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Simulation of the voltage sag types effects on induction motor performance

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ABSTRACT

This paper analyzes the effects caused by voltage sag types A, B, C and D on the induction motor performance. The main effects produced can be investigated in current, torque, and motor speed. These effects depend on several characteristics of the sag, such as sag type, magnitude, duration and recovery voltage instant. Voltage sags are generally caused by the faults on transmission and distribution systems. Several fault types may occur are single line to ground fault, line to line fault and two-line to ground fault and three-line fault. The faults produce propagation of voltage sags in power systems. The propagation of voltage sags through transformer winding connections can change types of voltage sag on the secondary side of the transformer and it is also depending on the fault types. In this study the transformer winding connection and fault types at a certain location is used as model for generating characteristics of the sag. PSCAD/EMTDC power system simulation was used for the purpose analysis.

Keywords: *Voltage sag types, induction motor, current peak, torque peak, speed loss.*

INTRODUCTION

The voltage sag is a reduction between 10 % and 90 % in the RMS value of voltage during a time period of 0.5 cycles to 1 minute (1). Voltage sags can result in tripping of customer equipment and shutting down of production lines leading to production loss and expensive restart procedures. The main causes of voltage sags are faults, motor starting, and transformer energizing. Voltage sags due to short circuit faults have become one of the most important power quality problems faced by industrial customers (2-3). Because commonly they can cause severe sags. Although duration of voltage sag caused by motor starting is generally longer, but voltage drops are usually small and do not cause serious problems at the customer locations (1).

In power systems, three-phase faults which result in severe sags are very rare. Single line-to ground faults that typically cause shallow sags, on the other hand are very common. The probabilities of the various types of faults are 70% single phase to ground, 15% phase to phase fault, 10% double phase to ground and 5% three phase fault [3].

Voltage sag can be characterized by magnitude and duration. Magnitude and duration are two essential and important sag characteristics which determine the equipment performance [1-2]. Typical which describe in terms of magnitude and duration for 50% voltage sag with a duration of four cycles such as in Figure 1.

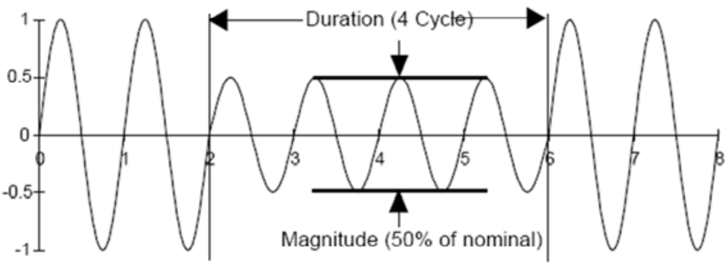


Figure 1: Voltage Sag Described Magnitude and Duration

The magnitude is determined by electrical distance to fault (impedance) and types of faults. The duration is determined by the fault clearing time. It is commonly low, less than one second and depend on the over current protection equipment, how long the fault current is allowed to flow. The others characteristics such as balance and unbalance voltage sags, phase angle shift or phase angle jump, point on wave of initiation and recovery have been found to influence significantly the equipment's sensitivity to the voltage sags [2]. Sensitive equipment to voltage sags include: computer controlled processes, adjustable speed drive, computer and induction motor.

Three-phase induction motors are one of the most pieces of equipment used in industrial systems. They are either directly connected to the power supply or through an adjustable speed drive according to the requirements of industrial systems. Regardless of connection, the performance of motors is greatly influenced by voltage sags [2-5-6]. Even induction motors are susceptible to staling under voltage sag or momentary interruption conditions for several seconds duration [7].

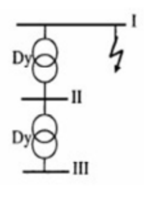
The performance of induction motor are subjected to voltage sags are different. They are depending on many factors such as; magnitude and duration of voltage sags, parameters of the motor, and mechanical inertia [5-6].

