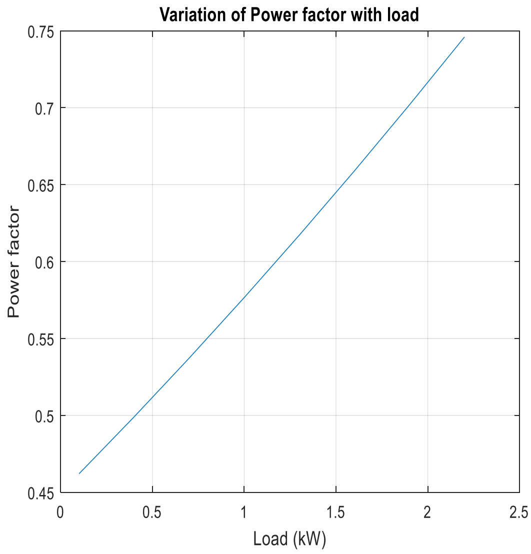


Figure. 21 Power Factor v/s load variation (V/F)

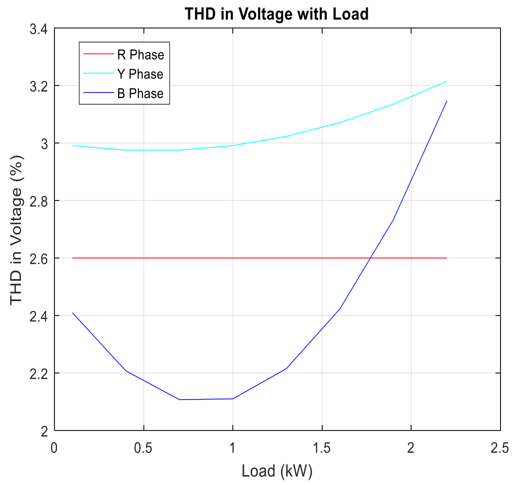


Figure. 22 Voltage THD v/s load variation (VVC+)

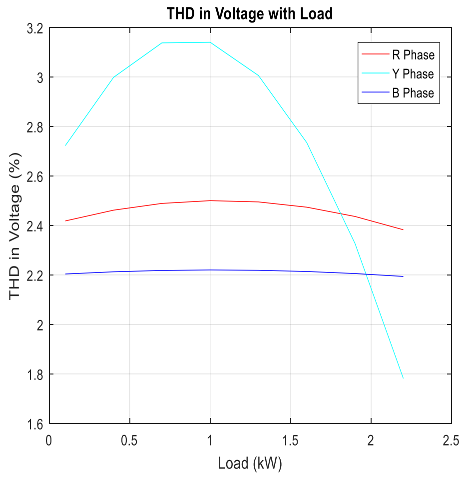


Figure. 23 Voltage THD v/s load variation (V/F)

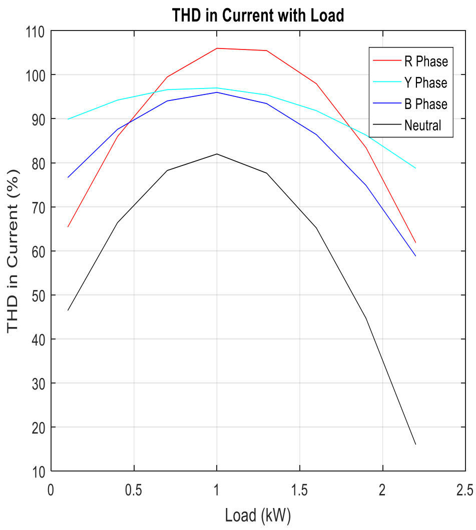


Figure. 24 Current THD v/s load variation (VVC+)

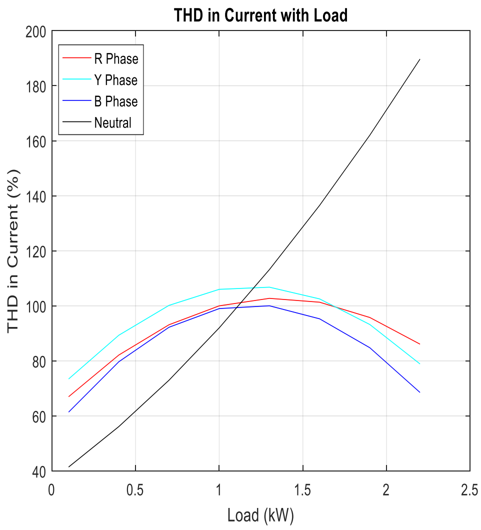


Figure. 25 Current THD v/s load variation (V/F)

