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The Performance of a Three-Phase Induction Motor under and over Unbalance Voltage

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ABSTRACT

Voltage unbalance is an adverse global phenomenon impacting three-phase induction motor output. Three-phase source voltage may become imbalanced in a variety of respects, while a balanced system preserves stable voltage magnitude and angles in three phases, but a completely balanced state is difficult to get. Imbalanced cases may differ in multiple ranges which may practically affect the motor. So, this work is an effort to analyze the operations with appropriate propositions. The output of a three-phase induction motor working with an imbalanced supply grid, MATLAB/SIMULINK is further used for simulation purposes and programming based on the asymmetrical component approach is adopted. A new design for system rerating is being proposed. As a case study, a 10 HP three-phase induction motor was used. The findings of the study show that to determine the output of the induction motor, positive voltage series must be respected under the voltage unbalance factor (VUF) or proportion voltage unbalance index with six various voltage magnitude imbalance conditions, the copper losses of three-phase induction motors were calculated under full load conditions by simulation. So, the qualified percentage change in total copper losses for the motor operating under imbalanced and balanced voltages was determined.

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أداء المحرك الحثي ثلاثي الأطوار تحت وفوق فولتية عدم الاتزان

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الخلاصة

عدم توازن الجهد هو ظاهرة عالمية تؤثر بشكل سلبي على إداء المحرك الحثي ثلاثي الأطوار. قد يصبح جهد المصدر ثلاثي الأطوار غير متوازن في مجموعة مختلفة من الحالات ، في الوقت الذي يحافظ النظام المتوازن على مقدار قيمة الجهد والزاوية في اطواره الثلاثة ، ولكن من الصعب الحصول على حالة متوازنة تمامًا. قد تختلف الحالات غير المتوازنة في نطاقات متعددة تؤثر عمليًا على اداء المحرك. لذلك , ان هذا العمل هو جهد لتحليل عمل المحرك مع الفرضيات المناسبة. حيث تم تحديد مختلف دلائل ومميزات المحرك كالسرعة , تيار الجزء الثابت وتيار الجزء الدوار وذلك من خلال نمذجة المحرك باستخدام تقنية MATLAB / SIMULINK لأغراض المحاكاة ويتم اعتماد البرمجة على أساس طريقة المركبات المتماثلة. تم اقتراح تصميم جديد لترشيد النظام. كدراسة حالة تم استخدام محرك حثي ثلاثي الأطوار بقدرة 10 حصان. تظهر نتائج الدراسة أنه لتحديد اداء المحرك الحثي ، يجب اعتماد مركبة الجهد الموجب تحت عامل عدم توازن الفولتية (VUF) أو عامل عدم توازن الفولتية النسبي مع ستة حالات مختلفة من عدم توازن مقدار الجهد، وتم حساب الخسائر للمحرك الحثي تحت ظرف الحمل الكامل عن طريق المحاكاة. كذلك تم تحديد النسبة المئوية للتغير المفروض في إجمالي الخسائر للمحرك الذي يعمل تحت جهد متوازن وغير متوازن.

الكلمات الدالة: عامل عدم توازن الفولتية المركب ، المحرك الحثي ثلاثي الأطوار ، المركبات المتماثلة ، عدم توازن الجهد ، التتابع السلبي ، التتابع الإيجابي.

1.Introduction

There are several detrimental consequences of a three-phase induction motor with an imbalanced voltage. Such results consist of increased losses, and therefore a rise in a temperature decrease in the motor's efficiency, torque, and a lifetime of insulation. Many researchers published many studies about the effects of imbalanced supply voltage on the operation of induction motor with three-phase. **Williams [1]** states that the main effects of the unbalanced line voltages on the operation of three-phase induction motors are increased losses and unbalanced line currents, imbalanced voltages steer to a fall in efficiency due to decreasing torque which work against the mechanical amount of torque. **Gafford et al. [2]** studied temperature rise and life reduction, and concluded that temperature rise above balanced operating temperature is due mostly to an increase in copper loss and unbalanced spatial spreading of stator copper loss. **Krause and Thomas [3]** reported that the efficiency of an analog computer in studying the operation of induction machinery is verified with computer results which show the dynamic actions of 2-phase and 3-phase machines through balanced and unbalanced running. **Oyama et al. [4]** made in series a static starter developing back to back thyristors with lines of the motor even now fixed used for soft operation starting and power factor development. A desirable small cost result for phase imbalance is to easily change the static operation starter for control strategy by modifying three thyristor couples firing angles individually. The thyristors which are connected in series assist asymmetrical function, impedances of changeable supply which once can be utilized to balancing the voltage through the phases of motor. **Lee [5]** explained several voltage imbalance conditions which are studied and imbalance influences on the induction motor performance are examined with similar voltage imbalance factor. **Wang [6]** defined a new factor of unbalance and it showed that the factor of unbalance together with complex voltage unbalance factor "CVUF" can be used to accurately evaluate induction motor performance under the condition of the imbalanced voltage supply, additional importance to establish the precise derating factor value is given to the angle of complex voltage unbalance factor "CVUF" and the private emphasis is positioned on the angle of complex voltage unbalance factor "CVUF" influence on the induction motor performance and best advantageous and badly behaved situation for derating factor and full permissible slips are reviewed. **Pillay et al. [7]** used part of a negative sequence in replacement to voltage unbalance factor "VUF" to consider the influence of imbalance and variances in the definition of voltage imbalance are also examined. **De Abreu and Emanuel [8]** studied the thermal displaying of real motors in the 2–200 Hp scale. Two significant conclusions have been drawn. First, voltage sub-harmonics have an exciting influence on the thermal aging of the motor. Second, the total cost of motor life loss because of harmonic contamination and voltage imbalance. **Faiz et al. [9]** studied the undesirable influences of a separable imbalanced voltage on the induction motor behavior. They proposed that the existing definitions of unbalanced voltages are not comprehensive and complete. Thus, the results are not very reliable for those who evaluate motor behavior. It exposed that a more precise imbalanced factor has to be defined for more precise results. Experimental calculations confirm the theoretical evaluation. **Quispe et al. [10]** used a statistical method to establish several multiple regression types to evaluate the effect of unbalance voltage on the efficiency and power factor of induction motors. The equations associate the next variables: the positive sequence voltage and the negative sequence voltage. **Raj et al. [11]** studied the form of non-sinusoidal of supply voltages distortion steers to the creation of unsafe harmonics that exchange the motor behavior, producing noise and pulsing torque. **Anwari [12]** used MATLAB software to examine induction motor behavior. The Simulink products indicate the International Electro-technical Commission that the voltage imbalance definition is shared with the imbalance condition coefficient which can be employed to calculate input power, total copper losses, total output producing torque, and power factor. **Aderibigbe et al. [13]** discovered the behavior of an induction motor working with three-phase using the analysis of phase frames under unbalanced voltage conditions. The results of this study proved that there are negative influences of supply unbalance on the performance of a three-phase induction motor. **Quispe et al. [14]** displayed a complete investigation of the voltage components for negative and positive sequence effect and the angle between them on numerous features such as power factor, losses, line currents, and efficiency under various imbalanced voltage conditions. An induction motor with three-phase about 3 HP has been applied as a situation analysis. The study effects illustrate that the voltage of a positive sequence should be measured with the voltage imbalance factor simultaneously. **Singh et al. [15]** explained the method used for steady-state analysis exactly, analyzed and compared various sources of definitions of voltage unbalance factor and Voltage unbalance effects on the motor and mitigation techniques are also presented. **Adekitan [16]** suggested an innovative phase unbalance concept which takes into account the normal 120° displacement of the three phases of the source. Commonly, unequal delivery loads above the three-phase, unsymmetrical impedances in the lines of three phases produced unbalanced voltage in three phases. Despite this reason, significant negative sequence currents can happen, even if the phase voltage unbalance is small, for the reason that relatively small impedance of negative sequence. This expansion has prepared drives of changeable speed both effective and inexpensive, a variable speed drive is an electronic device that controls the speed [17], so the induction motor has changed motors of DC mainly manufacturing requests. Through their mechanical construction, induction motors will benefit from the following advantages: simple and durable structure, low expense, low overhead maintenance and produced a wide variety of industrial applications with constant speed [18]. The most widely used electric motors have Partial horsepower in the world in many Domestic and industrial applications are single-phase induction motors due to its durability, simplicity of installation, low cost and maintenance [19]. But, induction motor with three-phase feed approximately 75 percent of the industry's overall electricity usage [20]. Induction motor with three-phase includes nearly 80 percent of manufacturing requests [21]. Larger efficiency and behavior can affect larger manufacturing requests due to expended larger total power by those motors. The behavior and quantity of every AC motor depend on the quality and stability of the electrical power grid which energies the motor. Generally, it is not strange to have unbalances and faults in different scales and times at any step because the electrical power grid operates on a very complicated transfer, generation, delivery, and consumption network. This in influence affects the overall efficiency of the electric power supplied. Greatest recent electrical machines are fabricated with protection measurement to avoid harm happening as an effect of electrical power feature reduction. Though, Long-term contact with such a decayed electrical power grid could result in devious harm or loss to the machine's behavior and life span. A large overall loss in mechanical amount is produced and loss of fabrication in the industry is caused for the reason that a minor ratio loss in efficiency. Thus, the influence of input electric power unbalance on AC motors is a critical part of the study. This work measures the output loss as well as helping to develop preventive measures to substitute and avoid these losses. The currents at normal working speed with unbalanced voltages will be significantly unbalanced in the direction of about 6 to 10 times the voltage unbalance [22]. If the ratio unbalanced voltage in the direction of 1% the additional losses are taken into account not essential enough to permit a derating of the motor [23]. Despite this, it is not strange that voltage unbalance can go to a much larger ratio and thus be the reason for much more essential added losses including a necessary derating of the motor. This presents a difficult problem in choosing the right overload protective devices, principally since devices chosen for one set of unbalanced conditions could be insufficient for a various set of unbalanced voltages. Despite their total benefits and various requests, induction motor with three-phase have many disadvantages, such as their susceptibility to imbalanced voltage conditions. The imbalance condition of voltage might still seem as a variation in magnitude or even as phase imbalance. The complex voltage unbalance will present effects that are more accurate since the CVUF covers two parameters the magnitude and the angle, it is worked to entirely describe the voltage unbalance effect. Computation of projected added losses due to voltage unbalance according to two definitions, NEMA and IEC, are passed out easily.