When the supply voltage to the induction motor decreases, the motor speed decreases and it's depends on type and duration of the voltage sags. The motor speed does not directly to its minimum level, but experience de-acceleration (slow down). When end of the sag the motor speeds experience re-acceleration toward normal level. Influence of loading on the speed of induction motor is not significant [7]. The voltage recovery instant after fault clearance, the motors may accelerate to normal condition, taking a large current depending on their speed and starting current characteristic. Usually the large motors are completed with protection system. These transient effects can trigger system protection the motor [5-6].

As mentioned previously, causes of voltage sag are faults, starting large motor and transformer energizing. This paper presents results of PSCAD/EMTD simulations on an induction motor caused by faults only. Performance changes of the sag type experienced by the motor that are caused by transformer winding connection are introduced. The performance of the motor characteristics namely: torque peak, current peak and speed loss occurred before, during and after the end of sag are presented.

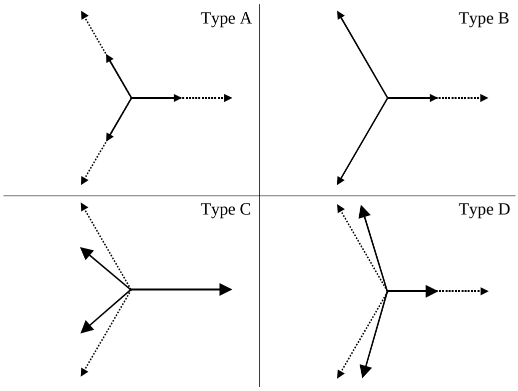
METHOD FOR CREATING TYPES OF VOLTAGE SAG

The most severe sags are due to short circuit and ground faults. Different types of faults lead to different types of voltage sags. The classifications of voltage sag produced by consider three-line, single-line and two-line faults, and existing transformer winding connection such as in Fig. 2. This Figure indicates a fault occurs at location I (bus I). This fault will cause voltage sags at another location (busses I, II and III). For example, when a single-line to ground fault (LG) occurs at the location I, a sag type B is seen at this location. But at the location II below delta-wye connection transformer at the same event is seen as a sag type C and at location III below another delta-star connected transformer the sag is observed as type D. Figure 2 (b) is voltage sag types A, B, C and D in phasor diagram.



Location / Voltage sag type			
Fault type	**I**	**II**	**III**
LLL	A	A	A
LG	B	C	D
LL	C	D	C
LLG	E	F	G

(a) Voltage Sag Types Due to Different Fault Types and Transformer Connection



(b) Voltage sag types in phasor

Figure 2: Voltage Sag Types A, B, C and D

There are seven sag types produced by these faults. In this paper, the classification into four types is used, according to in Figure 2 (b). This classification of three-line unbalanced sag is called as "Basic classification" was proposed by Bollen [(2-4)].

All the forth types of voltage sags can be created by faults with condition as follow:

- Voltage sag of type A is due to three-line faults (3L-G).
- Voltage sag of type B is due to single-line to ground faults (L-G).
- Voltage sag of type C is due to single-line to ground faults (2L-G) or line to line faults, and
- Voltage sag of type D is due to a single-line to ground fault after two delta-wye transformers or due to a line to line fault after one delta-wye transformer.

THE SYSTEM UNDER STUDY

System Modeling

To generate the voltage sag characteristics, an induction motor is supplied by a generator through a delta-wye connection transformer. For creating voltage sag type, some of fault types are simulated occurred at bus-bar. Performances of the induction motor are captured on the motor terminal.

One line diagram of system model for creating voltage sag types such as in Figure 3. For voltage sag types A and D, the faults location are simulated at Bus 1, whereas for voltage sag types B and C, the faults at Bus 2. The sag duration of 200 milliseconds and it starts from 0.4 seconds to 0.6 seconds.

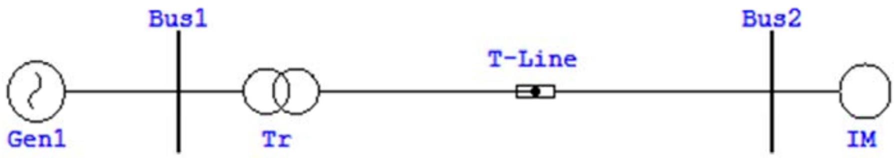


Figure 3: One Line Diagram of System Modeling Used for Creating Voltage Sag Types

Figure 3 shows a 0.5 MVA three phase transformer, 13.8/6 kV delta wye grounded connection is connected to a 0.36 MVA squirrel cage induction motor. For simulating the motor is operated in unloading condition.