6. Individual voltage harmonics

6.1. 5th Harmonic

The 5th harmonic voltage distortion is shown in fig. 26 for VVC+ and in fig. 27 for V/F speed control methods. It can be seen that distortion profile for both the cases is similar except that Y-phase shows a constant nature for VVC+ while in V/F the magnitude varies. Moreover the magnitude of distortion is higher in V/F method.

6.2. 7th harmonic

Voltage distortion for 7th harmonic is shown in fig. 28 for VVC+ and in fig. 29 for V/F. Both the figures shows that with the increase in the loadings the distortion decreases except for Y phase in the case of VVC+ and R phase in the case of V/F.

6.3. 11th Harmonic

For 11th harmonic distortion, the plots are shown in fig. 38 for VVC+ and in fig. 39 for V/F. For both the cases, the distortion profile is same except that the magnitude of the neutral current distortion is higher in the case of V/F control method as compared to VVC+.

6.4. 13th Harmonic

Fig. 40 and fig. 41 shows the distortion profile for 13th harmonic current distortion in the case of VVC+ and V/F respectively. It is found out that the distortion is considerably reduced for both cases. In the case of V/F, the neutral current distortion has higher magnitude.

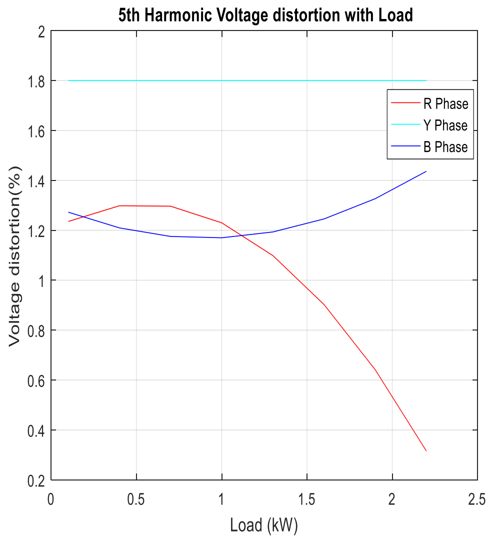


Figure. 26 5th harmonic voltage distortion v/s load variation (VVC+)

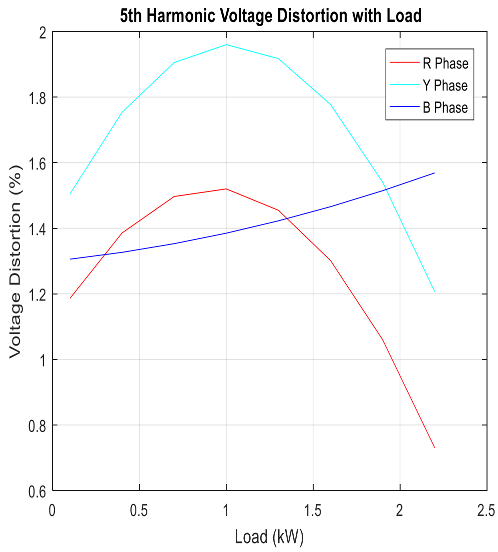


Figure. 27 5th harmonic voltage distortion v/s load variation (V/F)

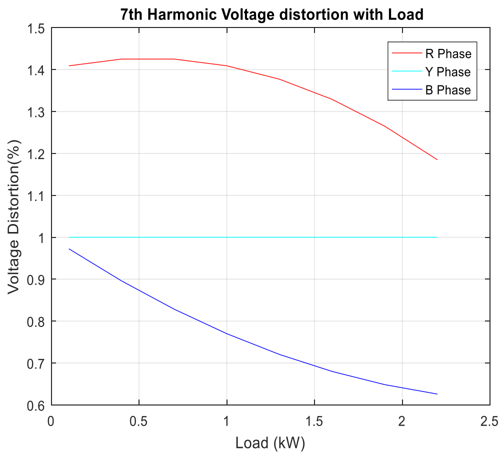


Figure. 28 7th harmonic voltage distortion v/s load variation (VVC+)

