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# Performance of a 3 - Phase Induction Motor against Unbalanced Voltage Operation

[1] Yogesh Patni, [2] Nitesh Kumar, [3] Vishal Pansare
[1][2][3] Asst Professor, MET's Institute of Engineering, Adgaon, Nashik

***Abstract*: -- For a 3- ϕ supply arrangement, voltage imbalance occurs when the amplitude and the phase angle in-phase voltage differs from the normal balanced conditions or both. Unbalanced Voltage Factor has its importance when the study of the effect of imbalance of voltage on the behaviour of 3- phase induction motor. Problems like OV and UV, oscillations, increased losses & disturbance in phase angle are the main problem of unbalance voltage factor. Evaluation of this abnormal conditions in the motor has main importance in the Induction machines. In this paper a actual load test to verification of the effect of the balance voltage and unbalanced voltages on the motor performance, have been investigated, including unbalance voltage factor, the importance of the +ve sequence voltage in the motor's apparent performance and importance of the –ve sequence voltage in the motors damage are pointed out. This is strongly recommended that the related regulations, derating factor, and temperature rise curves of the motor should be based on voltage Imbalance factor as well as on magnitude of +ve sequence voltage. In this paper the effect of the balance and unbalanced voltages on the motor performance have been verified just like +ve sequence, -ve sequence and rotor and stator current, speed, electromagnetic torque graphs.**

***Index Terms:* - 3- phase induction motor, voltage unbalance factor, +ve and –ve sequence voltage, power factor, temperature rise.**

## I. INTRODUCTION

Voltage unbalance is combination of under- or over voltage is known as a power quality problem at the electricity distribution level. This phenomenon is present in three-phase electrical power system. If the voltages of all phase are balanced at the transmission levels it may be possible voltages at the utilization level can become unbalanced due to the unequal load impedances, improper transposition of transmission lines, Absence of neutral in three phase star connection, unsymmetrical transformer winding, open delta connection of transformer, larger single or two phase loads, blown fuses on three-phase capacitor banks. Voltage unbalance have an serious impact on induction motor operation. A lot of efforts have been reported in literature the adverse effects on induction motor performance under unbalanced voltage supply condition. The I.M. is the simple and most rugged motor consists of a stator and a rotor. The interaction of currents flowing in the rotor bars and the stators' rotating magnetic field generates a torque. In an induction motor the rotor speed always lags behind the RMF speed, allowing the rotor bars to cut magnetic lines of forces and produce useful torque.

1. Three-phase induction motor: Induction motors are widely used in industrial, commercial and residential systems; once the supply voltage is unbalanced the ill effects on induction motors will cause an enormous impact on utilities, induction motor manufacturers and consumers. In fact, studies concerning three-phase induction motor operation under an unbalanced voltage source could be found since the 1950s. It has been proved that an induction motor operation under unbalanced voltage would lead to efficiency reduction. Further studies conducted on concerning temperature rise of induction motors under unbalanced voltage. Unbalanced voltage can cause extra temperature rise in an induction motor, which is likely to shorten the machine's life. Research in this field has mostly focused on the protection strategies. For instance, most of the study provided methods to protect induction motors from unbalanced voltages. For overall performance of induction motor, the following several important issues are considered. (1) quantitative evaluation of the impact of positive-sequence and negative sequence voltages on the motor's efficiency, power factor, and temperature rise, (2) the effects of voltage unbalance on the motor's load characteristics or real and reactive power consumption, (3) the adequacy and adoptability of regulations of unbalanced voltages, (4) the adequacy and adoptability of temperature rise and derating factor curves under unbalanced voltage conditions, and (5) the effects of over-voltage unbalance. An over-voltage unbalance is defined as unbalance due to the positive-sequence voltage higher than the rated value. Most research, including that conducted by EPRI research, focuses on the voltage unbalance caused by under-voltages. However, in several countries, over-voltage may occur in off-peak periods. These issues are discussed in this paper

**2. Definitions and comparisons of voltage umbalance: There are three definitions of voltage unbalance**:

(1) The line voltage unbalance rate (LVUR) as defined by National Electrical Manufactures Association (NEMA):

LVUR=(maximum voltage deviation from average line voltage magnitude)/(average line voltage magnitude)

 

$$LVUR = \frac{\text{Max}[[\text{Vab} - \text{Vavg}].[\text{Vbc} - \text{Vavg}].[\text{Vca} - \text{Vavg}]}{\text{Vavg}} x\ 100\ \%$$