Induction Motor Data

Induction motor used is a squirrel cage type EMTP 40 with internal parameters such as in Table 1.

Table 1: Internal Parameters of SQC 100 Model

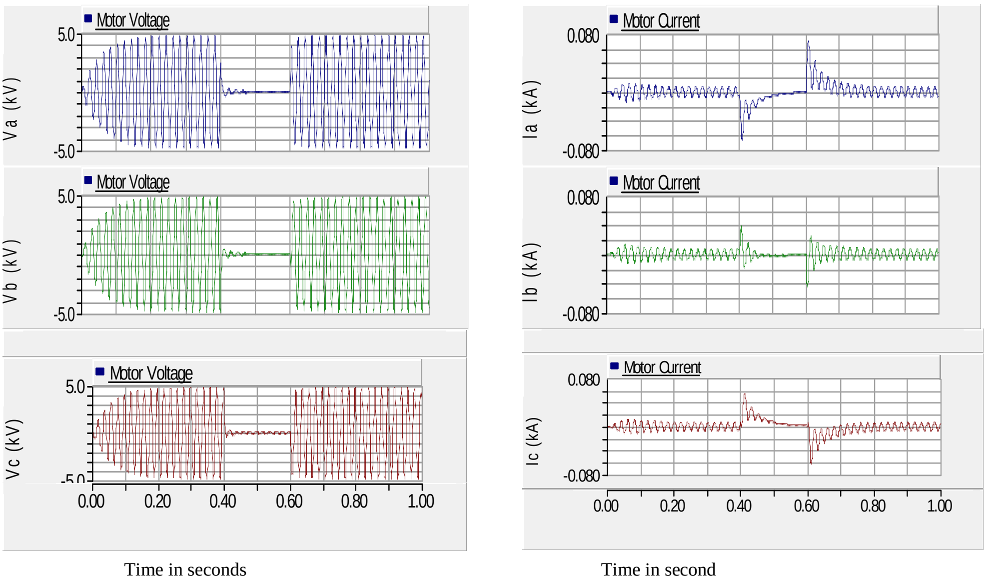
Power factor at rated load	0.85 p.u
Efficiency	0.96 p.u
Slip at full load	0.015 p.u
Starting current at full volts	0.9 p.u
Starting torque at full volt / Full load torque	5 p.u
Maximum torque / Full load torque	5.0 p.u
Number of poles	4
Polar moment of inertia (J)	10 kgm^2
Mechanical damping	0.08 P.u

RESULTS AND DISCUSSION

Performance of Induction Motor Caused by Voltage Sag Type A

Figure 4 shows phase voltages and phase currents at the motor terminal subjected to voltage sag type A. From this figure can be seen that all the three-phase voltages at motor terminal toward zero during fault occur. The current peaks occur at fault and voltage recovery instants. The currents can reach several times of its nominal value. Therefore the motor are supplied through one source, three-phase fault can cause the phases current are zero during fault is shown in Figure 5. Although there is no supply voltage to the motor, the motor's speed there is no stall and this is also depending on magnitude and duration of the voltage sag.

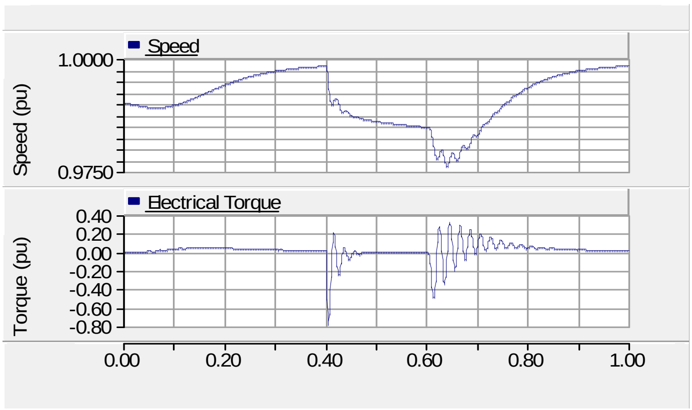
During fault the speed drops and after end of the fault the speed decreases. Next it will accelerate toward normal condition in several seconds after voltage recover. In same time the torque oscillates in several seconds and toward steady state before end of the sag. The torque repeats to oscillate after voltage recover and toward steady state around 200 milliseconds.