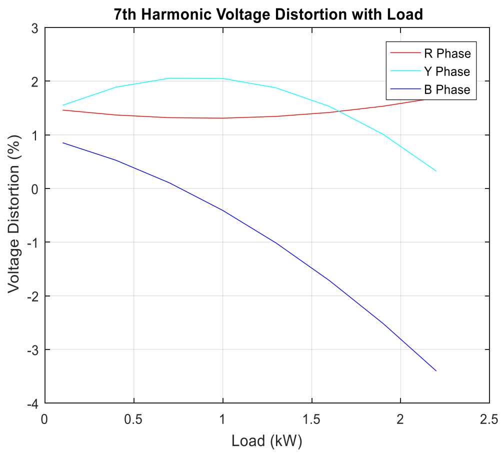
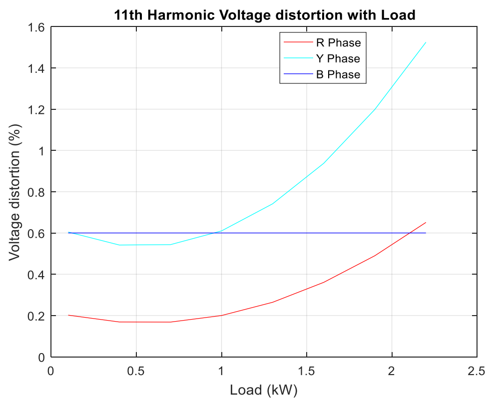


Figure. 29 7th harmonic voltage distortion v/s load variation (V/F)



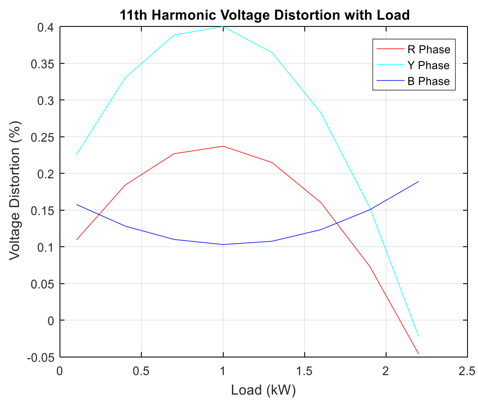


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Figure. 30 11th harmonic voltage distortion v/s load variation (VVC+)

Figure. 31 11th harmonic voltage distortion v/s load variation (V/F)

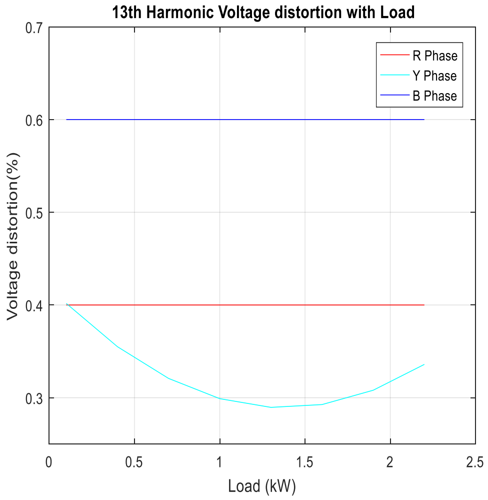

Fig. 32 13th harmonic voltage distortion v/s load variation (VVC+)

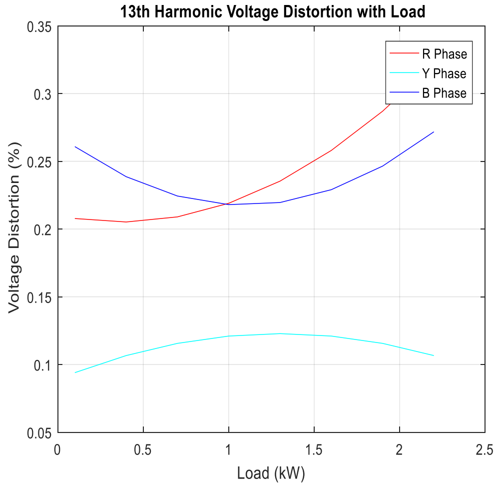

Fig. 33 13th harmonic voltage distortion v/s load variation (V/F)

