



EFFECT OF VOLTAGE SAG DURATION OF DIFFERENT TYPE VOLTAGE SAGS ON THE PERFORMANCE OF INDUCTION MOTOR

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Abstract

Voltage sag is one of the primary concerns in power quality disturbance, even though there are several ways to characterize voltage sag, two basic characteristics i.e. sag magnitude and sag duration are the two most commonly used. Electromagnetic torque generated by an induction motor is directly proportional to the square of the voltage. Due to the wide use and popularity of induction motors, this paper investigates the effect of voltage sag duration, on the performance of induction motors under different voltage sags at various points of sag initiation. MATLAB Simulink environment is used for simulations of induction motors under various voltage types of sags of magnitudes (0.2 pu, 0.5 pu, and 0.8 pu) and duration 10 cycles (instantaneous sag) or sag of duration 1 sec (momentary sag) is performed. The results of the simulations have been compared based on torque peaks and current peaks. It has been found that the torque peak for an instantaneous sag is similar to the torque peak for a momentary sag for each type of voltage sag. Whereas current peaks were affected by the sag duration it has been found for momentary voltage sag of Type A, Type C, and Type D the magnitude of the current peak increases in comparison to instantaneous voltage sag.

I. Introduction

According to research conducted by the U.S. Department of Energy, electric motors consume close to 60% of all the energy produced in the country. Motors in several industries, including the petroleum, chemical, paper, food, and textile industries, use more than 82% of the energy that is given to them. [1].

The power quality of the electrical system has a significant effect on the reliability and cost of the electrical system because of the development of new electronic technologies there is a greater demand for safe and dependable power around the world today [2]. Power quality issues generally occur due to harmonic voltage and currents, poor power factors, and voltage instability. It can also be described as the provision of voltage and system architecture that enables effective and interference-free usage of electrical energy from the distribution systems [4]. The presence of nonlinear loads affects the purity of the waveform supplied. Apart from nonlinear loads, system events such as switching of the capacitor, motor starting, and various faults that occur in the power system also cause power quality problems [6]. According to the IEEE standard 11 definitions "Power quality is the concept of powering and grounding electronic equipment in a manner that is

suitable to the operation of that equipment and compatible with premise wiring system and connected equipment” [5].

Voltage sag is a major quality issue that impacts sensitive and important loads significantly and has drawn attention among all power quality issues for decades. In a survey carried out in around 93 industries in three districts in Italy, it was found that 84% of the power quality disturbances are due to voltage sags and short interruptions [7]. A voltage sag is a duration (0.5 cycles to 1 minute) voltage variation in supply voltage. According to IEEE Std. 1159 is defined as the reduction in RMS value of voltage from nominal voltage for a time greater than 0.5 cycles of the power frequency but less than or equal to 1 minute” [5].

There are various causes of voltage sags such as voltage sag due to faults, energizing of the transformer, and starting of the induction motor.

According to the result of some studies, induction motors are one of the industrial equipment which is sensitive to voltage sags. The motor speed decreases due to the reduced motor torque which is proportional to the square of the terminal voltage and with the increase of current drawn from the line the slip increases [8]. The transient torque and current peaks will stress the drive shaft and motor insulation. Speed fluctuation on induction roots in industrial processes such as carpet, textile, and paper mills can cause damage to the end product [9, 10].

II. SAG TYPE AND CHARACTERIZATION

According to ABC classification, there are seven voltage sag types:

1. Sag A: A balanced three-phase sag will result in a Type A voltage sag.
2. Sag B: Faulted Phase Voltage is reduced
3. Sag C: Two affected phase voltage changes along the imaginary axis (both in magnitude and angle).
4. Sag D: Two affected phase voltage changes in the real axis only (drop in magnitude in remaining phase).
5. Sag E: reduced voltage magnitude in two affected phases
6. Sag F: Two affected phase voltage changes in both real and imaginary axis (drop in magnitude in remaining phase)
7. Sag G: Two affected phases' voltage in both axis and the remaining phase experience increase in voltage

A balanced three-phase voltage sag will result in a Type A sag. Since the voltage sag is balanced, the zero-sequence is zero, and a transformer will not affect the appearance of the voltage sag of phase-to-ground voltage and phase-to-phase voltage. A phase-to-ground fault will result in a Type B voltage sag and if a transformer removes the zero-sequence between fault location and load, the voltage sag will be of Type D voltage sag. A phase-to-phase fault will result in a Type C voltage sag. The voltage sags of types E, F, and G occur due to a two-phase-to-ground fault. In Table 1 various voltage sag type and their phasor equations and phasor diagrams where h is the sag magnitude ($0 \leq h \leq 1$) in this paper sag magnitude is the net root mean square voltage in percentage or per unit of the system-rated voltage.