This paper is to study the effect of supply voltage unbalance on the performance of an induction motor in its steady-state condition. Comparisons of the motor performance at different supply voltage unbalance factors on the motor current unbalance factor, motor current distortion, motor speed, motor output efficiency, and derating element of the motor are presented and discussed. Consideration of both the positive and negative sequence voltage is necessary for the exact evaluation of the voltage imbalance. It also attempts to discover the degree of these impacts. Unequal and distorted voltage supply are expected to have various types of impact on the motor. These impacts will be studied individually. In this paper, it is proposed to model and simulate the three-phase induction motor using MATLAB software to analyze and study the behavior of the machine when subjected to an unbalanced supply. It is intended to focus on motor derating, efficiency, developed torque, and other important factors that affect the performance of the motor in general.

2. Unbalanced Voltage Identifications

There are three voltage imbalance definitions are analyzed and stated as the following.

NEMA Identification (National Equipment Manufacturer's Association)

The NEMA definition of voltage unbalance, also called as the Line Voltage Unbalance Rate (LVUR) [24], is given by

$$\%LVUR = \frac{max\ voltage\ deviation\ from\ the\ average\ line\ voltage}{average\ line\ voltage} \times 100$$

The NEMA identification supposes that "the average voltage is always equal to the rated value, it works only with magnitudes, and phase angles are not included".

IEEE Identification

The IEEE identification of imbalance voltage, moreover called so the "Phase Voltage Unbalance Rate (PVUR)" [24], is given by

%PVUR

$$= \frac{max\ voltage\ deviation\ from\ the\ average\ phase\ voltage}{average\ phase\ voltageage} \times 100$$

The IEEE definition is similar to the NEMA description, the one variance is that the IEEE uses phase voltages instead of line-to-line voltages. Here for a second time, phase angle information is canceled while only magnitudes are taken into account.

IEC Identification

The IEC definition of voltage unbalance also called the exact description of imbalance voltage is described such as the proportion of "the negative sequence voltage component to the positive sequence voltage component" [24]. "The percentage voltage unbalance factor (% VUF)", or named exact description, Is provided by :

$$\%VUF = \frac{negative\ sequence\ voltage\ component}{positive\ sequence\ voltage\ component} \times 100$$

$$= \frac{V_n}{V_p} \times 100$$

by way of determining three-phase unbalanced line voltages $V_{ab}, V_{bc}, and\ V_{ca}$ (or phase voltages) we can get the positive sequence voltage component V_p and negative sequence voltage component V_n by obtaining two symmetrical components V_p and V_n (of the line or phase voltages). The two balanced components are specified as:

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

Where $a = 1\angle 120°$, $a^2 = 1\angle 240°$

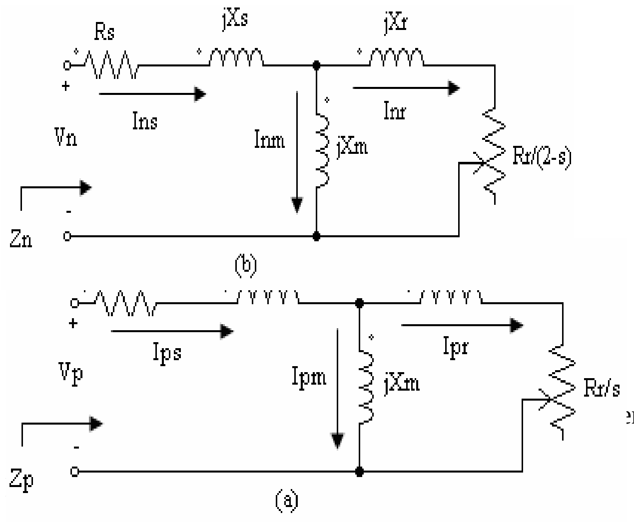
When investigating induction motor performance under unbalanced conditions, we can use the positive and negative sequence voltages theory. In addition to the imbalance voltage there is the "complex voltage unbalance factor (CVUF)" that is described by the "ratio of the negative sequence voltage phasor to the positive sequence voltage phasor" [6]. This measurement of CVUF has an angle and the magnitude in the following form:

$=K_v \angle\theta_v$, Where K_v the magnitude and CVUF $= \frac{V_n}{V_p}$

θ_v the angle of the CVUF.