(a) Phase voltages of voltage sag type A

(b) Phase currents due to voltage sag type A

Figure 4: Phase Voltages and Phase Currents at the Motor Terminal in Voltage Sag Type A Condition

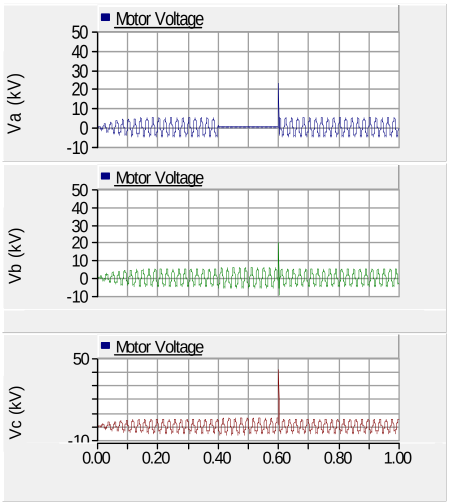


Time in seconds

Figure 5: Speed and Torque Variations due to Voltage Sag Type A

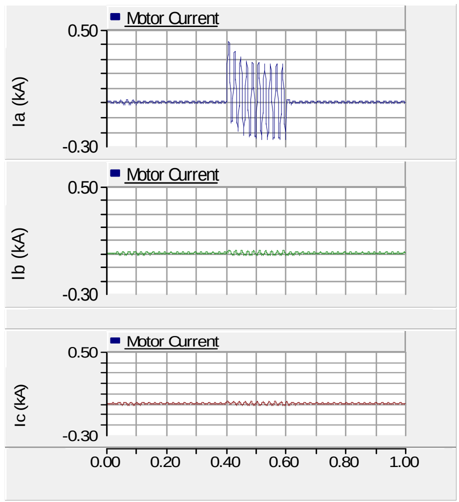
Performance of Induction Motor Caused by Voltage Sag Type B

The voltage sag type B is the voltage sag due to single-line to ground fault such as in Figure 6. Only one phase voltage experiences voltage sag (phase A). The fault creates voltages spike at voltage recovery instant or end of the voltage sag. The current of line faulted produces highly current, whereas two others do not increase. The speed decreases transiently then back to normal value after voltage recovers 200 milliseconds later. From Figure 7, the torque oscillates near to constant value and it returns to normal level after a few seconds end of the voltage sag.



Time in seconds

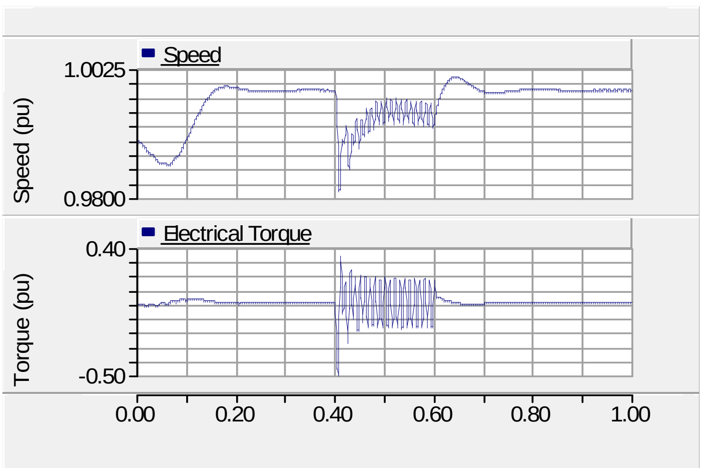
(a) Phase voltages of voltage sag type B



