A Study on Voltage Sag in Industry System with Adjustable Speed Drives

S. A. Azmi, M. F. Mohammed, S. R. A. Rahim, M. R. Adzman, Z. M. Isa, I. Daut

Abstract— The awareness of electric power quality has increased over the past decade as electronic equipment has become more susceptible to power disturbances. The most disruptive power disturbances is voltage sags. Voltage sags produce an important effect on the behavior of adjustable-speed drives (ASD's). Tripping of ASD is one of the greatest voltage sag problem, causing motor to stop with the resultant interruption of manufacturing process. The resulting loss of time and production, or damaged equipment may cause significant economical losses. This paper is focused on the effect of voltage sags on adjustable speed drive (ASD) which commonly used in industry system. Voltage sags are normally described by magnitude variation and unbalance (asymmetry). These factors are important to determine the behavior of ac motor drive during sags. A VSI (Voltage Source Inverter) driving a three-phase induction motor is analyzed through digital simulation. Simulation on sag depth and three types of voltage sags which are based on voltage sag classification, with an emphasis on the changes dc bridge voltage, rms inverter voltage and motor speed were done. Thus, voltages and speed measurement are obtained. Simulation results clearly show that the different types of sags and sag depth would cause dc-link voltage variation and finally result in motor speed changes.

Keywords: voltage sag, adjustable-speed drives, VSI, PWM.

I. INTRODUCTION

The electric utility environment has never been one of constant voltage and frequency due the existence of power quality disturbances such as voltage sag. According to IEEE Standard 1159-1995, voltage sag is defined as a decrease to between 0.1 and 0.9 p.u in rms voltage or current at the power frequency for duration of 0.5 cycles to 1 min [1]. This voltage sag produces an important effect on the behavior of sensitive electronic equipment. The sensitive electronic equipment such as adjustable-speed drives (ASDs) increases the potential for problems with electrical compatibility.

The dominant type of ASD is the pulse-width modulation (PWM) controlled voltage source inverter (VSI). The PWM ac ASD is a converter, comprising of a rectifier (or input inverter), a dc link (or dc bus), an inverter (or output inverter), and additional control and measurement circuits. All these circuits respond to various power quality disturbances both individually and as a complete assembly, leading to high and complex patterns of drive sensitivity.

To quantify the effect of ASD to voltage sags, it is necessary to characterize the parameters of voltage sags. In this paper, voltage sags are characterized by a duration and depth parameter which represented in a two dimensional rms voltage magnitude versus duration plot. The topology of an ASD with voltage source inverter, and the sensitivity of standard ASD are investigated through digital simulation. Voltage sag can be either balanced or unbalanced, depending on the cause [6].

Voltage sag is classified into three types which are type A, type E and type B as shown in figure 1.0 (a), (b) and (c). For type-A voltage sag, all three phase voltages drop in magnitude by the same amount while retaining 120° displacements. For type-B, only one phase voltage drops in magnitude while other two unsagged remain at nominal voltages. While, for type-E, 2 phase voltages drop in magnitude by the same amount and one phase remain at nominal voltage [2],[6].

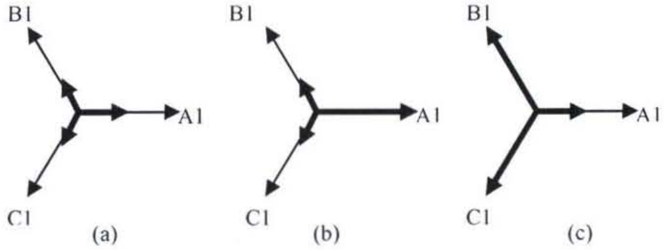

Figure 1: Voltage sag types. All sags have a magnitude of 50 %: (a) three-phase sags, (b) two-phase sags and (c) single-phase sag.

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II. DEVELOPMENT OF ADJUSTABLE SPEED DRIVES MODEL

A typical ASD system, which has four basic components: rectifier, DC link, inverter, and regulator. The rectifier converts line frequency alternating current (AC) to direct current (DC). The DC link smooths the output of the rectifier. And, the inverter generates an adjustable frequency and voltage AC output to the motor. Some applications may require regulators, which help control system output to optimize the process requirements [3].