3. A steady-state analysis of three-phase induction motors

Analysis of steady-state induction motor working with an unbalanced voltage source is workable using the "symmetrical component" method. This needs the expansion of equivalent circuits for positive and negative sequence illustration as shown in Figure (1). Every set of positively and negatively sequence voltages within the induction motor generates reciprocal balanced currents, besides that, the transcription of the two groups of current vectors, describes the real currents yielded by the unique imbalanced voltages during the three phases of the stator. Because of the positive sequence voltage, the machine's performance is the same as normal balance working. Whereas a backfield is formed by negatively sequence current, and if the rotor slip is s for the positively sequencing field, then (2-s) related to the negative sequencing field. The motor behaves as the addition of two independent motors, one side operating at slip s with V_p terminal voltage per phase and the last operating with terminal voltage V_n at slip (2-s) [6].



Equivalent of Negative sequence

ent equivalent circuits

corresponding zero, positive and negative-sequence components (V_o, V_p and V_n) of the voltages are given by:

$$\begin{bmatrix} V_o \\ V_p \\ V_n \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

Where a = 1∠120° , a^2 = 1∠240°

The Voltage Unbalance Factor according to IEC definition is given by:

$$VUF= \frac{V_n}{V_p} \times 100\% \quad (2)$$

the circuit input impedance is

$$Z_i = R_s + jX_s + \frac{(jX_m)\left(\frac{R_r}{S_i}+jX_r\right)}{\frac{R_r}{S_i}+j(X_r+X_m)} \quad (3)$$

impedance for positively sequence, i = p, ($S_p = s$)

impedance for negatively sequence, i = n($S_n = 2 - S$)

Positively sequence of rotor current and stator current Actuality given by:

$$I_{ps} = \frac{V_p(R_r+jsx_2)}{R_sR_r+s(X_m^2-X_1+X_2)+j(R_rX_1+sR_sX_2)} \quad (4)$$

$$I_{pr} = \frac{V_p \cdot jsx_m}{R_sR_r+s(X_m^2-X_1+X_2)+j(R_rX_1+sR_sX_2)} \quad (5)$$

Where

$= X_m + X_s\ X_1$

$= X_m + X_r\ X_2$

Similarly, negatively sequence of rotor current and stator current actuality given by:

$$I_{ns} = \frac{V_n(R_r+j(2-s)x_2)}{R_sR_r+(2-s)(X_m^2-X_1+X_2)+j(R_rX_1+(2-s)R_sX_2)} \quad (6)$$

$$I_{nr} = \frac{V_n \cdot j(2-s)x_m}{R_sR_r+(2-s)(X_m^2-X_1+X_2)+j(R_rX_1+(2-s)R_sX_2)} \quad (7)$$

by using expressions of "symmetrical components" of voltages and currents, then power factor and input power of motor could be described to :

$$\text{Input active power } (P_{in}) = Re[3(V_p \cdot I_{ps}^* + V_n \cdot I_{ns}^*)] \quad (8)$$

$$\text{Input reactive power}(Q_{in}) = Im[3(V_p \cdot I_{ps}^* + V_n \cdot I_{ns}^*)] \quad (9)$$

$$\text{Input power factor (p.f.)} = \cos\left[\tan^{-1}\left(\frac{Q_{in}}{P_{in}}\right)\right] \quad (10)$$

Whereas (*) means the use of a conjugate.

For the event that mechanical losses and core losses are ignored and because of positively and negatively sequence components, the output power might have been described by:

$$P_p = 3I_{pr}^2\left(\frac{1-s}{s}\right)R_r \quad (11)$$

$$P_n = 3I_{nr}^2\left(\frac{s-1}{2-s}\right)R_r \quad (12)$$

Whereas net output is;

$$P_{out} = P_p + P_n \quad (13)$$

Where P_n is negatively sequence at usual slip for the reason that rotor revolves in parallel direction of the magnetic field generated by negatively sequence component. Through positively and negatively sequence component, thus producing Torque are:

$$T_p = \frac{P_p}{\omega_m} = \frac{P_{pg}}{\omega_s} = \frac{3I_{pr}^2R_r}{S\omega_s} \quad (14)$$

$$T_n = \frac{P_n}{\omega_m} = \frac{P_{ng}}{\omega_s} = -\frac{3I_{nr}^2R_r}{(2-S)\omega_s} \quad (15)$$

Where ω_m is rotational angular speed, then ω_s be synchronization speed. So the total output torque of the motor is described by:

$$T = T_p + T_n = \frac{3R_r}{\omega_s}\left(\frac{I_{pr}^2}{s} - \frac{I_{nr}^2}{2-s}\right) \quad (16)$$

Motor efficiency is described by:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (17)$$

The efficiency can easily be obtained from the Simulink model by directly measuring the input and output power as will be shown in the next chapter.

4.Current Unbalance Factor (CUF)

Because a given small amount of voltage unbalance will generally imply a comparatively larger current unbalance, it is to consider the Current Unbalance Factor (CUF). As voltages of the stator are imbalance, then currents of the stator have been imbalance similarly. The coefficient of imbalance current is defined as [6]:

$$CCUF=\frac{I_n}{I_p}=K_v \angle\theta_v \quad (18)$$

Where K_v denotes to magnitude and θ_v to the angle of the CCUF.

5. Simulation influences of voltage unbalance on 3-ϕ asynchronous motor

The influences of various voltage imbalances throughout this research section on stator current, rotor speed, losses of copper, power factor and efficiency of 3-ϕ asynchronous motor verifying maximum load stable state conditions were implemented using MATLAB/SIMULINK background as in figure(2). The motor with 10 HP was assumed. The voltages provided by three phase were specified in Table(1). To display the influences of various imbalance voltage conditions, the different voltage imbalance is examined. Input data has been stated as:

Specifications	Values	Parameters	Values
Rated Power	10Hp (7.5 kW)	Stator resistance R_s	0.7384ohm
Rated Voltage	400/230 V	Rotor resistance R_r	0.7422ohm
Poles	4	Stator reactance X_s	0.9566 ohm
Rotor Speed	1440 rpm	Rotor reactance X_r	0.9566 ohm
Frequency	50 Hz	Magnetizing X_m	38.9872 ohm
Connection	Y	Friction factor	0.0343 kg-m2
Phase	3	Moment of Inertia	0.000503