Table 1: Various voltage sag and their phasor equations and phasor diagrams

Sag Type	Equations	Phasor
Sag A	$V_a = hV$ $V_b = -\frac{1}{2}hV - j\frac{\sqrt{3}}{2}hV$ $V_c = -\frac{1}{2}hV + j\frac{\sqrt{3}}{2}hV$	
Sag B	$V_a = hV$ $V_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}V$ $V_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}V$	
Sag C	$V_a = V$ $V_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}hV$ $V_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}hV$	
Sag D	$V_a = V$ $V_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}hV$ $V_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}hV$	
Sag E	$V_a = V$ $V_b = -\frac{1}{2}hV - j\frac{\sqrt{3}}{2}hV$ $V_c = -\frac{1}{2}hV + j\frac{\sqrt{3}}{2}hV$	
Sag F	$V_a = hV$ $V_b = -\frac{1}{2}hV - j\frac{1}{\sqrt{12}}(2+h)V$ $V_c = -\frac{1}{2}hV + j\frac{1}{\sqrt{12}}(2+h)V$	

Sag G	$V_a = \frac{1}{3}(2 + h)V$ $V_b = -\frac{1}{6}(2 + h)V - j\frac{\sqrt{3}}{2}hV$ $V_c = -\frac{1}{6}(2 + h)V + j\frac{\sqrt{3}}{2}hV$	
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A voltage sag is characterized by:

- Voltage sag Magnitude
- Duration of voltage sag
- Phase angle jump
- Point on a wave of sag initiation

Magnitude and duration are two fundamental important voltage sag characteristic that influences the performance of induction motor.

Parameters of Motors:

In Table 2 parameters of the motors that are used for the research work are given. Both the motors are pre-set models available in Matlab Simulink.

Table 2: Parameter of motor used.

Parameter	Motor 1 (5.4 HP)
Power Rating	4000 W
Voltage (line-to-line)	400 V
Frequency	50 Hz
Rated Speed	1430 RPM

III. Voltage sag effects:

The transient effect depends on many factors such as sag magnitude and duration, initial point-on-wave, electrical parameters, load, and mechanical inertia of the motor. Irrespective of the type of voltage sag the observed effects on the induction machine behavior are torque and current peaks.

The maximum torque peaks and current peaks are obtained after the fault instant or after the recovery voltage instant. The transients due to symmetrical voltage sag only depend on the sag magnitude and duration whereas the transients due to unsymmetrical voltage sags depend on sag magnitude and duration but also the point-on-wave which is also discussed in section V.

IV. Variable of interest

The tendency of torque oscillations to occur at the start and end of the voltage reduction is one of the major issues with a voltage sag. This phenomenon may disrupt the process or damage the motor. Another issue with voltage sag and induction machines is the behavior of the machine when the voltage sag occurs at the beginning of voltage drops because torque is proportional to the square of the voltage, and speed will also drop. The motor will draw a significant inrush current during the post-voltage sag stage, primarily to establish the air gap field but also because of the reacceleration. In the majority of practical applications, when a motor slows down, the load torque drops and the motor torque increases. This reduces the problem and facilitates an easier motor restart. The occurrence often happens so quickly that the torque can be regarded as constant and the actual speed loss is frequently lesser than expected. The motor will require a large current as described for

some loads with practically constant torque or high inertia, and for some loads, the motor won't be able to restart at all.

In this paper, the chosen variable to study the effect of the sag duration on the performance of the induction motor is torque peaks and current peaks. These values are calculated per unit as referred to as the nominal or rated current and torque is done by using equations 1 and 2.

$$i_{peak,p.u.} = \frac{i_{peak}}{\sqrt{2} I_N} = \frac{\max\{|i(t)|\}}{\sqrt{2} I_N} \quad \dots (1)$$

$$T_{peak,p.u.} = \frac{T_{peak}}{T_N} = \frac{\max\{|T(t)|\}}{T_N} \quad \dots (2)$$

Where T_N is nominal torque and I_N is nominal current [3].

V. RESULTS

Effects on sag duration of various voltage sag at different point-on-wave initiation on the performance of induction motor are represented in this section. The results are shown in terms of torque peaks and current peaks.

Table 3: Torque peaks of induction motor when subjected to voltage sag type A, B, C, D, E, F, and G at different point-on-wave initiation for sag duration of 0.2 sec and 1sec.