A balanced voltage source supply to the VSI system circuit is connected as shown in figure 2. The inverter rms ac voltage can be determined as below [5].

Three phase peak voltage, $V_{m,3}$:

$$V_{m,3} = \sqrt{2}V_{rms,3} / \sqrt{3} \quad (1)$$

Three phase bridge rectifier average output voltage can be found using equation (2) and (3). Three phase average dc voltage, $V_{dc,3}$:

$$V_{dc,3} = \left(3\sqrt{3}/\pi\right)V_{m,3} \quad (2)$$

Three phase inverter rms ac voltage, $V_{ac\ rms3}$:

$$V_{ac,rms3} = \sqrt{2/3}V_{s,3} \quad (3)$$

Where $V_{s,3}$ is rms input supply voltage = 415 V.

VSI (Voltage Source Inverter) Induction Motor System with Three Phase Balanced Sag

Figure 2 shows the circuit of three phase balanced voltage sags where during sag voltage, the magnitudes in all three phases are equal. Duration of all sags reduced in tests was the same in all sagged phases. The constructions of the circuit were conducted with three different depth sag voltages (80 %, 50 % and 20 % of rated voltage, 339 V).

VSI (Voltage Source Inverter) Induction Motor System with Two Phase Sag

Figure 3 shows the construction circuits of two-phase voltage sag with three different sag conditions. Two-phase voltage sag is where during sag voltage, magnitudes of two sagged phases are equal; voltage in third is "unsagged" phase is used as parameter, and it can be either rated or below rated. In this case, rated voltage 339 V is chosen.

VSI (Voltage Source Inverter) Induction Motor System with Single Phase Sag

Single-phase voltage sag, i.e., during sag voltage magnitude of one (sagged) phase is below the rated value, 339 V and voltage magnitudes in two other phases are used as a parameter-they are always equal and rated, or equal and below rated voltage. In this case, the rated voltage was chosen for two other phases. Figure 4 shows the circuit of 80% single-phase voltage sag.

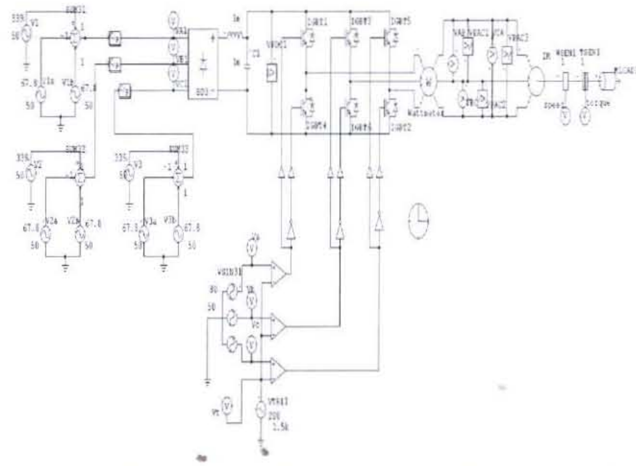

Figure 2: Three phase VSI system with 80 % three-phase balanced voltage sag.

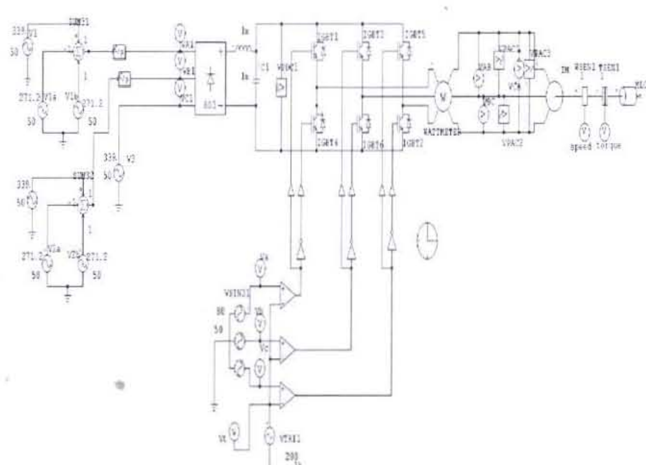

Figure 3: Three phase VSI system with 80% two-phase voltage sag.

