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MATHEMATICAL AND SIMULATION ANALYSIS OF THE EFFECT OF UNBALANCED VOLTAGES ON THREE PHASE INDUCTION MOTOR

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Abstract

The main aim of this paper is to evaluate the impacts on the running of a 3-ǾIM motor (3-PIM) running under an unbalanced input voltage. Study of unbalance supply conditions is very much required as this variable speed drive consumes most of the energy of the total power generated. Under eight different voltage unbalance conditions, the performance of three phase induction motor be calculated through MATLAB Simulink Model. Results of balanced voltage are used as a tool to analyze and compare the effects obtained by unbalanced voltages. The rotor current and their transient behavior were investigated during different unbalanced conditions. Total harmonic distortion has been calculated with MATLAB Simulink and results has been compared between various unbalanced supply conditions.

1. Introduction

A three phase induction motors is the most vital part of an assembly line in industry. Due to their various inconstant properties like no additional device required to start, simple in design, toughened composition, simple

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maintenance, cheap and precise accuracy it is commonly employed in electrical system. Its role in industry improved after the development of adjustable speed drives and its integration in energy conversion. There are many types of power quality disturbances occur in electrical system like voltage unbalance, harmonics and sag etc. Because of all of these disturbances study of voltage unbalance is more important in induction motor because of its extensive use. Abnormal supply conditions can be Over Voltage, Under Voltage, and Single Phasing and distributed levels of THD between the phases. Other factors also lead to unbalance voltage in power system including unbalanced loads, incomplete transposition of transmission lines, unsymmetrical transformer connections like open-Y, open delta transformer connections, blown fuses on three phase capacitor banks etc. Voltage unbalance is defined as the variation of voltage magnitude in three phases or the deviation in angle i.e. they are not 120° apart or both the situations can occur. The proposed paper introduces the different causes of abnormal voltage supply conditions in system and it's bad results on IM performance. The set up of a squirrel cage IM has been simulated on established MATLAB Simulink software. The results are simulated for different feasible samples of abnormal supply condition.

2. Interpretations of Voltage Unbalance

Main two interpretations are useful for calculation of abnormal voltage.

The first interpretation is defined by the NEMA and Generator standards (NEMA MGI), is as follows:

Percentage Voltage Unbalance (PVU)

$$= \frac{\text{Maximum voltage deviation from average valtage}}{\text{average valtage}} * 100$$

The second interpretation for voltage unbalance has been given by the International Technical Commission, is as follows:

Voltage Unbalance factor (VUF) (in %) $= (V_2/V_1) * 100$

where V_1 is the magnitude of positive sequence voltages.

V_2 is the magnitude of negative sequence voltages.

Both the two general indexes Percentage Voltage Unbalance and Voltage Unbalance factor are positive real numbers used to evaluate the abnormal voltage values that effects the performance of induction motors.

The Induction - Machine Model

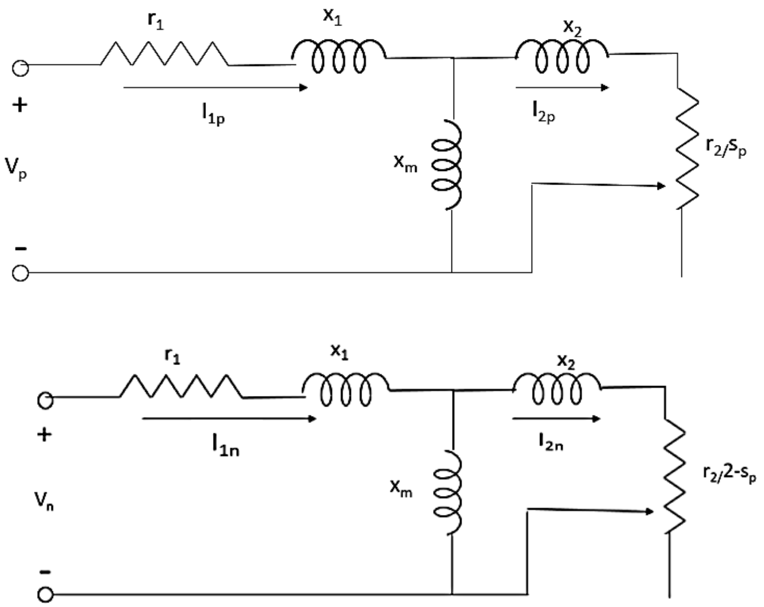


Figure 1. The sequence line-to neutral equivalent circuit of three phase induction machine.