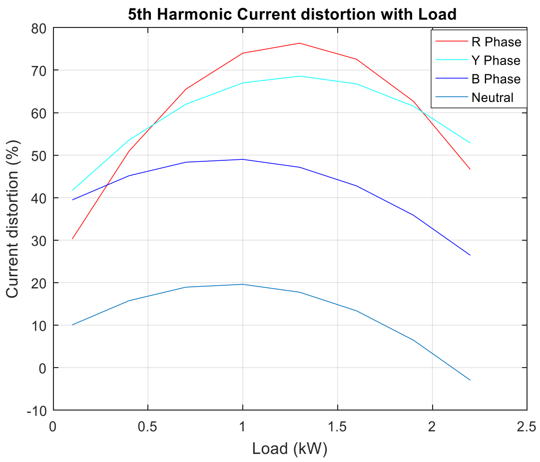

Fig. 34 5th harmonic current distortion v/s load variation (VVC+)

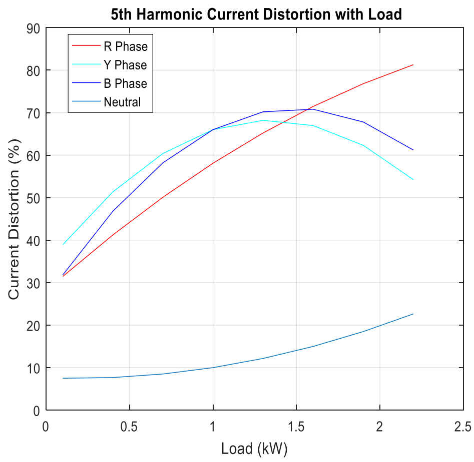

Fig. 35 7th harmonic current distortion v/s load variation (V/F)

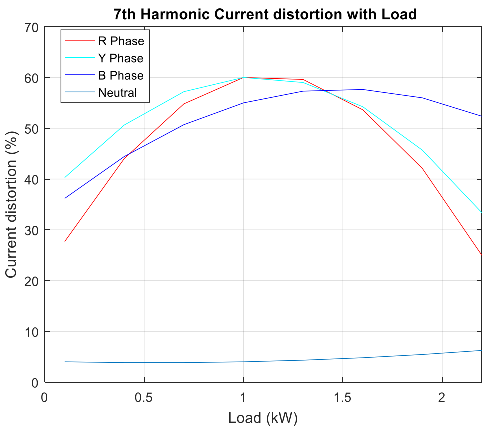

Fig. 36 7th harmonic current distortion v/s load variation (VVC+)

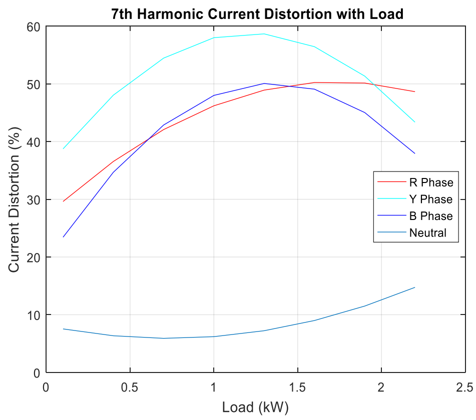

Fig. 37 7th harmonic current distortion v/s load variation (V/F)

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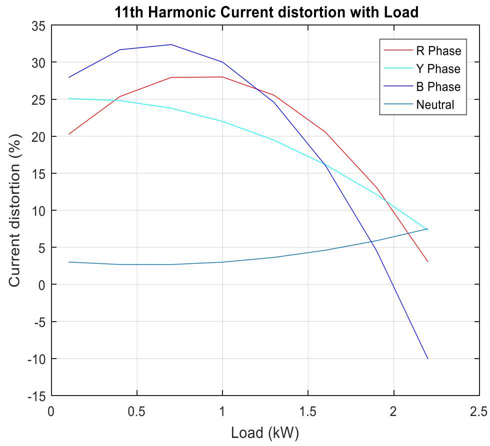