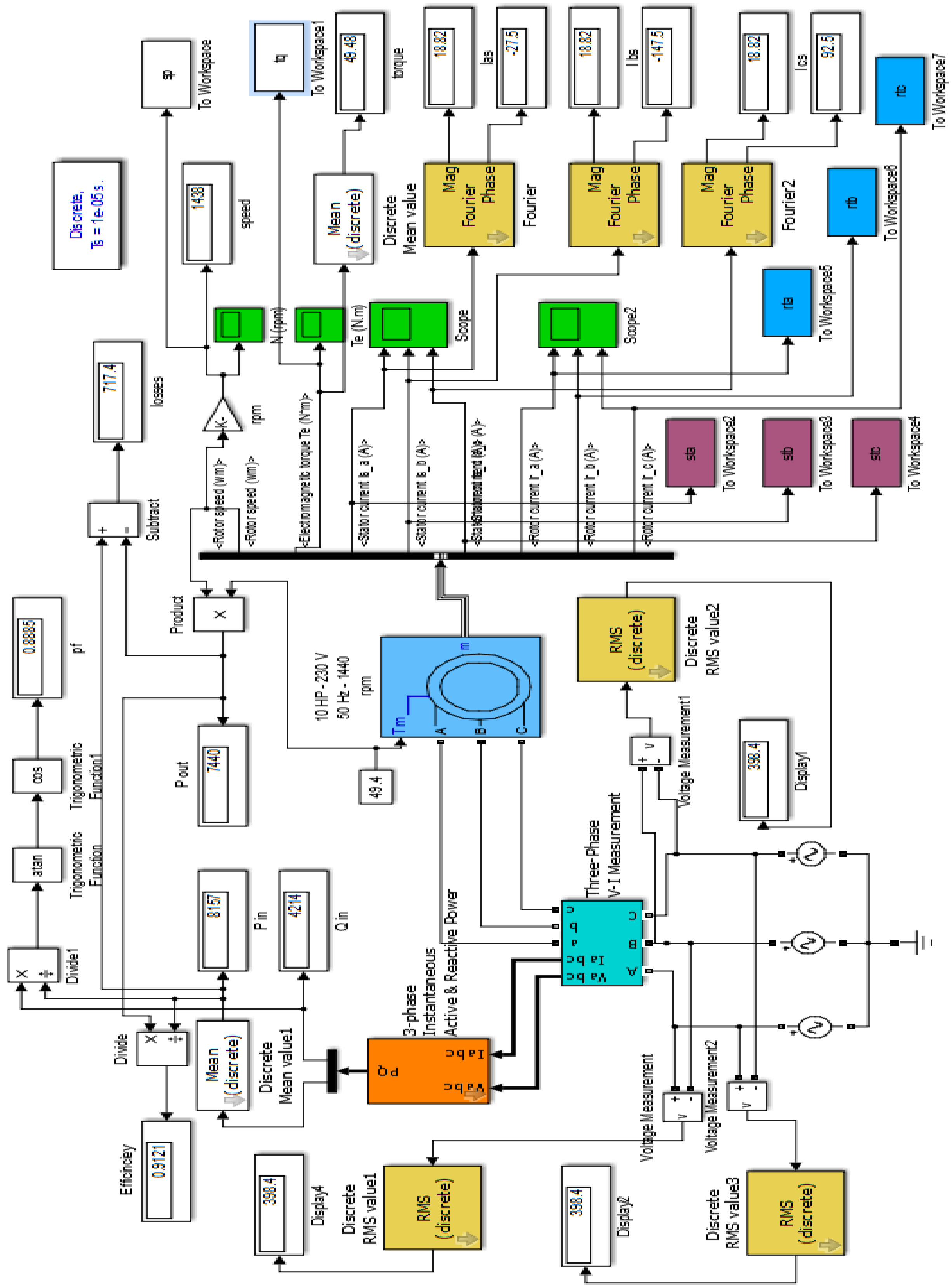


Fig.2. Matlap/Simulink for three phase induction motor supplied by balanced or unbalanced sinusoidal voltage

Table 1

Induction motor voltages at various possible unbalance voltage

Over Or under	V_a	V_b	V_c	Positive seq. V_p	Negative seq. V_n
Bal.	$230\angle 0°$	$230\angle -120°$	$230\angle -240°$	230	**0**
OVM	$244\angle 0°$	$238\angle -120°$	$232\angle -240°$	238	$\mathbf{2\sqrt{3}\angle 30°}$
UVM	$216\angle 0°$	$222\angle -120°$	$228\angle -240°$	222	$\mathbf{2\sqrt{3}\angle -150°}$
OVP	$230\angle 0°$	$230\angle -130°$	$230\angle -250°$	$176.7\angle 20.5°$	$\mathbf{63.11\angle -8.7°}$
UVP	$230\angle 0°$	$230\angle -115°$	$230\angle -230°$	$229.42\angle 5°$	$\mathbf{11.28\angle -55°}$
OVMP	$240\angle 0°$	$250\angle -130°$	$245\angle -260°$	$242.5\angle -10°$	$\mathbf{149.4\angle 86°}$
UVMP	$220\angle 0°$	$215\angle -110°$	$210\angle -225°$	$213.7\angle 8.2°$	$\mathbf{15.66\angle -54.3°}$

6. balanced and imbalanced voltage condition

6.1. Balanced case

In this section, a normal operating condition has been investigated. It is necessary to accomplish this to develop a reference for comparison purposes. This model has been simulated. In normal conditions, the motor was supplied by its rated voltage which is 400 volts (line to line). Figures (3) and (4) show the balanced situation of Simulink effects for speed and torque response. As the plot is presented in the shape, ripple torque is exactly ignored.