This circuit is applicable for both the networks i.e., for positive sequence as well as for negative sequence networks.

Where per phase values are defined as

V_p positive sequence voltage

V_n negative sequence voltage

R_s stator resistance

X_s stator reactance

R_r rotor resistance referred to stator

X_r rotor reactance referred to stator

X_m magnetizing reactance

Z_p positive- sequence impedance of motor

Z_n negative- sequence impedance of motor

I_{ps} stator positive- sequence current phasor

I_{pr} rotor positive- sequence current phasor

I_{ns} stator negative- sequence current phasor

I_{nr} rotor negative- sequence current phasor

s operating slip of motor.

When the system is balanced i.e., all the three voltages applied to induction machine are same

$$V_{ab} = 127\angle 0^{\circ}$$

$$V_{bc} = 127\angle 240^{\circ}$$

$$V_{ca} = 127\angle 120^{\circ}$$

By calculating from the below formulas

$$V_p = \frac{V_{ab} + aV_{bc} + a^2V_{ca}}{3} \tag{1}$$

$$V_n = \frac{V_{ab} + a^2V_{bc} + aV_{ca}}{3} \tag{2}$$

$$V_a = 127[\cos(0) + j\sin(0)]$$

$$= 127V$$

$$aV_b = 127[\cos(240) + j\sin(240)]$$

$$= 127V$$

$$a^2V_c = 127.0[\cos(120) + j\sin(120)]$$

$$= 127V$$

By putting the values in equation (1) V_p comes out to be 127 Volts and V_n is 0 as there is no unbalance condition.

$$Slip(s) = \left(\frac{\omega_{ms} - \omega_m}{\omega_{ms}}\right) \tag{3}$$

$$= \frac{1500 - 1440}{1500} = 0.04$$

$$Z_s = \frac{R_s + jX_s + (jX_m) + \left(\frac{R_r}{s} + jX_r\right)}{R_r/s + j(X_m + X_r)} \tag{4}$$

$$I_{ps} = \frac{V_p}{Z_1} \tag{5}$$

$$= \frac{127\angle 0^\circ}{17.53\angle -150.49^\circ}$$

$$= -6.29 + j3.56$$

$$I_{pr} = I_{ps} * \frac{jX_m}{R_r/s + j(X_m + X_r)} \tag{6}$$

$$I_{pr}(-6.29 + j3.56) * \frac{j38.9872}{18.55 + j39.94}$$

$$= 6.39\angle -4.59^\circ$$

$I_{ns} = 0$, $V_n = 0$ and $I_{nr} = 0$ as there is no unbalance in voltages

$$P_p = 3I_{pr}{}^2\left(\frac{1-s}{s}\right)R_r \tag{7}$$

$$P_p = 3[(6.39(\cos(-4.59 + j\sin(-4.59))))]^2 * \frac{0.96}{0.04} * 7822$$

$$= 2179.2W$$

$$P_n = 0$$

$$P_{out} = P_p + P_n \tag{8}$$

$= 2179.2W$

Input Active Power is

$$P_{in}\ \mathrm{Re}[3(V_p I_{ps} * + V_n I_{ns} *)] \tag{9}$$

$$P_{in} = \mathrm{Re}[3(127(-6.29 - j3.56))]$$

$2396.49W$

Input Reactive power is

$$Q_{in} = \mathrm{Im}\, g[3(V_p I_{ps} * + V_n I_{ns} *)] \tag{10}$$

$1356.36W$

$$pf = \cos\left[\tan^{-1}\left(\frac{Q_{in}}{P_{in}}\right)\right] \tag{11}$$

Efficiency of motor is defined as

$$\eta = \frac{P_{out}}{P_{in}} * 100 \tag{12}$$

90.9%

3. Simulation and Results

The proposed model is simulated in MATLAB to check the effects of unbalanced supply conditions.

Table 1. shows the values of voltages and angles taken for each of the three-phase supply voltages under different seven unbalanced conditions.

