Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2014/03/jls.htm
2014 Vol. 4 (S3), pp. 951-956/Nafar et al.
Research Article

UTILIZING MATLAB-SIMULINK FOR ANALYSIS THE INDUCTION MOTOR OPERATION UNDER UNBALANCED VOLTAGE SAG TO GRADUATE STUDENTS

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ABSTRACT
In this paper, the analysis of induction motors operation under voltage sags is investigated. Due to educational purpose of this research, a computer simulations using the MATLAB/SIMULINK toolbox is presented. The basic observed effects of voltage sags on induction motors are speed loss and current and torque transients associated with both voltage reduction and recovery. To review and better understating of this phenomena a MATLAB/SIMULINK technique is presented to teach this course to graduate students. The evaluation of the project involving more than 30 students indicates benefits of this project in teaching the subject.

INTRODUCTION
Many researches have analyzed the voltage sag and its problem as a main power quality phenomenon in power system. Voltage sag which is rms voltage reduction due to short circuit or induction motors starting could be lead to some problem in customers. The most equipment of power system could be undergoing due to voltage sag. One of the main power system equipment is induction motors that mostly used industrial customers. Voltage sag can affect the induction motors operation (Mahmoud, 2009). In other words if a voltage sag due to fault or motor starting occurred in a bus of system can affect the any induction motor operation which is installed in any point of system. On the other hand, installation of induction motors can change the characteristics of voltage sag that propagates to system. Some researchers have focused on the interaction between the induction motors and voltage sag. In (Das, 1990), it was shown that voltage sag will reduce the motor torque proportional to the square of the motor terminal voltage, the motor will slow down and the continuity of the output may be lost. Depending on the depth and the duration of the voltage, the motor speed may recover to its normal value as the voltage amplitude recovers. Otherwise, the motor speed may slow down and the torque exerted by the motor could not supply the load.

In (Richards and Laughton, 1998), the situation of reapplication of out of phase voltage (on voltage recovery) to a motor running with a strong remaining rotor field (during sag) was discussed. It was shown that this may result in electromagnetic and shaft torque and current transients which may exceed the starting values, and may be destructive to the motor shaft.

In (Bollen, 1996) the problem of prolonged voltage sag due to the presence of motor loads was shown. Depending upon the initial speed loss and the magnitude of the recovery voltage after fault clearance, the motors may accelerate, taking currents that may approach the starting currents of the motors. These starting currents of accelerating motors, flowing together through the supply system impedance, may prevent a fast recovery of voltage (Guasch *et al*., 2004). The stronger the electrical system in relation to the size of the accelerating motors, the greater is the power available for the motors to accelerate and recover.

Induction Motors and Unbalanced Faults

The behavior of an induction motor during an unbalanced fault is rather complicated. Only a network analysis program simulating a large part of the system can give an accurate picture of the quantitative effects. The following phenomena play a part in the interaction between system and induction motor during unbalanced faults.

- During the first one or two cycles after fault initiation the induction motor contributes to the fault. This causes an increase in positive-sequence voltage. Negative and zero-sequence voltages are not influenced.
- The induction motor slows down, causing a decrease in positive-sequence impedance. This decrease in impedance causes an increase in current and thus a drop in positive-sequence voltage.
- The negative-sequence impedance of the motor is low, typically 10-20% of the nominal positive-sequence impedance. The negative-sequence voltage due to the fault will thus be significantly damped at the motor terminals. The negative-sequence impedance is independent of the slip. The negative-sequence voltage will thus remain constant during the event.
- The induct ion motor does not take any zero-sequence current. The zero sequence voltage will thus not be influenced by the induction motor.

Simulations of the influence of induction motor loads on unbalanced sags are shown in (Bollen, 1995), (YalGinkaya and Bollen, 1994). Some of those results are reproduced here. The system studied was a radial one with large induction motor load connected to each of the low-voltage busses.

Without induction motor influence we would have seen a sag of type B of zero magnitude: zero voltage in phase 'a', and no change in the voltage in phase 'b' and phase 'c'. Instead we see a small non-zero voltage in phase 'a' and in the two non-faulted phases an initial increase followed by a slow decay. After fault clearing the system becomes balanced again, and the three phase voltages thus equal in amplitude. The motor re-acceleration causes a post-fault sag of about 100 ms duration.

