EFFECT OF VOLTAGE SAG TYPES ON AC MOTOR DRIVE : TEST RESULTS

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ABSTRACT

The primary function of any motor drives is to control the speed of a motor. Applications of motor drive have known as Adjustable Speed Drives (ASDs) have benefited many industrial facilities. Adjustable speed drives are reported one of the most sensitive loads to voltage sags because content electronically based. Many drives will trip if the voltage magnitude of one, two or all phases sag below 90%. When this occurs will cause shutdown the entire industrial operation process, thus to suffer financial losses and lost energy for utility. In this paper present results testing on sensitivity of AC motor drive during voltage sags types A, B, C and D. The ASD disrupts for all sag types with remaining voltages less than 70% of rated voltage and with duration 80 milliseconds and above. The ASD is more sensitive to voltage sag type A than other types.

Key Words : AC Motor adjustable speed drive, Voltage tolerance curve, Voltage sag types, AC motor drive, Tolerance Curve

INTRODUCTION

Voltage sags are the most frequent among various types of power quality disturbances (e.g., voltage sag, voltage swells, over voltages, interruption, transients, voltage unbalance, and short interruptions, transient, voltage unbalance, voltage flicker and harmonics).¹ The voltage sags have great influence on sensitivity of electronic ASDs. An ASD is to control the speed of an induction motor or synchronous motor by converting fixed frequency/fixed magnitude AC main supply voltage to a variable frequency/variable magnitude voltage at the motor terminal. Improved efficiency, energy saving and process control are some of the benefits that ASDs provide, therefore ASDs is widely used in many industrial and other application. Effect of ASD to voltage sags can significantly for many industrial processes because ASDs are one of the most sensitive loads to voltage sag.² Mostly ASDs are equipped with an under-voltage protection on DC bus. When the DC bus voltage drops below setting value of under voltage protection level $V_{\text{min}}$, the ASD trips. Some ASDs have the option of re-start immediately, others re-start after a certain delay time and others only admit a manual re-start operation. In textile and paper mills, a brief of voltage sag may potentially cause and ASD to introduce speed fluctuations which can damage the end product. This can result in significant loss in revenue and costly down time.

Voltage sag and voltage tolerance curve

Voltage sags are defined as a sudden reduction of the supply the RMS voltage between (10-90) % of the nominal voltage at the power frequency, for duration from a half cycle to one minute. If the duration is greater than 1 minute it is considered as under voltage.³ Voltage sag is classified as instantaneous when its duration ranges from 0.5 to 30 cycles, momentary lasting between 30 cycles and 3 seconds and temporary extending from 3 to 60 seconds. Main source of voltage sags is fault on utility system and within the facility. It can also be caused by energizing of heavy loads or starting of large motor.

The sensitivity of ASD to voltage sag is often expressed in terms of only their magnitude and duration which called rectangular voltage-
tolerance curve as in Fig 1. The curve provides information about the minimum voltage for specified maximum duration and can be tolerated by the ASD. According to the Fig 1, the equipment must be able to tolerate a voltage sag to $V_{\text{min}}$ for duration up to $T_{\text{max}}$. When the voltage sag is longer than the specified duration and deeper than specified voltage magnitude will to meet sensitivity area (the ASD may be disruption, trip or malfunction).

![Fig. 1: Rectangular voltage tolerance curve](image)

**Characteristics and classifications of voltage sag**

Magnitude and duration of voltage sags have been used for development of equipment sensitivity and indices. They are main characteristics of voltage sag. Other voltage sag characteristics i.e., point on wave of initiation of sag, phase jump, recovery, three-phase balance and unbalance are also very important for assessing equipment sensitivity to voltage sags. The most severe sag voltage sags are due to short circuit fault and ground faults. Different types of faults lead to different types of voltage sags. The classification considers three-phase, single-phase and two-phase faults, star and delta-connected equipment and all types of transformer connection. A, B, C and D classification as proposed by Bollen, such as in Fig 2. Type A sag is caused by three phase fault and types B, C and D are caused by single phase and phase to phase faults.