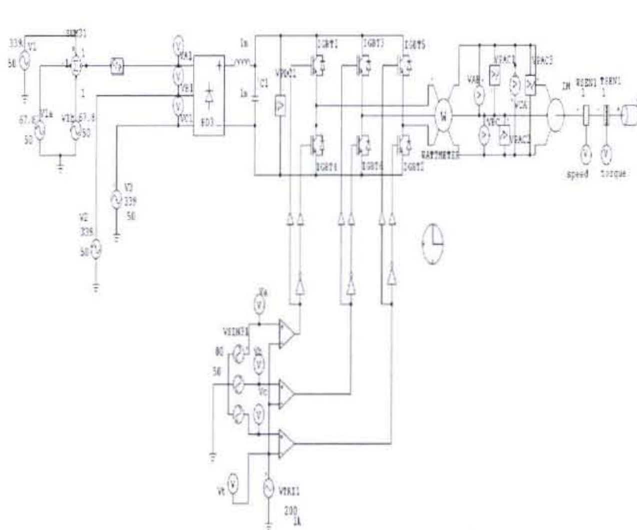

Figure 4: Three phase VSI system with 80% of single-phase voltage sag.

III. SIMULATION OF THREE PHASE BALANCED VOLTAGE SAG (TYPE A)

The result simulation of three-phase balanced voltage sag circuit with different percentages are shown in figure 5,6and 7.

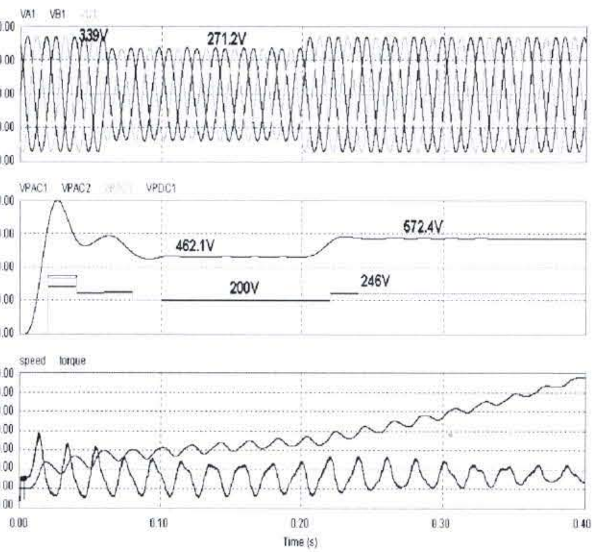

Figure 5: Simulation result of 80 % three-phase voltage sag: (a) Line voltages, VA1, VB1 and VC1; (b)average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

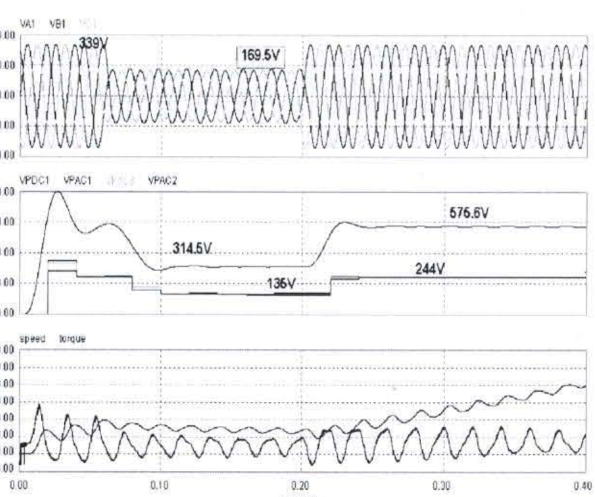

Figure 6: Simulation result of 50 % three-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b)average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