The non-zero voltage in the faulted phase is due to the drop in negative-sequence voltage. We saw in (2) that the voltage in the faulted phase during a single-phase fault is given as:

$$V_a = \frac{(Z_{F1}+Z_{F2}+Z_{F0})}{(Z_{S1}+Z_{S2}+Z_{S0})+(Z_{F1}+Z_{F2}+Z_{F0})}$$

$$V_b = a^2 - \frac{a^2 Z_{S1} + aZ_{S2} + Z_{F0})}{(Z_{S1}+Z_{S2}+Z_{S0})+(Z_{F1}+Z_{F2}+Z_{F0})} \qquad (2)$$

$$V_c = a - \frac{aZ_{S1} + a^2 Z_{S2} + Z_{S0})}{(Z_{S1}+Z_{S2}+Z_{S0})+(Z_{F1}+Z_{F2}+Z_{F0})}$$

Therefore:

$$V_a = V_1 + V_2 + V_0 = |V_1| - |V_2| - |V_0| \qquad (3)$$

The effect of the induction motor is that *V2* drops in absolute value, causing an increase in voltage in the faulted phase.

During the sag, the positive-sequence voltage also drops, which shows up as the slow but steady decrease in voltage in all phases.

The non-faulted phases show an initial increase in voltage. The explanation for this is as follows. The voltage in the non-faulted phases during a single-phase fault is made up of a positive-sequence, a negative-sequence, and a zero-sequence component. For phase c this summation in the complex plane is for the system without inductionmotor load.

$$V_c = V_{c1} + V_{c0} + V_{c2} = \frac{2}{3}a - \frac{1}{3} - \frac{1}{3}a^2 = a \qquad (4)$$

Due to the induction motor load, the positive-sequence voltage will not immediately drop from 1 pu to 0.67 pu. The negative-sequence voltage will jump from zero to its new value immediately. The consequence is that the resulting voltage amplitude slightly exceeds its pre-fault value. After a few cycles the induction motor no longer keeps up the positive-sequence voltage. The voltage in the non-faulted phases drops below its pre-event value due to negative- and positive-sequence voltages being less than 33% and 67%, respectively.

RESULTS AND DISCUSSION

To find out the interaction between the voltage sag and its effects on induction motors a MATLAB/SIMULINK based simulation has been performed.
The parameter of induction motor which analyzed in this paper is listed as Table 1.

Table 1: Motor Parameters (Mahmoud, 2009)

Rated Power	2500 kW
Rated Voltage	11000 V
Frequency	50 Hz
Full Load Current	153 A
RPM	1496
Starting Current	600% FLC
Starting time	22 sec
Power factor	0.90
Moment of Inertia	560 Kg.m2
Rated Torque (T)	15959 N.m
Locked Rotor Torque	75%
Pull up Torque	65%
Breakdown Torque	270%

The simulation of model is presented in Figure 1.