**Operation of adjustable speed drives**

An adjustable speed drive is equipment designed to control the speed of an induction motor, generating sinusoidal voltages and currents with the necessary frequency and magnitude. The ASDs consist of AC/DC rectifier, DC link and pre charge circuit, DC/AC inverter and control system. In input section, rectifier converts AC voltage in DC voltage. DC link consist occasionally a series inductor and shunt capacitor to smooth out DC voltage from rectifier and so reduce the harmonics distortion in the current taken from the supply. In out-put section, the inverter converts DC into variable frequency and variable voltage AC supply. The out-put of the inverter is fed to the motor. The topology of ASD’s is shown in Fig. 3.

Voltage sags are the most frequent cause of disrupted operations for many industrial processes, particularly those using modern electronic equipments which are very sensitive to short duration supply voltage variations. Adjustable speed drive is one of used in industrial and it is most sensitive equipment against voltage sags. Tripping may occur due to several phenomena.

The drive controller or protection will detect a change in operation conditions and trip the
drive to prevent damage to the power electronic components. When DC-bus voltage drop resulting from voltage sag causes mal-operation or tripping of the drive controller. The increased line currents during the sag or the post-sag may cause over current trip or blowing of fuses protecting the power electronics components. The process driven by the motor will not be able to tolerate the drop in speed or the torque variation due to the sag.

**Fig. 2**: Voltage sag types A, B, C and D

**Fig. 3**: Typical Adjustable Speed Drives (ASDs) system.

During voltage sag or momentary interruption, diodes in an ASD rectifier bridge will not conduct if the peak line voltage drops below the DC bus voltage. While the ASD is still controlling the motor and its load, energy is drawn from DC-bus capacitors, which will cause the DC bus voltage decrease. If the DC-bus voltage drops below the ASD are under voltage trip point before the line voltage returns, then the control circuit will respond according to the drive’s program, typically shutting down the drive. When nominal AC voltage is recovered, some ASDs re-start immediately, others re-start after a certain delay time and others only admit a manual re-start operation. The various automatic re-start options are only relevant when the process tolerates a certain level of speed and torque variation. Because of The ASD is connected to motor, in the process to stop or fluctuate the motor and process speed, it can result in damaged process equipment, unusable product, cleans up, and bad quality product, all of which can be extremely expensive.

**Effects of voltage sags on adjustable speed drives**

Modern industrial equipment incorporates many electronic devices. Power electronic is
used extensively in AC and DC motor drives, process heating, and power supplies. Programmable Logic Controllers (PLCs) and other computers utilize switch mode power supplies. The power electronic components are easily damaged if subjected to high current or voltage surge and the control of these devices usually protect the electronic by tripping.

When voltage sags occur, the power supply voltage is below DC bus voltage, power flowing to ASD is interrupted and DC Bus capacitor will have to supply the load. Therefore, the DC bus voltage will decrease to a voltage level at which ASD inverter will be disconnected. The DC voltage drop depends on the characteristics of the voltage sag, its magnitude, duration, balance, unbalance and phase jump, on the capacity available at the DC bus and the power consumed by the load. Behavior of Adjustable Speed Drives (ASDs) to voltage sags showed in several of published papers and reports. The existing reports are in simulation models found in references 2, 4, 5 and experimental tests results also in reference. 6, 7 Reference 2, analyzed the sensitivity of DC ASD to balanced and unbalanced voltage sags. Influence of sag characteristics such as, sag types, magnitude, duration and phase-angle jump on ASD by consideration control DC drive. Impact of power supply anomalies on ASD has studied in. 4 The paper analyzed impact voltage sag and continuous unbalance on DC bus voltage. When the DC bus voltage drops exceed setting value of under voltage relay, the ASD will trip. Extra capacitance is required to improve the ASD ride trough capability. Reference 5, investigated influence of unsymmetrical voltage sag on torque and dc bus voltage with different control algorithm e.g., torque ripple in scalar control, rotor field oriented and direct torque control. Testing results of sensitivity of ASD have conducted in. 6 The paper analyzes standard SEMI F47 to equipment immunity to voltage sags with immunity level of ASD resulted by testing. Sensitivity of ASD to voltage sag can be improved by adjusting re-setting Low Voltage Ride Trough (LVRT).