Time in seconds

(b) Phase currents due to voltage sag type B

Figure 6: Phase Voltages and Phase Currents at the Motor Terminal in Voltage Sag Type B Condition

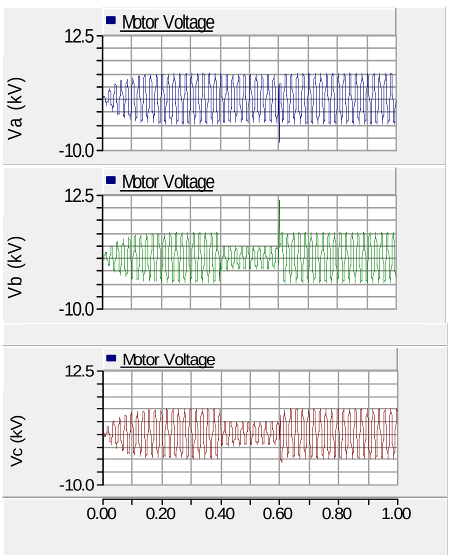


Time in seconds

Figure 7: Speed and Torque Variations due to Voltage Sag Type B

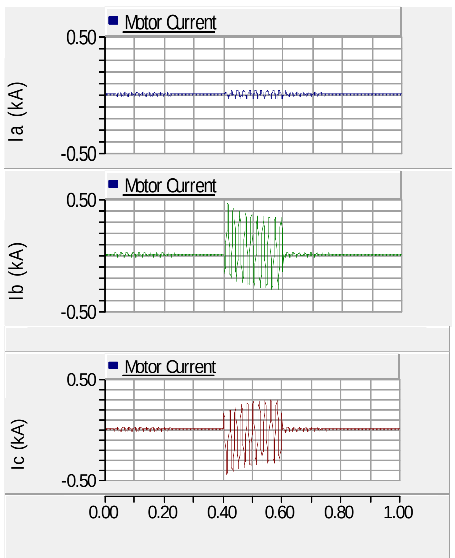
Performance of Induction Motor Caused by Voltage Sag Type C

Voltage sag type C is produced by line-line fault at the bus 2. The effects resulted on the current; speed and torque are shown in Figure 8 and Figure 9. Two lines faulted experience voltage sag and have highly current during fault in different waveform. The speed slow down gradually during fault and increase gradually also to normal level after voltage recovers. During fault, the torque tendency oscillates and reaches steady state after the end of the sag.



Time in seconds

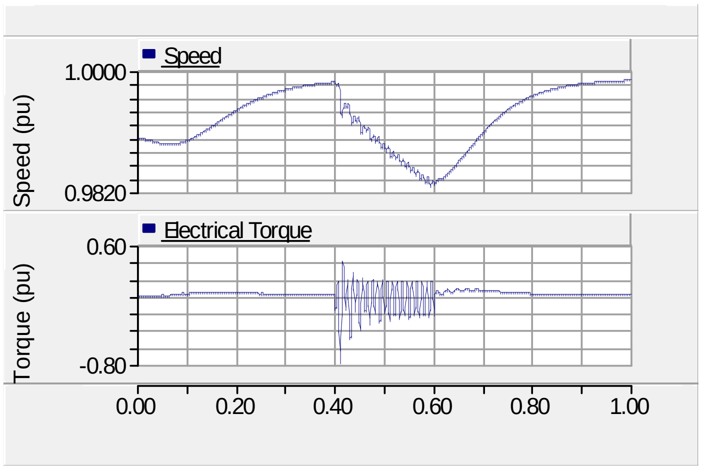
(a) Phase voltages of voltage sag type C



Time in seconds

(b) Phase currents due to voltage sag type C

Figure 8: Phase Voltages and Phase Currents at the Motor Terminal in Voltage Sag Type C

