# Effects of Distribution Network Unbalance Voltage Types in Respect to Identical Unbalance Factor on the Induction Motors

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### Abstract

**The induction motors are extensively used in the industry because of their simplicity reason of economical technical preferences in residental , commercial and Industrial systems. The unbalance voltage conditions has been taken into consideration by electrical engineers for studing power quality. Exessively growing warm for rotors and stators, defect of shok entropy armature and insulation sa well as damaged bearings, remarkable power defect , unbalance of current of line and lower outcome resulted from the negative effectives of the voltage unbalance. In this paper , speed, torque copper losses are to be analysed under the condition of six types of voltage equilibrium by three voltage unbalance factor, a type of three-phase induction motor, thru simulation and practical test.**

## 1. Introduction

Untransposed power lines, unbalance loads, V connection transformers, burnt fuses in capacitor banks etc. result in power system unbalance. This problem worries the electric producer companies. Even by a small unbalance voltage in electric power lines, it produces unbalance currents in the electric power lines. Actually the induction motors are used widely in industry. A small unbalance voltage causes non economical operation of electric motors [1-7]. If the unbalance among the three-phase voltage becomes excessively it will cause to increase the positive sequence amplitude than the nominative voltage of motor. In the excessive unbalance voltage, the positive sequence will be the nominative voltage. In the literatures the most studies have been concentrated on the under voltage unbalance, while, in non-peak hours, the over voltage unbalance take place. Unbalance Voltage factor is expressed in terms of the negative voltage sequence verses positive voltage sequence [11]. Most of voltage regulators (of unbalance voltage) devices, consider only the voltage unbalance factor (VUF), regardless of its origin. For example the standard BS-4999 [8], limits the VUF of electrical motors to 2%. The standard MGI 12.45-1987, NEMA proposes maximum 5-percent-high over voltage unbalance. Practically there is a lot of voltage unbalance cases with the same VUF. VUF solely is not able to predict the voltage unbalance case.

In this paper the unbalance voltage cases with the same VUF for induction motors are introduced and their effects on rotor speed, torque and copper losses of the motor will be investigated. It will be shown by simulation results that, there is six different unbalance cases for every VUF that their effects on the IM are different. By a simple experimental set-up we have verified the simulation results.

## 2. Induction machine equivalent circuit in the unbalance conditions

In this case the equivalent circuit consists of two sequence circuits, connecting in parallel.

The positive sequence circuit behavior is the same as the balance voltage operation. The negative sequence current generates an inverse electromagnetic field. If the rotor slip in the positive sequence is shown by s, it will be 2-s in the negative sequence circuit. The positive and negative sequence equivalent circuits of IM have been shown in figures 1 and 2 [9]. The motor behavior will be determined by composition of both equivalent circuits, one with electromagnetic field rotating with slip s and terminal voltage *Vp* and the other one with electromagnetic field rotating with slip (2-s) and terminal voltage *Vn*.

## 3. Effect of unbalance voltage on the induction motor

There are difference cases of unbalance voltages with the same VUF factor. In this paper, 6 different unbalance cases are discussed as follows:

Balance case (0): in this case, each three phases are equal and hold 120 degree of phase difference.

Unbalance case (1): the unbalance voltage will be caused by increasing one of the phases $(1\Phi - OV)$. The capacitors usually are applied for compensation of the system reactive power. If one of the three phase voltage is excessively compensated for retaining the power network voltage, the voltage of this phase will become greater than the nominated level. This causes an unbalance voltage by increasing the voltage of one the phases.

Unbalance case (2): the unbalance voltage will be caused by increasing two phases $(2\Phi - OV)$. If two phases of the three phases may be excessively compensated, the voltages of these two phases will become more than the nominal level. This causes to reveal the unbalance in the two phase voltage system.

Unbalance case (3): the unbalance voltage will be caused by increasing all three phases $(3\Phi - OV)$. If the three phase voltages be excessively compensated differently, then the voltages of every 3phases will be greater than the nominal level. This occurs when a plant will be stopped, but their capacitors are in the circuit.