- Balanced condition
- $3 - \varnothing$ Under voltage
- $2 - \varnothing$ Under voltage (UV)
- $1 - \varnothing$ Under voltage (UV)
- $1 - \varnothing$ Over voltage (OV)
- $2 - \varnothing$ Over voltage (OV)

- $3 - \varnothing$ Over voltage (OV)

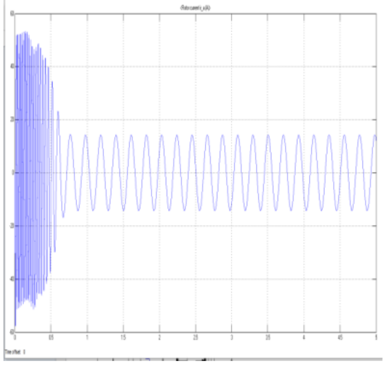
Table1. Calculation of Efficiency at different voltage supply conditions.

Voltage conditions	VUF (%)	V_a	V_b	V_c	Positive Voltage (V_p)	Negative Voltage (V_p)	Efficiency (%)
Balanced	0	127.0∟0°	127.0∟240°	127.0∟120°	127.0	0	90.89
3-Ø UV	4	110.0∟0°	112.7∟240°	125.0∟120°	115.86	4.66	88.7
2-Ø UV	4	111.8∟0°	114.3∟240°	127.0∟120°	117.69	4.7	89.14
1-Ø UV	4	112.4∟0°	127.0∟240°	127.0∟120°	122.13	4.86	89.16
3-ØUV	6	103.2∟0°	107.2∟240°	127∟120°	111.79∟0°	6.69∟50.14°	87
2-Ø UV	6	105∟0°	108.6∟240°	127∟120°	113.5∟0°	6.803∟51.34°	88.67
1-Ø-UV	6	105.4∟0°	127.0∟240°	127∟120°	119.81∟0°	7.19∟0°	87.9

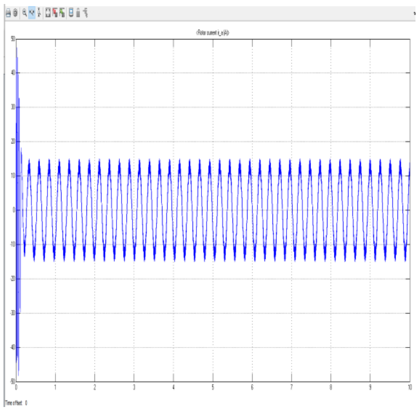
Calculations has been done to study that the how the various unbalance conditions effect the three-phase induction motor with the same VUF and rated output. In addition to three - phase supply voltages and their sequence components, results obtained for efficiency of IM. The table indicates that with same VUF change in positive sequence voltage is (6.27V and 8.02V for VUF=4% and 6% respectively) and change in negative sequence voltage components (0.2 V and 0.5V for VUF=4% and 6% respectively). With the same VUF condition, we are able to understand the status of voltage unbalance from the value of positive sequence voltage. It is very important to consider the positive sequence as it plays an important role in voltage unbalance analysis. It is found that a higher positive sequence voltage gives a higher motor efficiency. The results show that 1-φ UV condition has more positive sequence voltage than other unbalanced conditions and it has highest efficiency than other unbalance conditions.