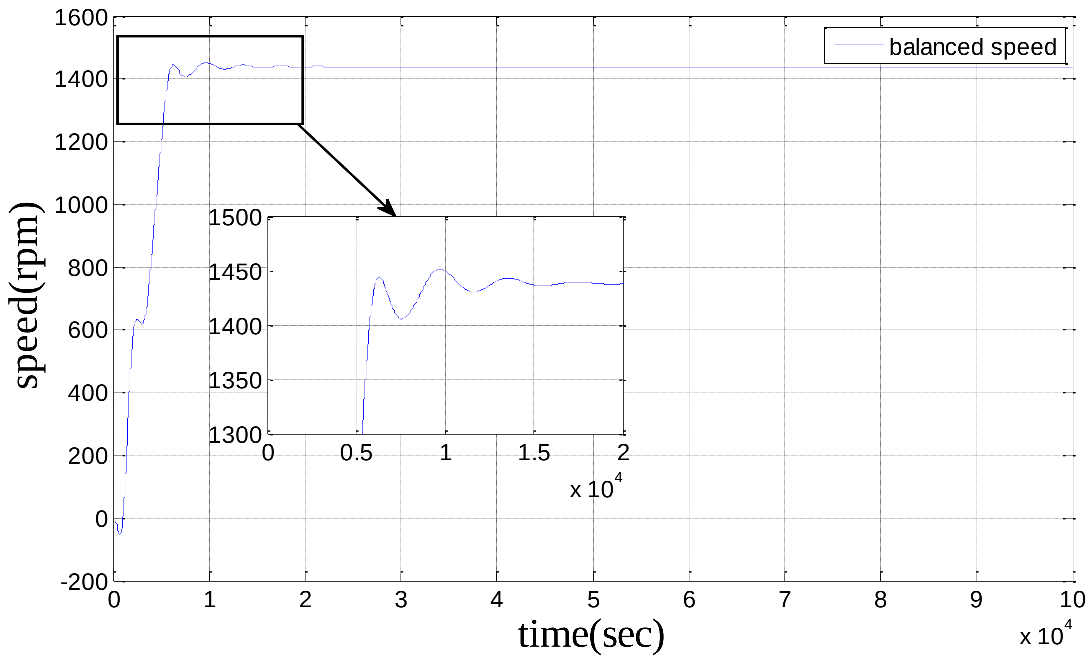


Fig.3. speed response of balanced case

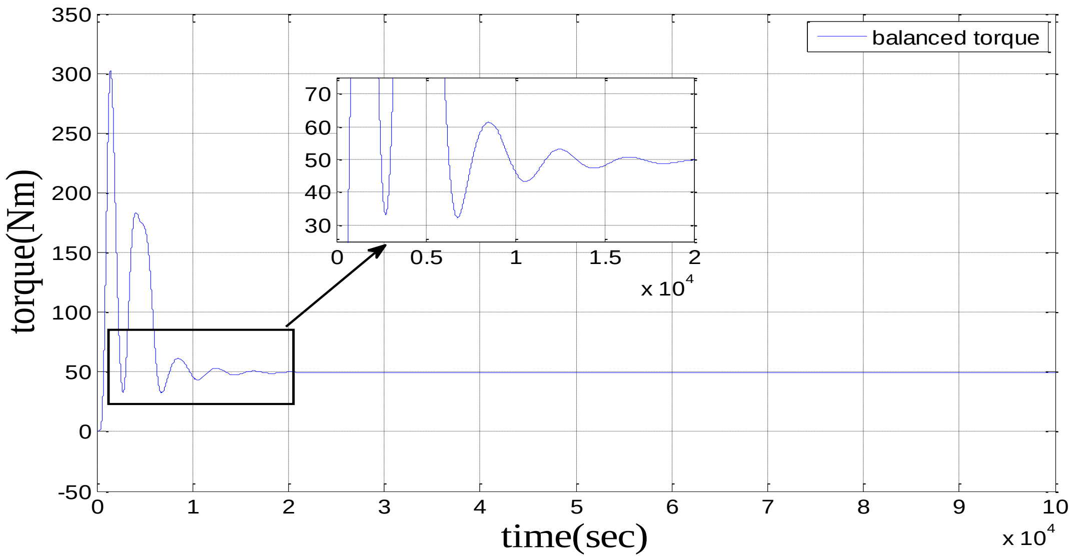


Fig.4. torque response of balanced case

6.2. Imbalanced cases

The unbalance in the phase and the magnitude of the voltage has been considered.

6.2.1 Imbalanced in the magnitude of voltages

Within that section, all phases are supposed to have an imbalance of over or under the rating voltages (OVM,UVM). Figures (5) and (6) show the speed and torque components respectively from a simulation system. The average torque is reduced as compared to the balanced operating, whereas the ripple has enlarged greatly.