	Torque Peaks for sag duration of 0.2 sec	Torque Peaks for sag duration of 1 sec
SAGA		
SAG B		
SAG C		

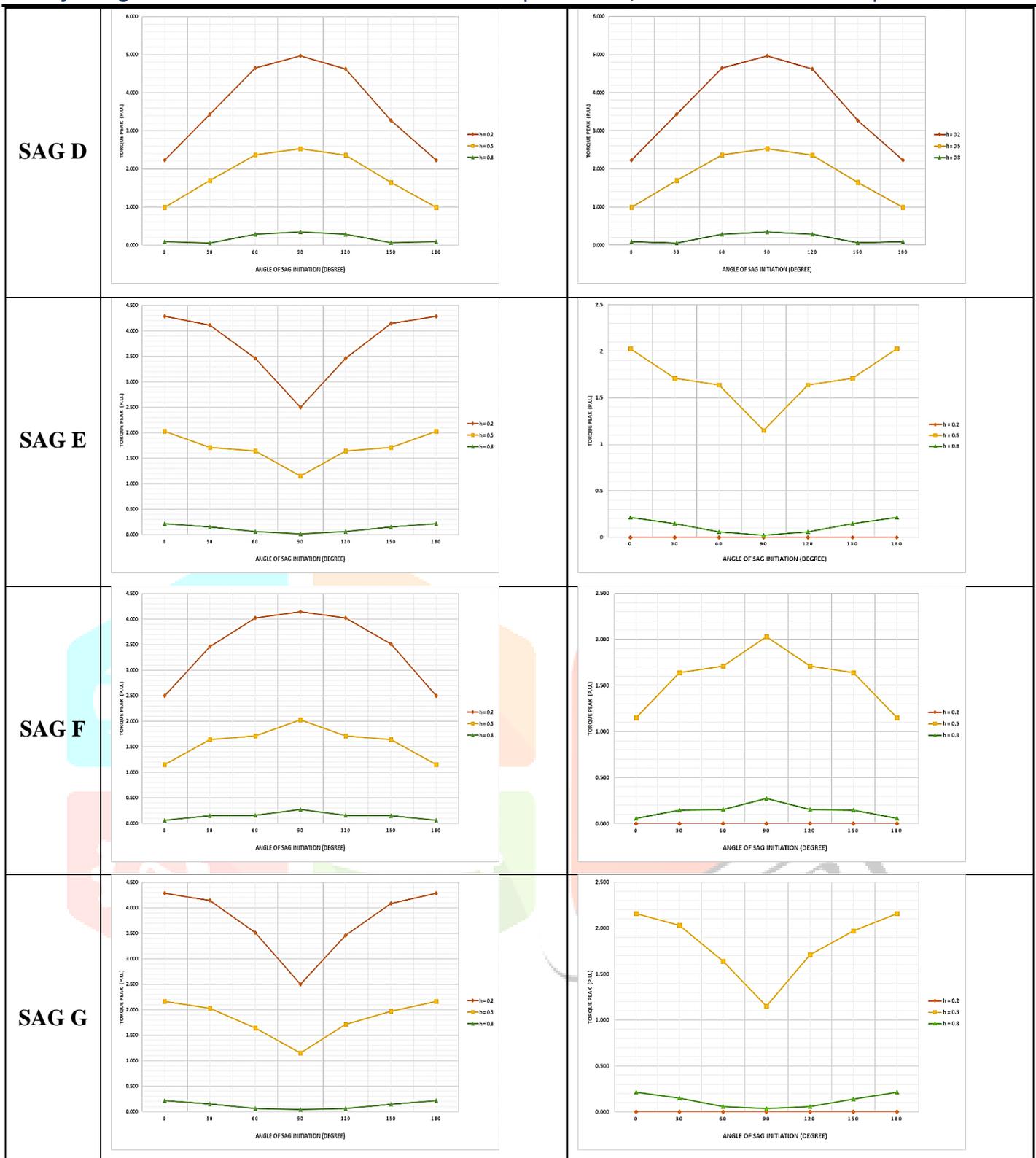
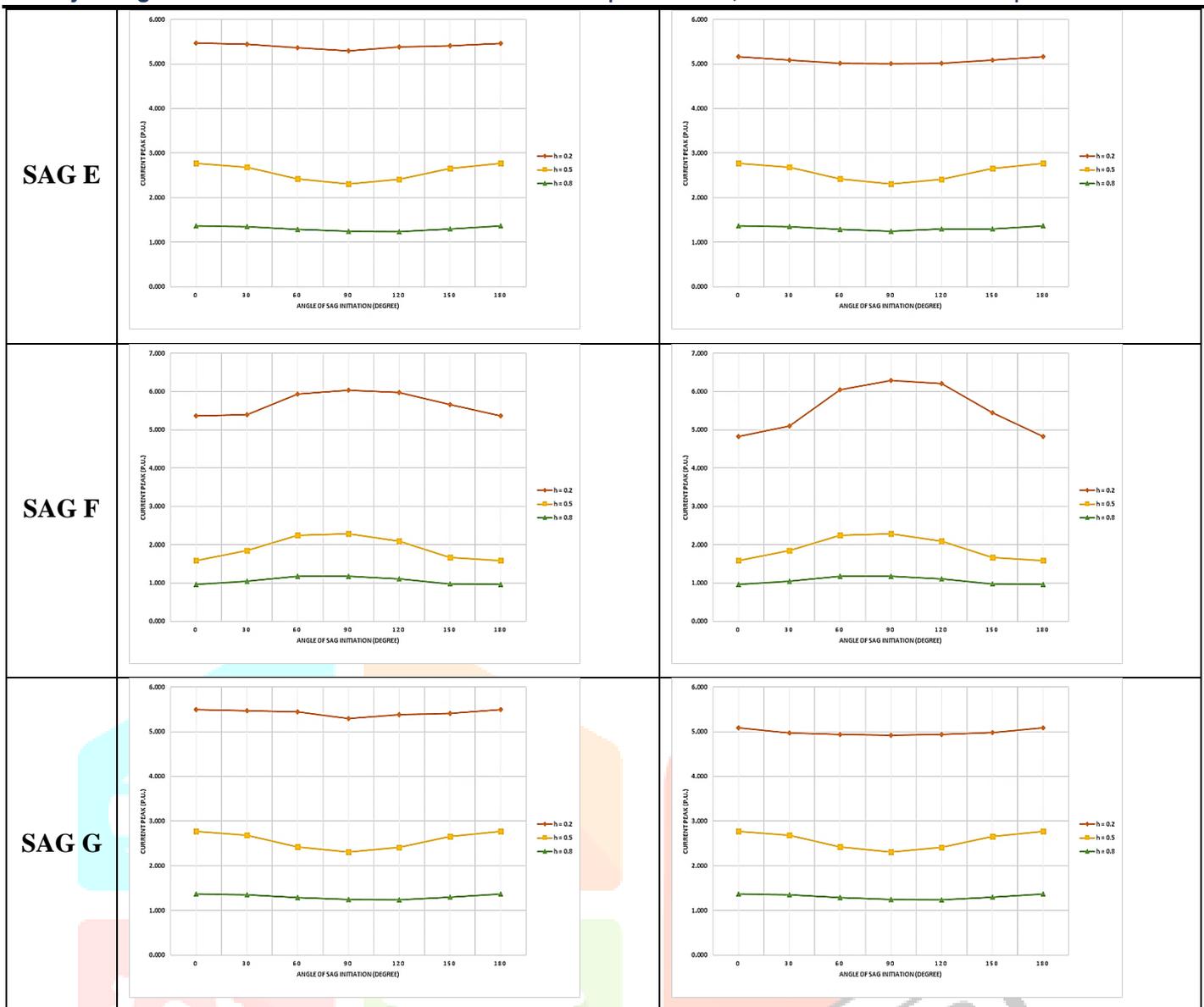