Unbalance case (4): unbalance is in the effective of voltage decrease of one of the phases $(1\Phi - UV)$. This occurs while existing a one-phase great load not being an enough compensator in the power system. In this case, the voltage domain of that phase is less than the other two phases unbalance case (5): the unbalance is in the effect of different two phase voltage decrease $(2\Phi - UV)$. This occurs while existing two expensive loads on two phases and a non – existence compensator in the power system.

Unbalance case (6): unbalance is in the effect of voltage decrease of every 3 phases $(3\Phi - UV)$ . This occurs in the effect of a very expensive and unbalance load of every 3 phases. The quantitative factor of voltage unbalance is defined in the different standards as following [10]. According to standard NEMA, the line voltage unbalance rate is defined as following:

$$\%LVUR = \frac{\begin{matrix} Max\ voltage\ deviation \\ from\ \ avg.\ line\ voltage \end{matrix}}{Avg\ .line\ voltage} * 100 \quad (1)$$

According to standard IEEE, the phase voltage unbalance rate is defined as following:

$$\%\ PVUR\ = \frac{\begin{matrix} Max\ \ .voltage\ \ deviation \\ from\ \ \ avg\ .\ \ phasevolta\ ge \end{matrix}}{Avg\ .\ \ phase\ \ \ voltage} * 100 \quad (2)$$

In the unbalance conditions, both negative as well as positive sequence voltages produce the balance current – as in front – in the induction motor and the composition of two sets of the current vectors, demonstrating the real currents in every 3 stator phases by the main unbalance voltage. The behavior of the machine in front of the positive sequence voltage is basically similar to the balance operation: the motor output power is calculated as following in the unbalance feed conditions:

$$P_m = I_p^2 r_2 \frac{(1-s)}{s} - I_n^2 r_2 \frac{(1-s)}{(2-s)} \quad (3)$$

Ip is the positive sequence current
In is the negative sequence current
The output power decrease is in the reason of the negative sequence current. The electromagnetic torque is obtained of the following equation:

$$T = r_2 \left[ \frac{I_p^2}{s} - \frac{I_n^2}{(2-s)} \right] / \omega_{syn.} \quad (4)$$

Mentioning that, the output torque decrease in the reason of the vector current, is negative. The negative and positive sequence currents are as relatives of their successive voltages – the parameters of motor and slip's', therefore by using the following given equations, the currents Ip and In are obtained using the in-front successive voltages, parameters of motor and slip's'.

$$I_p = \frac{V_p}{\sqrt{\left\{ \left[ r_1 + (r_2'/s) \right]^2 + (x_1 + x_2')^2 \right\}}} \quad (5)$$

$$I_n = \frac{V_n}{\sqrt{\left\{ \left[ r_1 + r_2'/(2-s) \right]^2 + (x_1 + x_2')^2 \right\}}} \quad (6)$$

By using the equivalent circuits, the curve of speed-torque, the negative and positive components, is as the figure 3. the above curve, is the positive sequence torque. The positive sequence torque is as a under- work motor torque with a similar balance source. The rotating field based on the negative currents, exist a negative torque with a peak in the third zone. Therefore, in the unbalance conditions, the machine productive torque is lessered a level of the balanced state productive torque , the motor will last more time for run up.