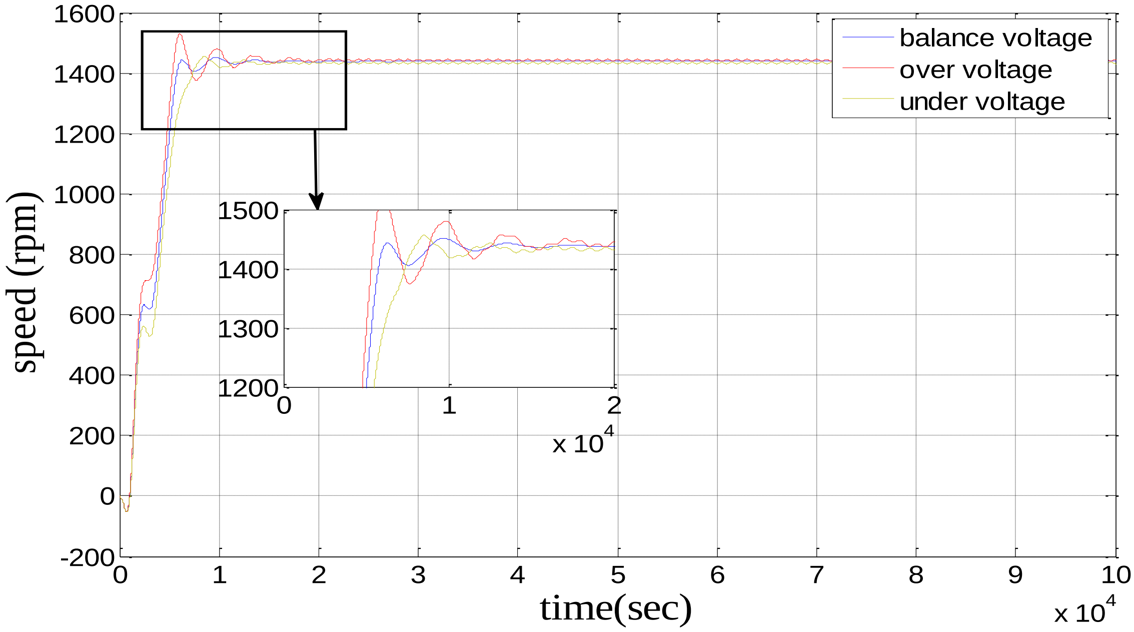


Fig.5. speed response for over and under unbalanced volt age magnitude

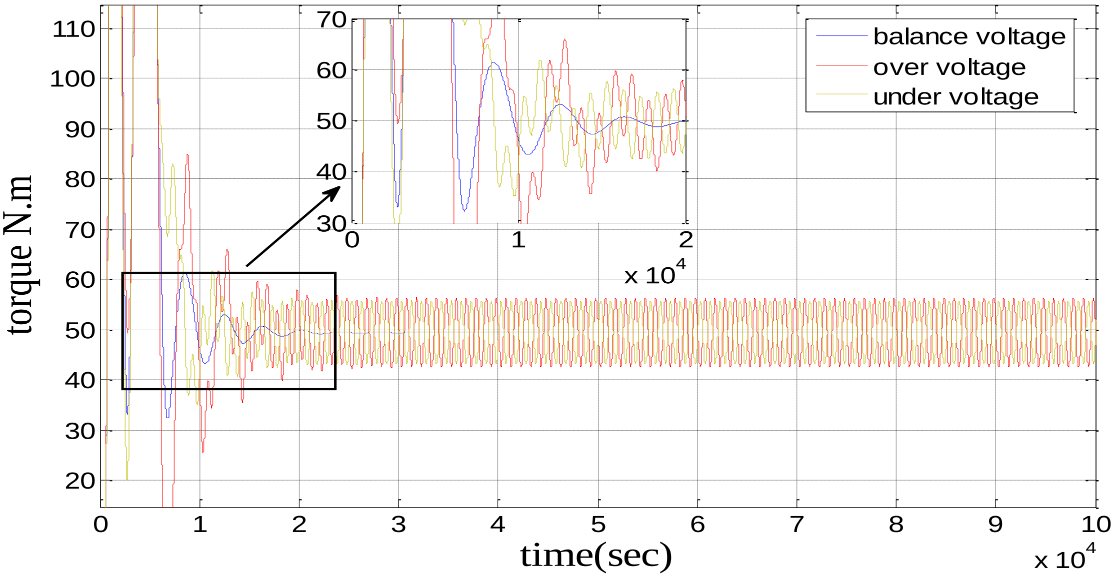


Fig.6. torque response for over and under unbalanced voltage magnitude

6.2.2 Imbalance in the phases of voltages

Within that section, imbalance phases for over or under the phase of supplied voltage (OVP,UVP) are supposed. Figures (7) and (8) show the torque and speed respectively for that situation depending on the pattern, the torque ripple is greatly higher although the average torque is slightly lower relative to the balance situation.

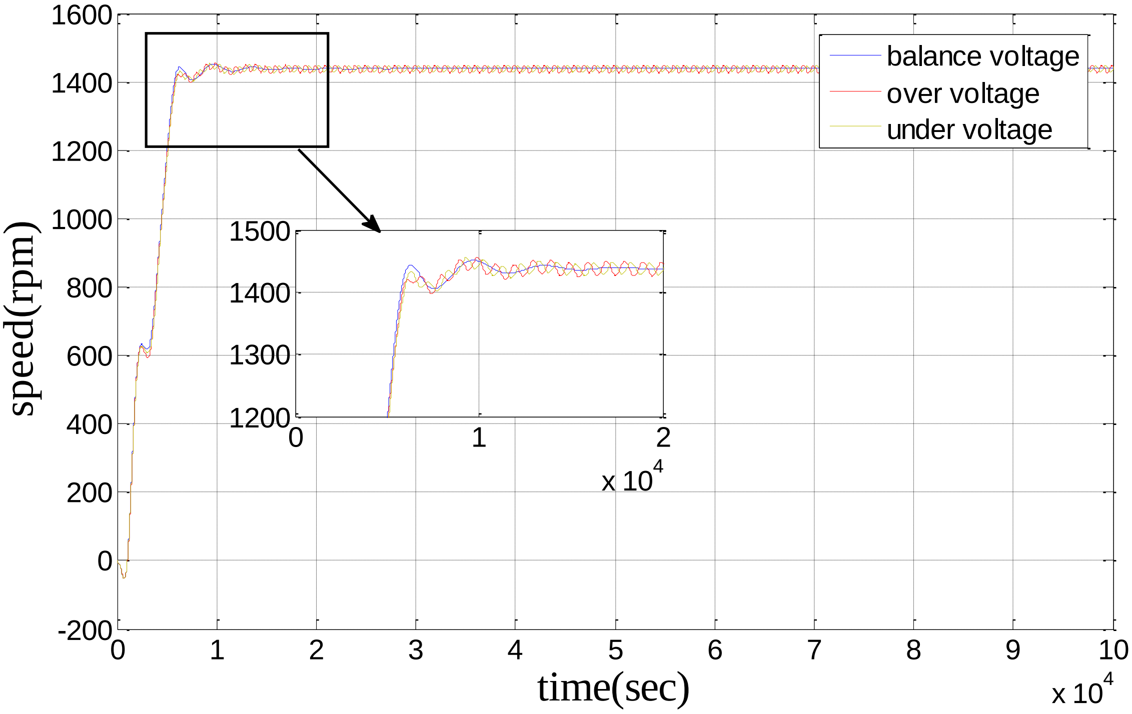


Fig.7. speed response for over and under unbalanced voltage phase

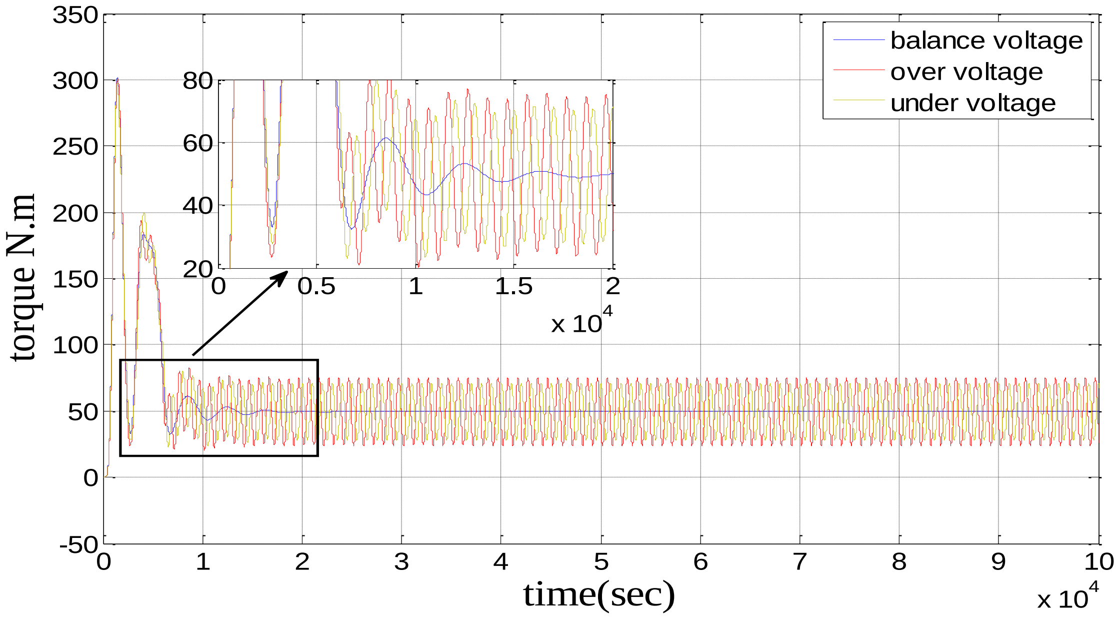


Fig.8. torque response for over and under unbalanced voltage phase

6.2.3 Imbalance in the phases and value of voltages

Within that section, an imbalance of over or under voltage Phase and magnitude (OVPM,UVPM) are supposed. The speed and torque components have been shown in Figures (9) and (10) respectively. Throughout this situation, the ripple is expanded further as predicted and the average torque is reduced. Pulsing torque is disfavored from the output point of view thus it is necessary to identify and prevent various types of imbalance voltage