Table 3 shows the result of the simulation for torque peaks under various voltage sag of sag duration of 0.2 sec and 1 sec. Torque peaks are almost constant for all initiation angles for sag A. Maximum torque peaks are obtained at a sag initiation angle of 90° for Sag B, Sag D, and Sag F, and minimum peaks are observed at an angle of 0°. Opposite results are obtained for Sag C, Sag E, and Sag G. The values of torque peaks are the same for sag type E and sag type G at each angle.

The maximum and minimum values of torque peaks for sag type E, sag D, and Sag F are equal. Similarly, Sag C and Sag D have similar values of maximum and minimum torque peaks. Maximum torque peaks are obtained in Sag type C and Sag type D. For voltage sag A of the magnitude of 0.2 and sag duration of 1-sec motor stalls.

Table 4: Current peaks of induction motor when subjected to voltage sag type A, B, C, D, E, F, and G at different point-on-wave initiation for sag duration of 0.2 sec and 1sec.

	Current Peaks for sag duration of 0.2 sec	Current Peaks for sag duration of 1 sec
SAGA		
SAG B		
SAG C		
SAG D		



Results from the simulation in terms of the current peak for a voltage sag duration of 1 sec under full load are shown in table 4. For Sag B, Sag D, and sag F maximum and minimum current peaks are obtained at sag initiation angles of 90° and 0° respectively. Maximum and minimum current peaks are obtained at 0° and 90° respectively for sag C, sag E, and sag G. The magnitude of peak current for sag A is almost the same at each sag initiation angle.

Conclusions

The effect of the duration of voltage sag on the performance of induction motors under various voltage sag has been studied based on torque peaks and current peaks. All seven types of voltage sag according to ABC classification have been applied to the induction motors having sag initiation angles of 0° , 30° , 60° , 90° , 120° , 150° , and 180° subjected to various voltage sag of combinations of sag magnitudes 0.2, 0.5, and 0.8 and sag duration of 0.2 sec and 1 sec.

It was observed that torque peaks remain the same for both the instantaneous sag as well as momentary sag whereas for voltage sag type A, type C, and type D the current peaks were higher in magnitude for momentary sag than the current peaks for instantaneous voltage sag.

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