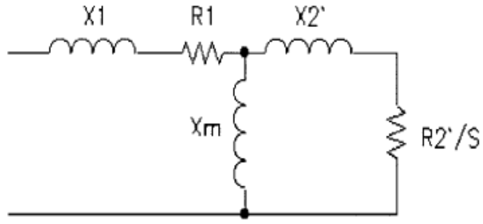


**Fig. 1:**positive sequence equivalent circuit

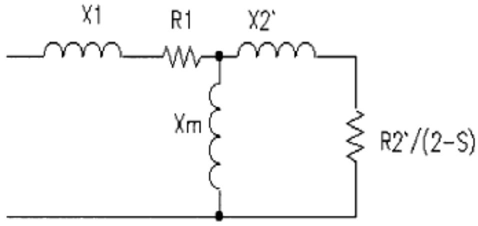


**Fig.2:** negative sequence equivalent circuit

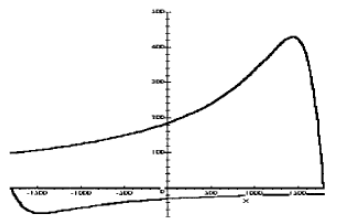

**Fig.3:** induction motor negative and positive torque

## 4. simulation results

In this section, the effect of voltage unbalance on speed , torque and copper loss of induction motor is demonstrated. Simulation has been performed by MATLAB software.
The studied motor characteristics are 50 Hz, 400v, 15Kw and 1460 rpm. The results are obtained according to figures 4 to 8 for speed, torque and copper losses. The horizontal axis of all figures, expresses the case number of unbalance voltage. The rows 1 to 3 of the horizontal axis is related to increasing of the voltage unbalance case and the rows 4 to 6 express the voltage decrease. It can be seen from figure 4 that the rotor speed increases by increasing the voltage unbalance cases and decreases by decreasing them.
The figure 5 shows the torque variations of induction motor. According to the this figure, the torque increases than the balance case, and in the increase voltage unbalance cases and decrease in the decrease voltage unbalance cases.
Figures 6 to 8 show the copper losses of motors in the different unbalance voltage cases. As the above figures show, the copper losses of induction motor increases in all unbalance cases than

the balance cases. By increasing the voltage unbalance factor, the copper losses will increase. In all unbalance cases (cases 1 to 6), by increasing the unbalance phases, the copper losses increase as well, but it will be more increase than the copper losses increase. In the unbalance case, the motor 3-phase currents are excessively non-monotonous and sometimes are greater than the nominative level (figure 9), further; the addition of voltages losses to the stator armature insulation cause to decrease the motor age. In voltage unbalance conditions, the motor speed, vibrates in addition to deviation from the nominative level(figure10).


**Fig.4:** speed in the different unbalance condition

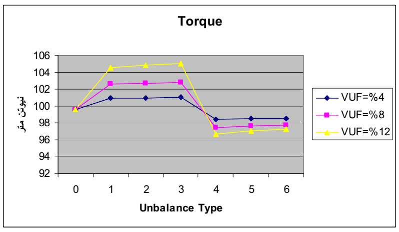


**Fig.5:** torque in the different unbalance condition

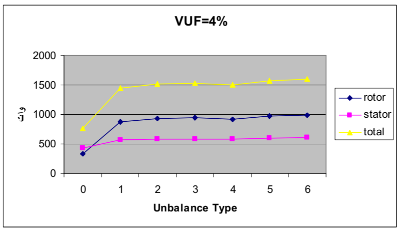


**Fig. 6:** copper losses in unbalance voltage condition with VUF=4%

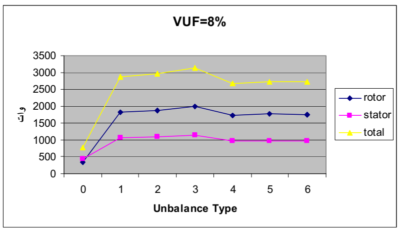


**Fig.7:** copper losses in unbalance voltage condition with VUF=8%

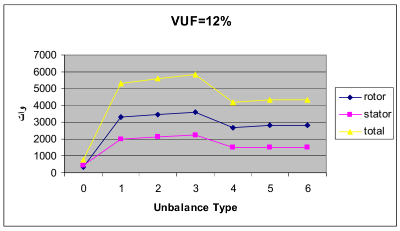


**Fig. 8:** copper losses in unbalance voltage condition with VUF=12%

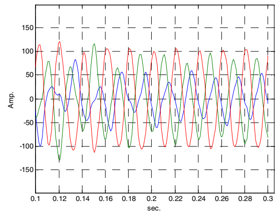


**Fig. 9:** stator current in the unbalance voltage (No.3) with VUF=12%

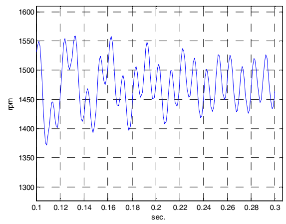


**Fig.10:** motor speed in the unbalance voltage (No.3) with VUF=12%

## 5. experimental test results

In order to evaluating the similation results, a laboratorial set including a 3-phase 120w, 380v, 50Hz, 1320rpm induction motor determined with an electromagnetic brake (as a mechanical load), a 3-phase power supply and measuring devices were used (figure 11).