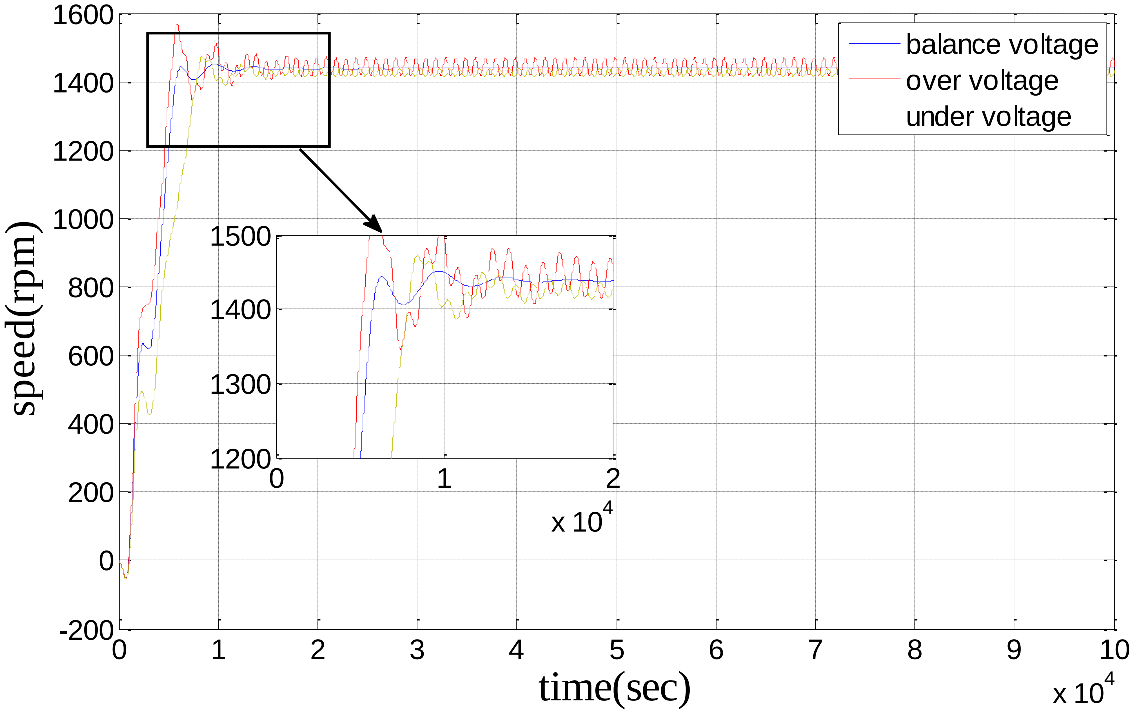


Fig.9. speed response for over and under unbalanced voltage magnitude and phase

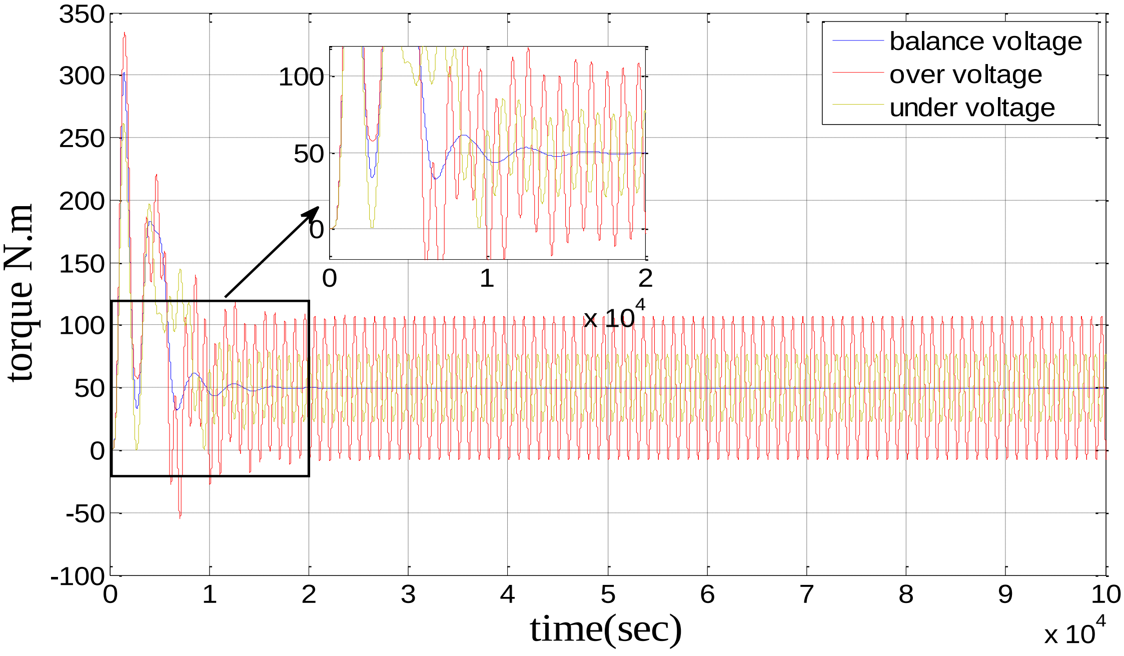


Fig.10. torque response for over and under unbalanced voltage magnitude and phase

Table 2

stator currents motor at various possible unbalance voltage conditions

Over Or under	I_{as}(peak)	(peak)I_{bs}	(peak)I_{cs}
balance	$18.82\angle-27.5°$	$18.82\angle-147.5°$	**$18.82\angle 92.5°$**
OVM	$20.6\angle-28.6°$	$17.32\angle-155°$	**$17.32\angle 98°$**
UVM	$17\angle-26°$	$20.71\angle-141°$	**$20.6\angle 88°$**
OVP	$24.6\angle-16°$	$24.6\angle-172.4°$	**$10\angle 86°$**
UVP	$20\angle-44.43°$	$13\angle-125°$	**$25.7\angle-105.4°$**
OVMP	$25.5\angle 7.73°$	$36\angle-173°$	**$10.6\angle 6.6°$**
UVMP	$21.59\angle-45.5°$	$13.35\angle-109.6°$	**$29.94\angle 110.8°$**

Table 3

positive and negative sequence components and behavior of Induction motor at different possible imbalance conditions

Over Or under	Positive seq. I_p	Negative seq. I_n	P_{in} (W)	(P_{out} W)	Losses	Effi.%
balance	$11.82\angle 2.24°$	0	8157	7440	717	**91.2**
OVM	$18.34\angle-28.5°$	$2.26\angle-28.8°$	8149	7471	677	**91.1**
UVM	$19.34\angle-26.3°$	$2.31\angle 151°$	8192	7406	787	**90.4**
OVP	$11.17\angle-89.7°$	$8.27\angle 156.4°$	8334	7423	912	**89.06**
UVP	$18.8\angle-22.53°$	$7.5\angle-114.3°$	8238	7485	798	**90.37**
OVMP	$18.42\angle-39.4°$	$18.62\angle 53.78°$	8907	7382	1525	**82.88**
UVMP	$20.16\angle-17.1°$	$15.13\angle-131°$	8450	7438	1013	**88.02**

Table 4

Output performance and unbalance voltage factor of Induction motor at different possible imbalance conditions