**AIMS AND OBJECTIVES**

The aim of this paper is to analyze the effect of voltage sag types, depth and duration on the sensitivity of AC motor drive through voltage tolerance curve. A three phase ASD of 0.5 HP, 50/60 Hz, 400-480 Volt, 2 A with load of induction motor of 0.5 HP, 415 Volt was used in this experiment.

**MATERIAL AND METHODS**

**Testing of adjustable speed drive**

This section aim to illustrate the design of the experiment for ASD testing and procedure followed to obtain the results sensitivity of adjustable speed drive.

**Experimental set-up**

Fig. 4 shows experimental set-up for investigating of ASD sensitivity to voltage sags. The experimental configuration consist of a voltage sag generator, Adjustable Speed Drive (ASD) and induction motor. The sag generator can be adjusted by through personal computer to provide a wide variety of the sag characteristics i.e., magnitude, duration, balance and unbalance.

**Testing procedure**

1. Connect the ASD such as in Fig 4.
2. Voltage sag of different magnitudes starting (sag depth 90 % to 10 %) of nominal voltage in step 10%.
3. At each sag depth, vary the sag duration from 5 milliseconds (ms) to 500 milliseconds (ms) in the following way 5, 10, 20, 30, 40,…., 500 milliseconds.
4. If the sags of certain magnitude and duration causes the ASD disrupts was assumed to be sensitive to this type of sags. The testing is repeated until 3 times and then is recorded in a Table 1.
5. Based on the obtained data is plotted as voltage tolerance curve.

**RESULTS AND DISCUSSION**

Table 1 is an example of ASD testing result for sag type A. This table represents points (0) and (x) which ASD is operating normal and disrupt (degrading performance) conditions, respectively. The ASD in operating normal condition, it means ASD keep running during voltage sag and disruption condition, it means drive stop running during voltage sag but it re-start immediately, when the end voltage sag. Voltage tolerance
curves of the ASD for voltage sag types A, B, C and D are shown in Fig. 5 to Fig. 8. From these figures can be shown that there is no effect on the performance of the ASD for sag depth 80% and above for all sag duration. The voltage sag magnitude threshold for all types sag varies between 50 – 70% of rated voltage with duration threshold varies between 70-80 milliseconds. Those are also depending on types of the voltage sag applied. The ASD is more sensitive to balance voltage sag (type A) than other type’s causes of the third phase voltage decrease. The ASD disrupt for sag depth 70% with duration 80 milliseconds and the ASD faster to disrupt for deeper sag. For types other (types C and D) the voltage sag magnitude threshold is 60% of nominal voltage, with duration 70 milliseconds. They are slightly different for deeper sag, for example sag type C and type D for duration threshold 70 milliseconds, magnitude voltage sag threshold is 30 % and 20% of nominal voltage respectively. The ASD is less sensitive to voltage sag type B and the threshold voltage sag magnitude is 50% of rated nominal voltage with duration threshold of 80 ms, this is caused by only single-phase experience voltage sag.

![Fig. 4: Configuration of the experiment](image)

**Table 1: Observation result of the ASD under type A voltage sag**

<table>
<thead>
<tr>
<th>Voltage Sag</th>
<th>Sag duration in millisecond</th>
</tr>
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<tbody>
<tr>
<td>90%</td>
<td>60</td>
</tr>
<tr>
<td>80%</td>
<td>0</td>
</tr>
<tr>
<td>70%</td>
<td>0</td>
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<td>20%</td>
<td>0</td>
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<tr>
<td>10%</td>
<td>0</td>
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</table>
Fig. 5: Voltage tolerance curve of the ASD against type A voltage sag

Fig. 6: Voltage tolerance curve of the ASD against type B voltage sag

Fig. 7: Voltage tolerance curve of the ASD against type C voltage sag
CONCLUSION

The sensitivity of the ASD to voltage sag was presented. The ASD disrupts caused by supply voltage to DC bus voltage drops below under protection level. The sensitivity is depending on types of voltage sag applied. Voltage sag type A is more severe than others types. The ASD disrupts for all type sag with remaining voltages less than 70% of rated voltage and with duration 80 ms and above.

REFERENCES