Where $\text{Vavg} = \frac{\text{Vab+vbc+Vca}}{3}$

**(2)The phase voltage unbalance rate (PVUR) as defined in IEEE Std 141,**

$$\text{PVUR} = \frac{\text{maximum voltage deviation from average phase voltage magnitude}}{\text{average phase voltage magnitude}}$$

$$\text{LVUR} = \frac{\text{Max}[[\text{Va} - \text{Vavg}].[\text{Vb} - \text{Vavg}].[\text{Vc} - \text{Vavg}]}{\text{Vavg}} x100\ \%$$

**(3) Voltage unbalance factor: VUF is defined as the ratio of the negative-sequence voltage component to the positive-sequence voltage component [6],**

$$\text{VUF}(\%) = \frac{\text{negative sequence voltage component}}{\text{positive sequence voltage component}}$$

3. Effects on a three-phase induction motor in eight voltage unbalance cases with the same VUF: In order to study how the unbalance conditions in a real power system affect a three-phase induction motor and the importance of the sequence voltage components, a 3HP,3 induction motor is selected to take real tests with the same VUF and rated output. In addition to the supplied three-phase voltages and their positive- and negative-sequence components, including efficiency, power factor, loss increase rate (LsIR) and load increase rate (LdIR) of the 3 Hp, 3 ,induction motor. With the same VUF, the changes in the positive-sequence voltage components and the changes in the negative-sequence voltage. Under the same VUF condition, we know the status of voltage unbalance from the magnitude of positive sequence voltage. Therefore, the component of the positive sequence voltage plays an important role in the voltage unbalance analysis. It is found that with the same VUF, (1) a higher positive-sequence voltage gives a higher motor efficiency and a lower power factor, and (2) among the cases studied, the motor efficiency varies from 80.532% to 83.584% for VUF= 4% and from 79.673% to 82.494% for VUF= 6%, and the power factor vanes from 85.3% to 80.8% for VUF = 4% and from 85.4% to 79.4% for VUF= 6%. In terms of energy consumption, a lower induction motor efficiency leads to a higher electricity energy loss. From a customer’s viewpoint, the efficiency reduction of an induction motor due to supply voltage unbalance results in a higher electricity charge for the same work done. So far as utility is concerned, the efficiency reduction leads to an increase in the total load and a decrease in the spinning reserve of the total generators.

4. Effects of single phase under-voltage unbalance: Three-phase voltages and positive- and negative-sequence voltages, power factor and efficiency of the 3HP, 3 induction motor with single phase under-voltage unbalance and rated output power. For the cases, higher VUF yields lower efficiency and higher power factor. In general, customers know that in a supply voltage unbalance, the operating characteristics of a three-phase induction motor will not be as good as in the balanced case, but most customers do not know that the unbalance may cause a higher power factor.

5. The effects of negative-sequence voltage components on an induction motor : The negative-sequence voltage component also has contributions to the effects of unbalance on a motor's performance. In order to distinguish the effects of the negative-sequence voltage from those of positive-sequence voltage, the positive-sequence voltage of the supplied three phase voltage was fixed at V1=127 V and the negative sequence voltage was adjusted so that the VUF varied from 1% to 7%. It can be seen that the maximum changes in efficiency and power factor are 1.84% and 0.48% respectively. The negative-sequence voltage component has little effect on the power factor. In other words, the power factor of an induction motor is mainly affected by the positive-sequence voltage component.

Here Performance of three-phase induction motor under balanced and unbalanced voltage supply is done using Simulink. Simulink is the extremely powerful tool of MATLAB. The phase currents, the deliverable power to the motor, stator current and efficiency of the motor are propose. In order to analyze the performance of a three phase induction motor, symmetrical components analysis is must be use. In this method, positive and negative sequence components are used for analysis of three phase induction motor.