Fig. 38 11th harmonic current distortion v/s load variation (VVC+)

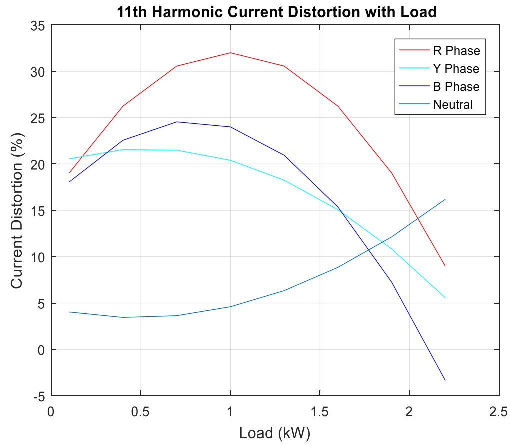

Fig. 39 11th harmonic current distortion v/s load variation (V/F)

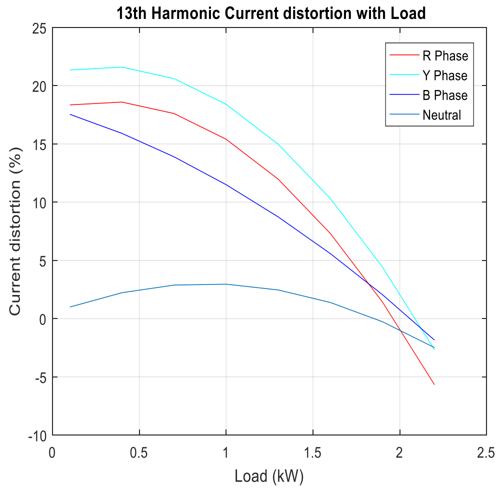

Fig. 40 13th harmonic current distortion v/s load variation (VVC+)

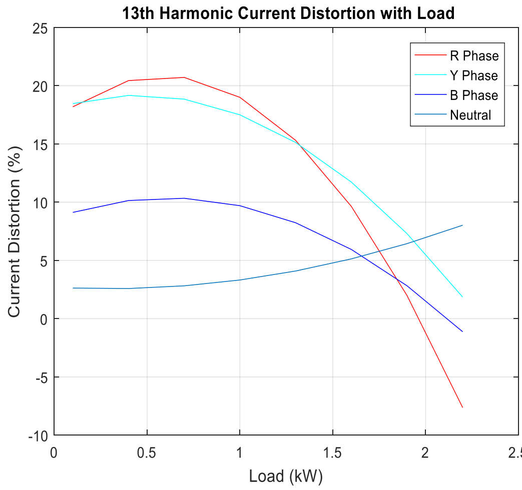

Fig. 41 13th harmonic current distortion v/s load variation (V/F)

7. Comparison Table

The various power quality parameters are tabulated in Table 2 with respect to both the control strategies used for speed control of induction motors. Table 3 and Table 4 shows the various harmonic distortion of voltage and current. The tabulation helps to compare the performance of VFD when fed through different control techniques.

Table 2. Comparison of various PQ parameters for VVC+ and V/F methods

Parameter	**VVC+**	**V/F**	**Comment**
Phase Voltage	Varies between 230V-237V	Varies between 218V-233V	Voltage profile is better in VVC+ as voltage variation is less in VVC+.
Line Current	Varies between 0.75A-5A Neutral current varies between 0.1A-0.5A.	Varies between 0.5A-4.4A Neutral current varies between 0.1A-1.3A	Neutral current is high in the case of V/F. VVC+ is better.
Voltage Unbalance	Varies between 0.4%-0.65%. Decreases with the increase in load.	Varies between 0.55%-0.65% . Increases with the load and then decreases.	Unbalance decreases in the case of VVC+, hence better.
Current Unbalance	Varies between 10%-40%.	Varies between 0.1%-36%. Even comes to lower values at higher loading.	V/F has lower values and is superior.
Frequency	Varies between 49.7Hz-50.22 Hz.	Varies between 50.02 Hz-50.17 Hz.	V/F is superior as the variation is less.
Active Power	Varies between 250W-2400W	Varies between 300W-1900W	
Reactive Power	Varies between 120VAr-490VAr	Varies between 20VAr-380VAr	V/F has less reactive power requirement and hence better.
Apparent Power	Varies between 500VA-3250VA	Varies between 500VA-2700VA	
Power Factor	Varies between 0.475-0.7	Varies between 0.470-0.75	There is a rapid improvement in power factor in case of VVC+, hence better.
Voltage THD	Varies between 2.1%-3.2%	Varies between 1.8%-3.15%.	
Current THD	Varies between 15%-105%	Varies between 40%-190%.	Neutral current THD is much higher in V/F. Thereby VVC+ is superior.