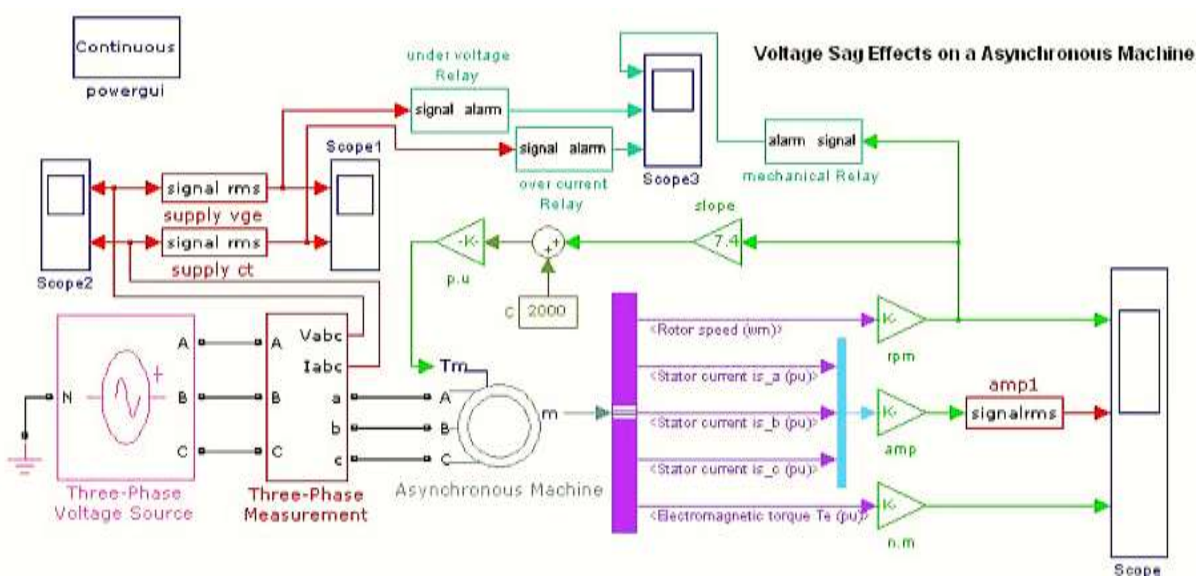

Figure 1: The simulated model

The results of this normal situation are shown in Figure 2. From these results, the following remarks are noted: The motor speed accelerates gradually during the starting period till it reaches its operating speed at 1486 rpm in about 20 seconds. The starting current of the motor rushes to about 930 A, i.e.

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approximately 600% of full load, then the current decreases to its normal current of about 118 A (the motor operates at 80% of its full load).

The motor is subjected to a pulsating torque from +72,000 N.m to -54,000 N.m (peak to peak), for a period of 2 seconds. After which, these pulsations decay and the motor operates with increasing unidirectional torque until it reaches its maximum value of 50,000 N.m in 20 seconds. After which the motor torque intersects with the load torque at the operating point and the motor continues to deliver its normal torque of 13,000 N.m.

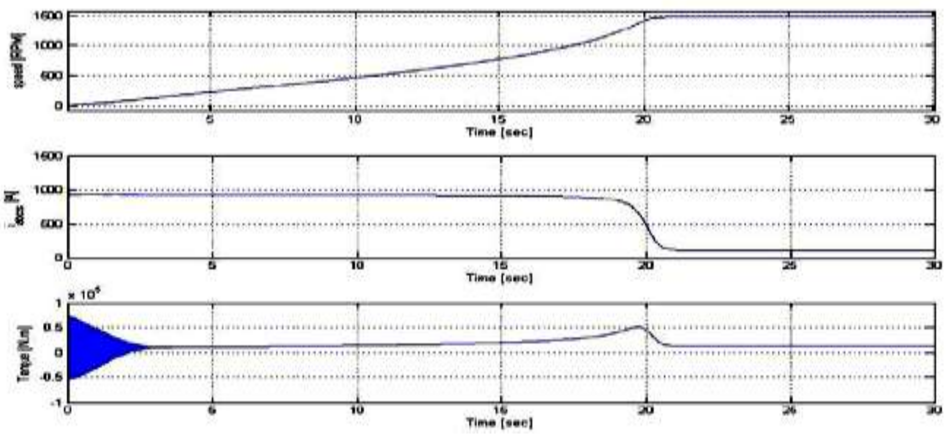

Figure 2: Operation the induction motor under normal voltage

The motor is subjected to a three phase voltage sag with 80% magnitude and a duration of 1 sec. the sag starts at t=30 sec and recovers 1 sec later. This situation is presented in Figure 3.