Balanced Case: In this part we examine balanced operating condition.In normal condition, motor was supplied by its rated voltage which is 220 volts peak for each phase. The voltages applied as follows: V=220 00 & Simulation results are shown as in figure:

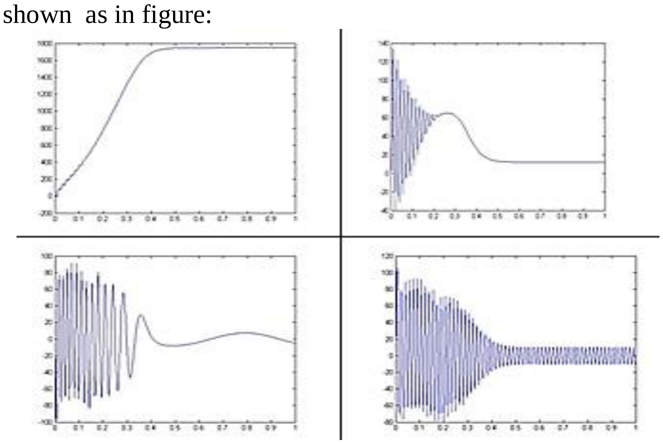

***Figure1:Rotor & Stator Current, Speed & Electromag. Torque Te(N-m) against Time t sec***

 

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Here unbalance in the phase and the magnitude of the voltage has been considered. In order to model the electrical motor symmetrical components can be used. Unbalance in the Magnitude of Voltage : Here the unbalance in magnitude of the voltage has been considered. In order to model the electrical motor symmetrical components can be used. A wide variety of research has done on modeling of unbalanced condition.

**Unbalanced Case :**
1. Unbalanced in the Voltage Magnitude :
Va=230 00 , Vb=231 2400, Vc=235 1200
Positive sequence voltage: 232 V,
Negative sequence voltage= 1.5275

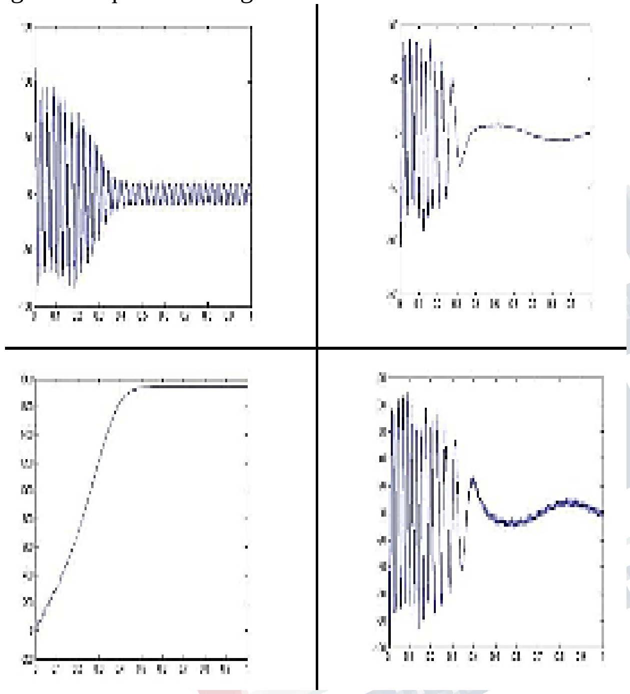

***Figure2: Rotor & Stator Current, Speed & Electromag.Torque Te (N-m) against Time t***

Case 2: In this case an unbalance of 10% of rated voltage is assumed for phase B & C voltages resp. So, the value of the voltages for phases A, B & C would be:

Va $= 230\angle\ 0$,
Vb $= 230*0.90\angle -120$, Vc $= 230*0.90\angle -240$, F =60 Hz , P= 3 HP, Ns= 1725 rpm
Positive sequence voltage = 214.6667
Negative sequence voltage = 7.6667

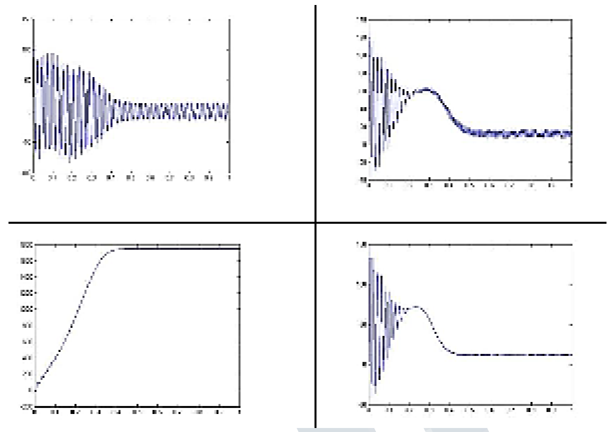

Figure 3: Rotor & Stator Current, Speed & Electromag Torque Te (N-m) against Time t sec