3.1 Impact of unbalanced supply conditions on Rotor Current

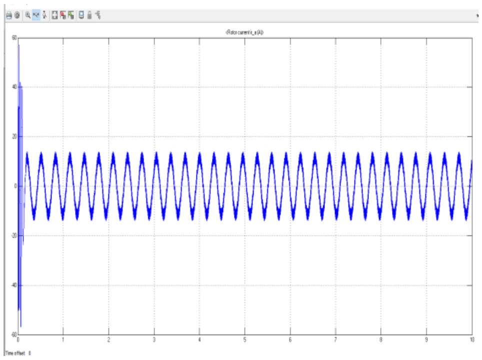
current at balanced voltage



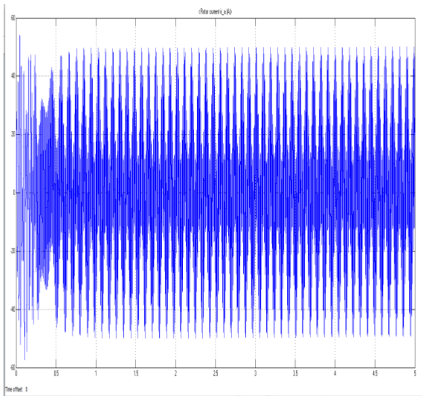
current at two phase undervoltage



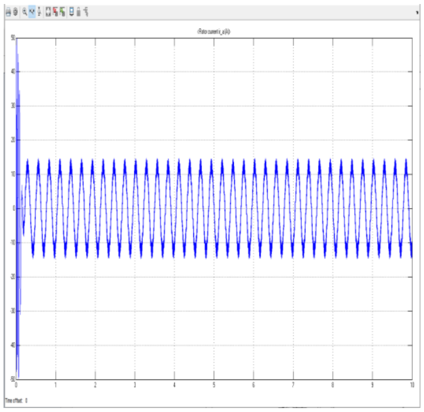
current at single phase over volt



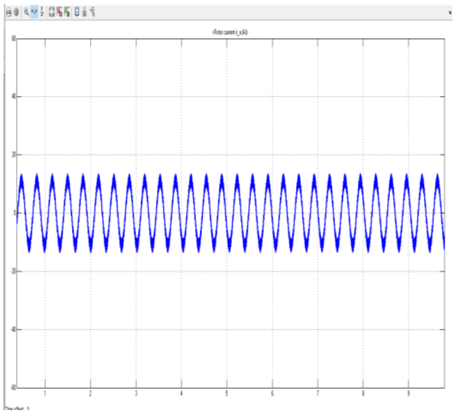
current at 3 phase UV



current at single phase undervoltage



current for 2 phase over volt



current at three phase over voltage

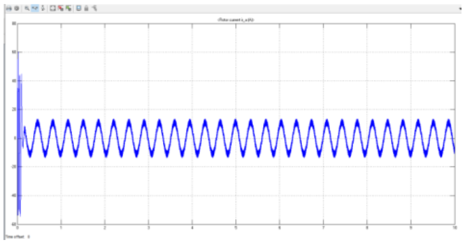


Figure 2. Effects on Rotor Currents under different supply conditions.

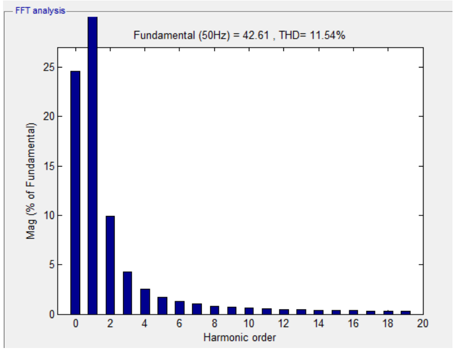
Figure 2. shows the results for the rotor currents considering different unbalanced conditions stated above. The results are obtained showing the behavior of rotor currents which are transient in nature. After an initial increased fluctuation of the current, the graph shows that it takes approximately 0.6 seconds to resolve to the rated rotor current, when the voltage is balanced. High frequency components are obtained in the rotor currents when the voltage is undervoltage as well as overvoltage. This analysis shows that high frequency but low value components are set up in rotor currents when the magnitude of supply is unbalanced. But in any deviation in phase angle, high frequency and high value components are set up in rotor currents. The effect of phase angle deviation is more prominent than the effect shows by change in both magnitude and phase angle.

3.2 Calculation of Total Harmonic Distortion

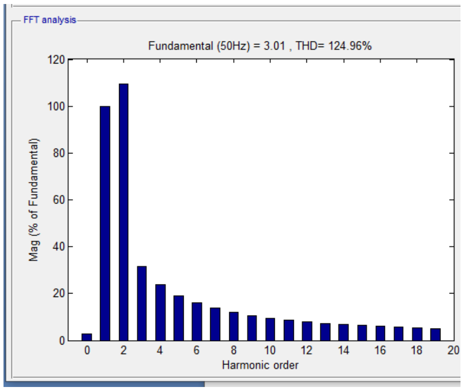
Table 2. THD calculations at different voltage supply conditions with same VUF.

Voltage conditions	VUF(%)	V_a	V_b	V_c	THD(%)
Balanced	0	127.0∟0°	127.0∟240°	127.0∟120°	11.54
3-Ø UV	4	110.0∟0°	112.7∟240°	125.0∟120°	129.29
2-Ø UV	4	111.8∟0°	114.3∟240°	127.0∟120°	129.46
1-Ø UV	4	112.4∟0°	127.0∟240°	127.0∟120°	120.68
1-Ø-OV	4	142.9∟0°	127.0∟240°	127.0∟120°	217.89
2-Ø-OV	4	145.9∟0°	138.3∟240°	127.0∟120°	215.26
3-Ø-OV	4	148.2∟0°	139.7∟240°	129.0∟120°	229.22