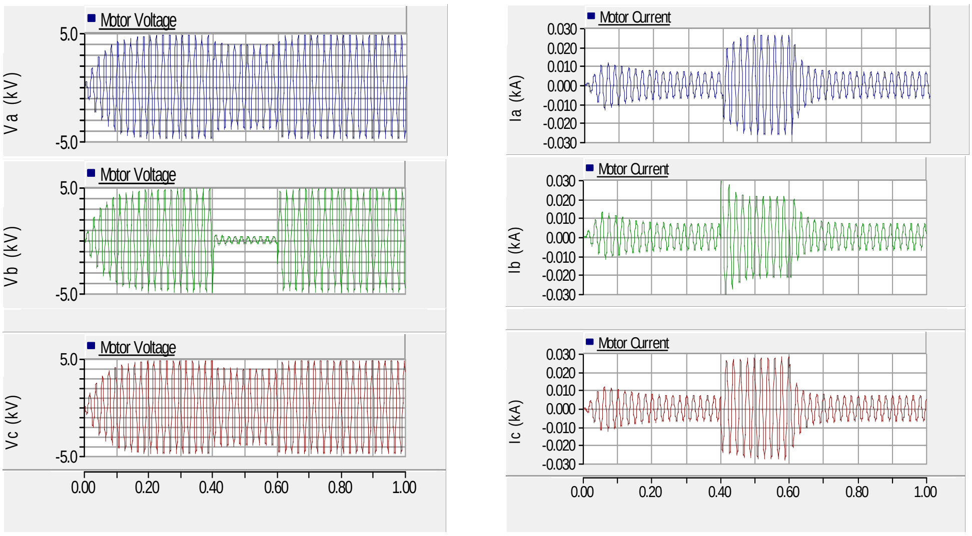


Time in seconds

Figure 9: Speed and Torque Variations due to Voltage Sag Type C

Performance of Induction Motor Caused by Voltage Sag Type D

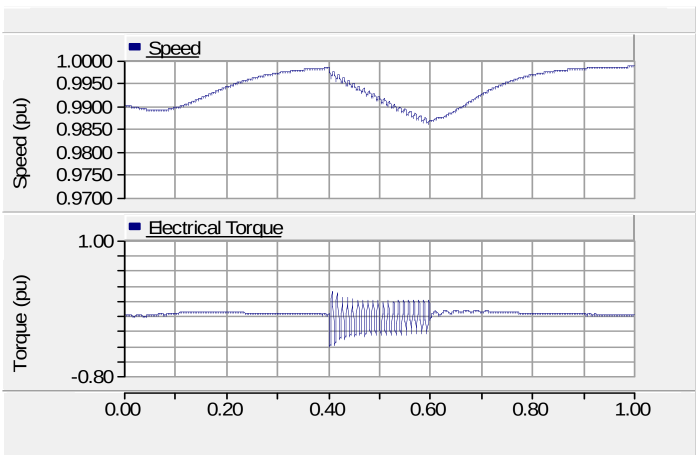
The voltage sag types D are also resulted from line-line fault, but it occurs at different fault location. Propagation of the fault through a transformer winding connection will change type of voltage sag. This can be observed in Figure 10 (a), two phases are subjected to fault produce only one phase experience voltage sag significantly, whereas two phases other drop not significantly. All the phase currents increase significantly and they can reach several times the current before fault. The speed and torque almost similar to type C, but the speed and torque of variation are less deep.



Time in seconds | Time in seconds

(a) Phase voltages of voltage sag type D | (b) Phase currents due to voltage sag type D

Figure 10: Phase Voltages and Phase Currents at the Motor Terminal in Voltage Sag Type D



Time in seconds

Figure 11: Speed and Torque Variations due to Voltage Sag Type D

CONCLUSIONS

The results of the simulation can explain that voltage sag type A causes the current peak higher than other types. Variation of the speed and the torque resulted are deeper. These occur at beginning voltage sag and after recovery voltage instants. The voltage sag type B produces current peak in one phase only. The speed decreases transiently and back to normal in few seconds whereas the torque oscillates until voltage recovers. Voltage sag type C and D result in speed decrease and return to normal gradually and the torque oscillates during voltage sag only. The motor currents in two phases are increase in sag type C, whereas in sag type D is all the three phases.

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