**Case3:**
**Unbalance in the Voltage Magnitude Case -2:**
Va $= 230\angle\ 0$,Vb $= 230*0.90\angle -120$,
Vc $= 230*0.80\angle -240$ F=60 Hz ,
P= 3 HP, Ns= 1725 rpm
Positive sequence voltage = 207 V,
Negative sequence voltage= 13.2791

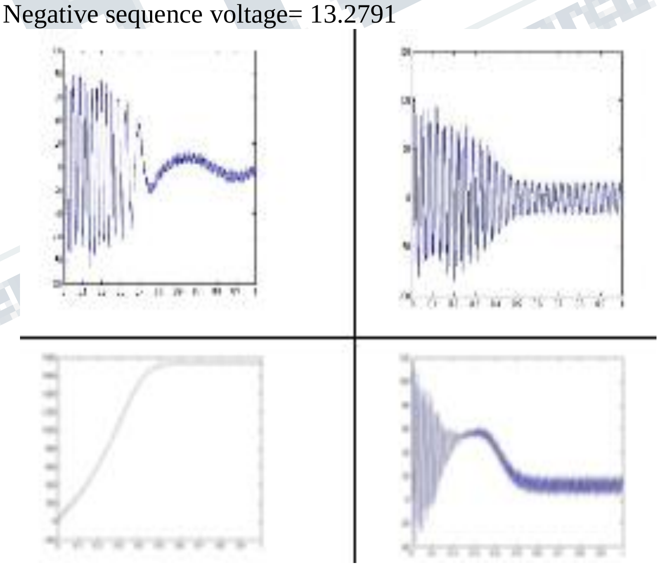

***Figure 4: Rotor & Stator Current, Speed & Electromag.Torque Te (N-m) against Time t sec***

Unbalance in the Voltage Magnitude and Phase

Va $= 230\angle\ 0$, Vb $= 230*0.90\angle\ 216$

Vc $= 230*0.90\angle\ 132$, F =60 Hz

P= 3 HP, Ns= 1725 rpm.

P= 3 HP, Ns= 1725 rpm.
Positive sequence voltage = 207.6472 , Negative sequence voltage= 48.2254

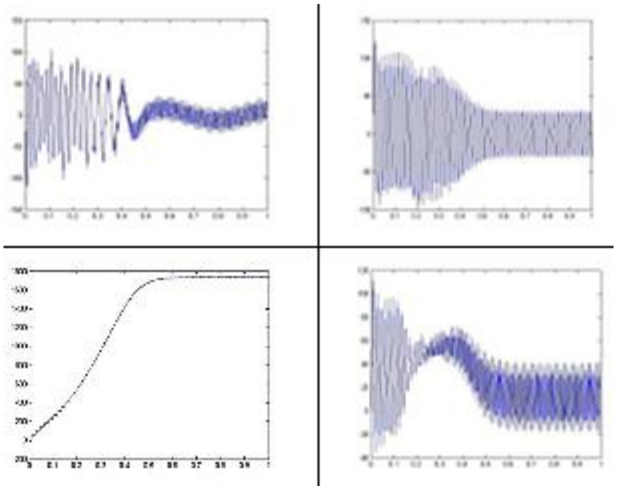

*Figure 5: Rotor & Stator Current, Speed & Electromag. Torque Te (N-m) against Time t*

## VII. CONCLUSION

Regarding the effects of a supply voltage unbalance on a three-phase induction motor, We have concluded that three-phase induction motor if operating on unbalance voltage degrades the performance and shortens the life of a three-phase motor. Performance also depends on negative- and the positive-sequence voltages. A higher positive-sequence voltage will lead to a higher motor efficiency and a lower power factor. Voltage unbalance will lead to an extra temperature rise in the motor and shorten the life span of the motor. According to the results, an under-voltage unbalance usually causes the worst temperature rise. By increasing the unbalance voltage, the maximum amplitude of the current and torque are notably increased. It is known that voltage unbalance causes extra loads to the utilities and additional charges to consumers for same on balanced supply. A given value of VUF may correspond to different voltage unbalance cases yielding different temperature rises. It is strongly suggested that the derating curve and temperature rise curve should take the positive sequence voltage into consideration to improve reliability and safe operation of an induction motor. Voltage unbalance causes extra loads to utilities and additional charges to consumers. Therefore, reducing system unbalance to decrease system loads and release the capacities of the power system is important, especially for a power system with little spinning reserve. Besides, the extra electricity charges and machinery damage caused by voltage unbalance often result in arguments between consumers and utilities.

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