Over Or under	speed	(N.m)$T_{av.}$	(CVUF)%	(CCUF)%	p.f.
balance	1438	49.4	0	0	**0.88**
OVM	1444	49.4	$1.46\angle 30°$	$12.33\angle -0.3°$	**0.85**
UVM	1432	49.4	$1.56\angle 150°$	$11.96\angle 177.3°$	**0.91**
OVP	1435	49.4	$63.11\angle -8.7°$	$74.04\angle -114°$	**0.94**
UVP	1447	49.4	$4.9\angle -60°$	$39.9\angle -91.75°$	**0.76**
OVMP	1427	49.4	$61.6\angle 96°$	$101.11\angle 93.18°$	**0.98**
UVMP	1438	49.4	$7.33\angle -62.52°$	$75.04\angle -113.3°$	**0.75**

7. Influence of Unbalanced Voltage Supply on Rotational Speed

Under balanced conditions for sinusoidal supply in figure (3) the rotor rotates at the rated speed of 1438 rpm and a steady-state is achieved within nearly 0.14 seconds. The effects of various imbalanced situations for sinusoidal supply on rotational speed are explained in Figures (5,7,9). Increasing the voltage magnitude, increased gradually the speed of the rotor that achieves a faster stable level at 0.12 sec to become 1444 rpm as shown in figure (5), but the decreasing value of voltage leads to decrease the rotor speed to 1432 rpm. Any increase in the phase angle products a small decrease in speed of the rotor to become 1435 rpm while a decrease in the angle of phase produces raises the rotational speed to become 1447 rpm as shown in figures (7). A drop in two the voltage amplitude and the phase angle shows the minimum stable of rotor speed and lead to decrease the rotational speed as presented in figure (9) to reach 1427 rpm. All these speed results are stated in a table (4).

8. Influence of Unbalanced Voltage Supply on Torque

Since a primary transient response, the torque achieves a stable state rate of 49.4 N.m in voltage balance situations for sinusoidal supply as shown in figure (4). Moreover, the torque is not fixed at a stable state and goes up and down under all imbalanced voltage situations for sinusoidal supply as shown in figures (6,8,10). For amplitude above and below voltage the torque swings through 50 N.m as in figure (6). Therefore the swinging rises in amplitude many cycles with every phase angle conversion (up or down) as shown in figures (8). This swinging rises more since both the amplitude and the phase of the supply voltage are raised as shown in figure (10). Even so, a reduction in both the magnitude and the angle of the phase leads to an equivalent transient torque as that observed in the phase angle transition.

9. Influence of Unbalanced Voltage Supply on Stator Current

Currents of a stator in balanced and unbalanced voltage amplitude and phase angle situations as displayed in a table (2). The stator currents increased generally when voltage unbalanced are occurring in magnitude or in phase for both over and under unbalances voltage, for comparison in balance condition the stator current equal to 18.82A and become 20.6A for over magnitude unbalance condition and become 24.6A for under magnitude, but there is a large increase in stator currents when voltage unbalance occur in magnitude and phase for over and under conditions to become 25.5 A,21.59 A respectively. The stable state stator current is increased gradually by a reduction in voltage amplitude. A reduction in the angle of the phase nearly increases the current of the stator as referred to that generated in a balanced state.

10. Effect of Unbalanced Voltage Supply on Input Powe, losses, Power Factor and Efficiency

Table (3) indicates that the greater mark of imbalance in voltage would reduce asynchronous motor output efficiency. The motor operating on an imbalance under voltage will generate less efficiency compared to when it is working under situations of imbalanced overvoltage. The motor's efficiency is reduced dramatically when the under-voltage unbalance rises. The minor efficiency of asynchronous motors contributes to greater electric power utilization (losses), even though it has a good power factor than it was under situations of imbalance overvoltage. From this table, it is apparent that just defining the mark of voltage imbalance is not adequate to measure input power, output, total copper losses, and power factor of an imbalanced supply working motor. Specifying whether one over or under voltage imbalanced factor wherein the motor works is also required. In such situations, the voltage imbalance phase angle may be ignored. Consequently, applying the IEC description and identifying the above or below voltage imbalance factor condition for comparing input power, average copper losses, efficiency, and input power of the asynchronous motor running with an imbalanced voltage source will be sufficiently satisfied.

11. Results discussion

Table (1) shows voltages of the asynchronous motor at different probable imbalance voltage situations. The results get ready from Simulink of the asynchronous motor as presented in figure 2. A motor is modeled for balancing voltage and unbalancing voltage variation inside allowable limits. This is already modeled for various probable situations of imbalance conditions over or under voltage. A result from the table presents the positive and negative sequence components cases of over and under Voltage unbalanced conditions to evaluate the effects on the efficiency, it is necessary to use both sequence components as conclusion of Quispe. Table (2) shows the positive and negative sequence currents components cases of over and under unbalanced voltage conditions. These are found whether a difference in Voltage, behavior, p.f if voltage variance is inside acceptable borders. For voltage imbalance coefficient of almost more than 5% and the motor is modeled for over and under various situations, for that it is noticed that there is a difference in current, and current imbalance factor, Efficiency, power factor and similarly in voltage component of negative sequence which are shown in tables (3) and (4). Furthermore, imbalance Current changes about six to ten times of that imbalance voltage element. Therefore, as losses rise, efficiency decreases with an imbalance of voltage rise. Negative sequencing element is so responsive for imbalance voltage while Positive sequencing variance is fewer. Likewise, there is a fewer variant in speed by voltage imbalance. When current rises with imbalanced voltage rising, power factor raises together. Also, as compared with Lee's paper it should be noted from Table 4 that the power factor of the motor in an unbalanced case may be greater than in the balanced case. MATLAB/Simulink results for speed and torque which shows that ripple is almost negligible. An Unbalanced condition introduces a negative sequence component. Figures (5-10) shows an unbalance condition waveforms are sinusoidal. Moreover. results for voltage imbalanced for speed and torque which show the ripple in waveforms largely. Imbalances of voltage in one phase produce significant imbalances in the current. Large unbalance in current just like that with over a 5 percent imbalance state was not preferred due to a major reduction in performance resulting because of an increase in temperature, which may result in harm to the motor.

12. Conclusion

The amount needed to study the behavior of a 3ϕ asynchronous motor that operates by an imbalanced voltage source is the grade of imbalance voltage. This was claimed that the prevalent motor operating conditions are not measured correctly unless specifying the phase angle of the unbalance component and the coefficient of the unbalance condition. The VUF's IEC definition is sufficiently reliable to assess input power, total losses of copper, power factor, and total output torque since they're not based on the phase angle of the imbalance factor. Nevertheless, CVUF, which consists of both the voltage unbalance magnitude and phase angle, could be done for measuring average current, average losses of copper and derating influence of the motor. Not all the output amounts can be measured precisely unless specifying the state of imbalanced voltage. Consequently, an unbalance factor might have been added to describe the imbalanced condition, that further is whether in below or above voltage imbalanced. The investigation of significant imbalance effects is rather essential. Therefore, it should be suggested for future research work. It has been effective to investigate the operation of large size 3-ϕ asynchronous motor, which may give more vision into the influences of imbalanced voltage and voltage harmonics.

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