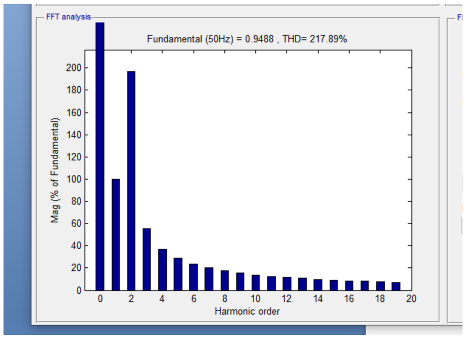
THD at balanced voltage



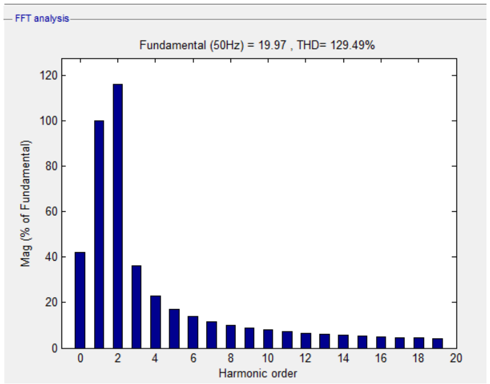
THD at two phase under voltage



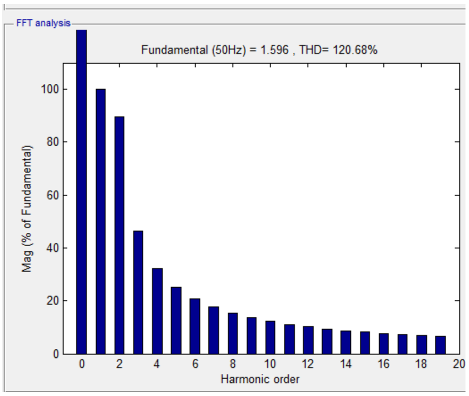
THD at single phase over voltage



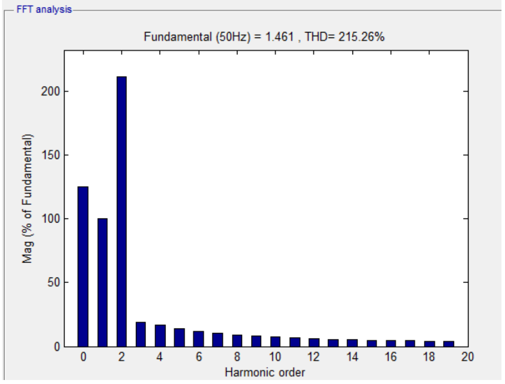
THD at three phase undervoltage



THD at single phase undervoltage



THD at two phase over voltage



THD at three phase over voltage

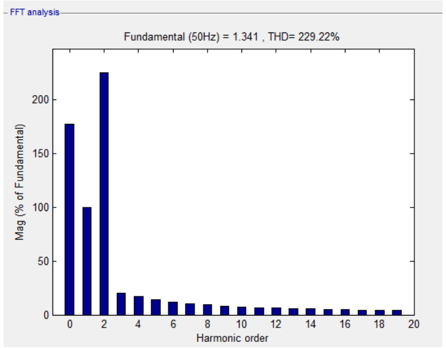


Figure 3. THD of different unbalance voltage supply conditions.

Figure 3. shows the graph of THD obtained by the different supply conditions. It shows that when voltage is balanced it gives less value of THD as compared to other supply condition. When the voltage is 2 phase undervoltage it gives worst value of THD as compared to other under voltage supply conditions. Overvoltage supply condition gives the worst result as the value of THD is obtained too high.

4. Conclusion

From the above analysis we can conclude that from the magnitude of positive sequence voltage and degree of unbalance, we can evaluate the characteristics of power system. Reduction in efficiency when supplied by unbalanced voltages will lead to higher electricity charges. Consequently, it will increase the total load and decrease in spinning reserve of the total generators. Change in angles and overvoltage gives more unwanted results as compared to change in undervoltage supply conditions. The results obtained by overvoltage in terms of THD are worst. Negative sequence currents are introduced due to unbalance supply conditions as compared to balanced conditions. These unbalance currents and oscillatory torques leads to more vibrations and noise which will damage the motor. Favorable results can be obtained by applying PWM technique as their currents and torques will give low ripples which will protect the motor from unwanted oscillations and vibrations.

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