Induction motor were fed by six introduced unbalance voltage cases and the its copper losses were measured. Figure 12 shows the 3-phase induction motor copper losses for experimental test with different voltage unbalance conditions. The practical test results confirm by comparing the figure 12 with figures 6, 7 and 8 (simulation results).

Fig.11: induction motor and applied practical test equipment

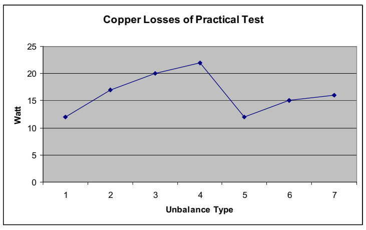


**Fig. 12 :** copper losses of practical test

## 6 Conclusion

The voltage unbalance case causes to deviate the speed and torque of motor from the nominal levels and also, causes to increase of motor's copper losses. In addition to the negative sequence of voltage, the positive sequence of voltage also should be considersd for analysing the voltage unbalance effects on the operation of induction motor. The different voltage unbalance cases with the similar VUF results different copper losses. The increasing of voltage unbalance factor cause to more copper losses. The copper losses are listed from the worst voltage unbalance case as follow: $(2\Phi - OV), (3\Phi - OV), (3\Phi - UV),$ $(2\Phi - UV), (1\Phi - UV), (1\Phi - OV),$

At least, there are 6 voltage unbalance cases by the similar VUF, therefore it is proposed that, the positive voltage sequence is to be used for determining the genuine conditions of the systems. In investigation of the unbalance voltage effects, in addition to the VUF, the positive voltage sequence should be used. Clearly, only using the percent VUF is not careful for estimating the unbalance voltage problems. The positive voltage sequence must be considered in analysing the voltage unbalance problems.

## 7. References

[1] Linders, J.R."Effects of power supply variations on AC motor characteristics, "IEEE Trans. Ind. Applicant, vol. IA-8, no.4, Jul/Aug 1972, pp.383-400

[2] Keresting, W.H. and Philips, W.H."Phase frame analysis of the effects of voltage unbalance on induction machines" IEEE Trans. Ind. Applicant, vol. 33 , vol.2, Mar/Apr 1997 , pp.415-420.

[3]Wallace,A.K., Jouanne, A.R.Von, Wiedenbrug, E.I., Andrews, P.S., Wohlgemuth,C.W., Douglass, J. and Wainwright, G." The measured effects of under-voltage, over voltage and unbalanced voltage on the efficiency and power factor of induction motors over wide ranges of load" Intl. conf. Electrical Machines and Drives, 1-3 Sept. 1997, pp.258-262

[4] Lee,C.Y.,Chin, B.W., Lee,W.J. and Hsu, Y.F. "Effects of various unbalanced voltages on the operation performance of an induction motor under the same voltage unbalance factor condition,"IEEE Conf. Industrial and Commercial Power Systems Technical Conference, 11-16 May 1997, pp.51-59.

[5] Lee,C.Y. " Effects of unbalanced voltage on the operation performance of a three-phase induction motor" IEEE Trans. Energy Conversion, vol.14 , vol.2 , pp.202-208 , Jun.1999.

[6] Wang , Y.J. "Analysis of effects of three-phase voltage unbalance on induction motors with emphais on the angle of the complex voltage unbalance factor," IEEE Trans. Energy Conversion , vol.16 , pp.270-275 , Sep 2001

[7] Kersting, W.H."Causes and effects of unbalanced voltages serving an induction motor," IEEE Trans. Ind. Applicant., vol.37 , no.1, pp.165-170, Jan/Feb.2001.

[8] British standard BS-4999 "General Requirments for Rotating Electrical Machines".

[9] NEMA Standard MGI 12.45-1987,"Voltage Unbalance".

[10]c.thanga raj promid agarwal, s.p.srivastava, "performance analysis of a three phase squirrel induction motor under unbalanced supply voltages", 2006 IEEE conf. on power quality

[11]jawad faiz, h.ebrahimpour, "precise derating of three phase induction motors with unbalanced voltage",IAS,pp.485-491,2005