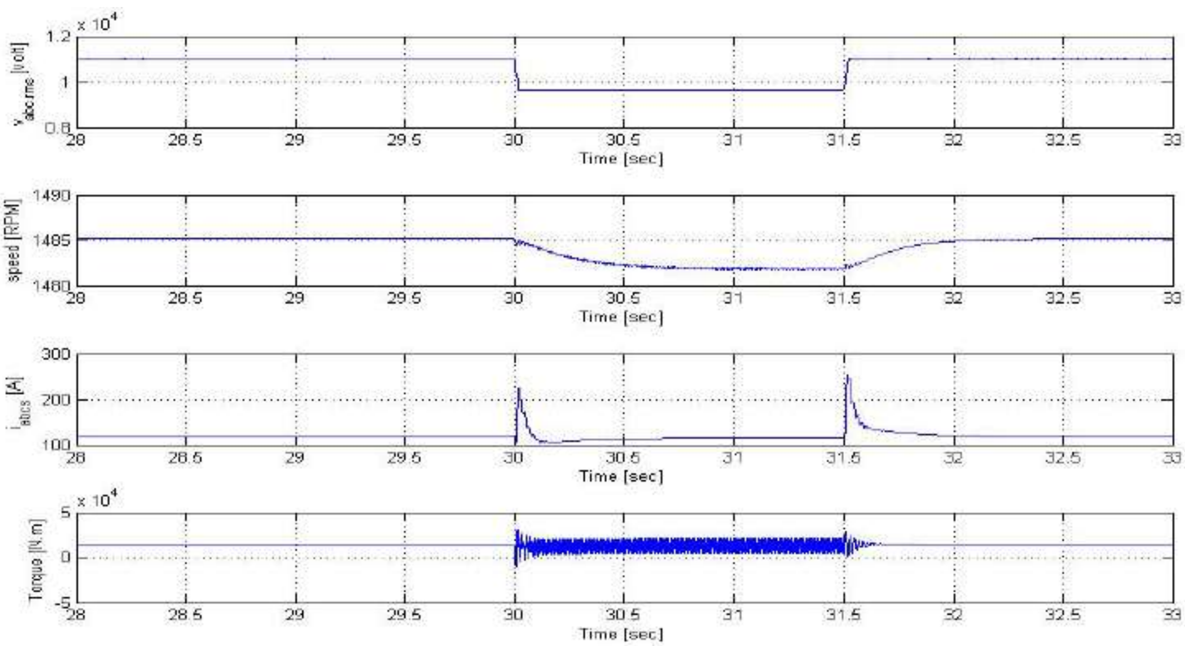

Figure 3: Operation the induction motor under unbalanced voltage sag

The speed drops to a value of 1483 rpm (94% of normal). The motor current increases on occurrence of the sag event reaching a value of 163 A (164% of normal and 17% of starting), then drops eventually since a new operating point is reached. The motor continues running with increasing current till the voltage recover. At this instant, the initial operating point is reached and the motor draws a transient current of 337 A (285% of normal and 36% of starting). The torque also shows two transients on sag occurrence and on full voltage recovery. The sag transient approaches 24,500 N.m (193% of normal and 37% of starting), whereas the recovery transient approaches 32,400 N.m (230% of normal and 44% of starting).

Students Feedback

The methodology illustrated in this paper has explained for 30 senior undergraduate students in power system, all of them have passed power quality courses. The students employ the methodology and in the presence of instructor filled a questionnaire form. The questionnaire, comprising six questions, is listed in Table 2. The students graded them as 1(poor), 2 (medium), 3 (good), and 4 (excellent). Figure 4 shows the global results obtained from the students' questionnaire.

Table 2: Questionnaire Answered by the Students and Engineers

Question	Score
1. The content of this practical is valuable for a student of engineering course	
2. Are you understanding the concept of harmonics and its difference with other power quality phenomena	
3. Are you more familiar with the influence of harmonics on power system operation	
4. Are you more familiar with the influence of harmonics compensation on power THD and power factor	
5. Are you more familiar with the influence of harmonics on deceasing iron and copper loss	
6. Are you more familiar with the performance of shunt active filters in harmonics compensation under steady state	

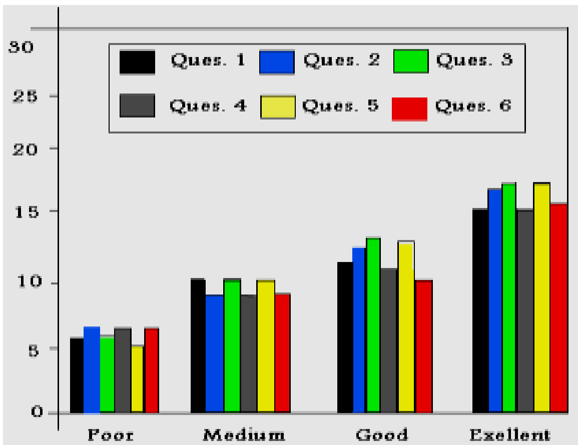

Figure 4: Answers of students to the questionnaire

Table 3 gives the average scores for each question out of students' feedback.

Table 3: Average Score Obtained From Students' Answers

	Average Score
Question 1	3.00
Question 2	3.50
Question 3	4.00
Question 4	3.82
Question 5	3.75
Question 6	3.53
Total	3.34

Conclusion

In this paper, the analysis of induction motors operation under voltage sags is investigated. Results have also showed that three-phase voltage sags and sags occurring at zero crossing are the most severe events. Transient currents occurring at the instants of voltage sag and voltage recovery are directly proportional to the voltage drop, not to the remaining voltage magnitude. Transient currents and torques induced at the instant of sag recovery are higher than those induced at the instant of sag starting. Unloaded motors and motors operated at voltages higher than the nominal voltage are less affected by voltage sags.

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