Table 3 Voltage distortion for different harmonics

Harmonic Number	**VVC+**	**V/F**	**Comments**
5	Varies between 0.1%-1.8%	Varies between 0.7%-1.9%	Both are similar
7	Varies between 0.65%-1.43%	Varies between 0.1%-2.1%	V/F has more distortion.
11	Varies between 0.19%-1.5%	Varies between 0.1%-0.37%	VVC+ has more distortion.
13	Varies between 0.25%-0.6%	Varies between 0.1%-0.3%	VVC+ has more distortion.

Table 4 Current distortion for different harmonics

Harmonic number	VVC+	V/F	Comments
5	Line current distortion variation-28%-75% Neutral current distortion variation- 0.1%-20%	Line current distortion variation- 32%-82% Neutral current distortion variation- 8%-22%	Neutral current has more distortion in the case of V/F.
7	Line current distortion variation- 27%-80% Neutral current distortion variation- 0.4%-0.7%	Line current distortion variation- 24%-58% Neutral current distortion variation- 5%-15%	Neutral current distortion is more in V/F.
11	Line current distortion variation-0.1%-33% Neutral current distortion variation- 3%-7%	Line current distortion variation- 0.1%-33% Neutral current distortion variation- 3%-17%	Neutral current distortion is more in V/F/
13	Line current distortion variation- 0.1%-22% Neutral current distortion variation- 0.1%-2.5%	Line current distortion variation-0.1%-22% Neutral current distortion variation- 2%-8%	Neutral current distortion is more in V/F.

8. Conclusion

In this work parameter prediction was carried out using curve fitting tool of MATLAB. Moreover the two control strategies used for the speed control of induction motor are compared. With reference to Table 2 to Table 4 we can draw the following conclusions. The VVC+ was found out to be superior as compared to V/F we talk about overall performance. For the power quality parameters like voltage, current, voltage unbalance, power factor and current THD, VVC+ is more preferred whereas for voltage THD, frequency profile, and unbalance in current V/F is superior. Overall if we consider, VVC+ is more superior as compared to V/F. Phase voltages varies for individual test cases which is obtained from the tabulation. There is variation in different test cases but change in voltage is limited to certain extend shown in table 4. The Y and R phase of voltage is followed by the B phase. The supply voltage is unbalanced due to variations in the phase voltages. When loaded the system voltage is greater than the no load system voltage. Unbalance in system voltage is due to the presence of voltage harmonics and unbalanced three phase supply loading. It can be observed that the percentage unbalance in voltage is getting decreased when the system is loaded. But change in voltage should be in acceptable rate as per table 4. Unbalance in current is because of current harmonics and unbalanced loading which draws unbalanced currents from the supply. If the supply voltage is unbalanced the currents drawn will also be unbalanced. As the load increases the real power required to drive the load increases, so this increase is drawn from the supply. Reactive power drawn to produce flux increases as the load also increases. As the unbalance in voltage and current reduces when machine is loaded which results in increase in system efficiency. The power factor of the machine increases when the machine is loaded which also leads to an increase in efficiency. Apparent power increases, real power increases at a higher rate when compared with reactive power rise. VFD has a rectifier on the front end which draws a non-sinusoidal source current (Current harmonics) which causes voltage harmonics. When induction machine is loaded the current drawn by the rectifier increases so THD of a loaded machine is more than the THD of the machine under no load.

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