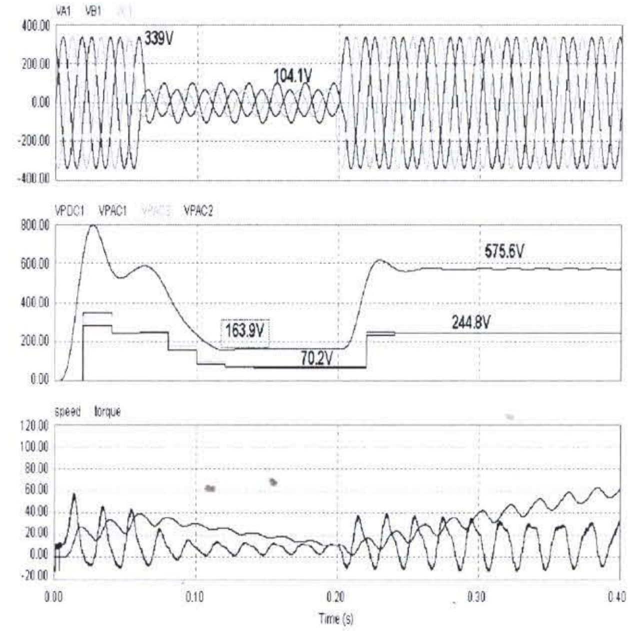

Figure 7: Simulation result of 20 % three-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b)average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

From figure 5, 6 and 7, it is determine that lower voltage sag would cause the average dc voltage and inverter rms ac voltage drop to a lower level. For motor speed waveforms, deeper the voltage sags, the rate of motor speed increased.

IV. SIMULATION OF TWO-PHASE VOLTAGE SAG (TYPE E)

Figure 8, 9 and 10 show the result simulation from VSI system under two-phase with different percentage of voltage sag.

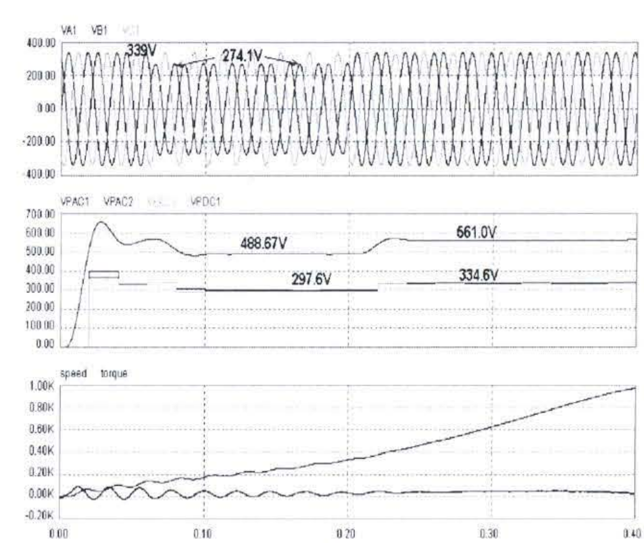

Figure 8: Simulation result of 80 % two-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b) average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

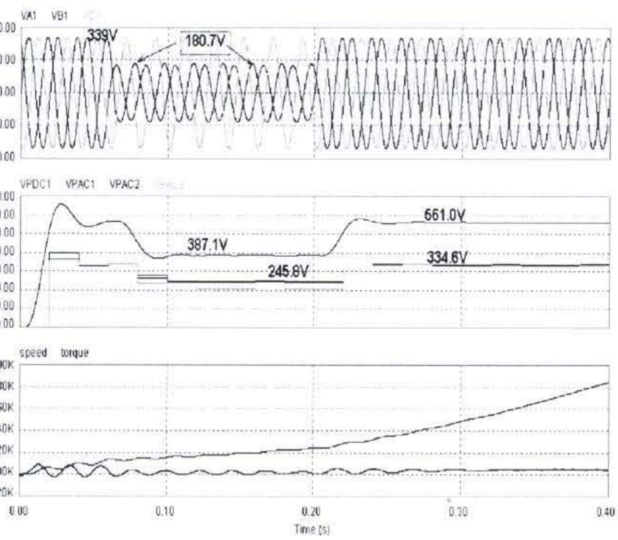

Figure 9: Simulation result of 50 % two-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b) average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

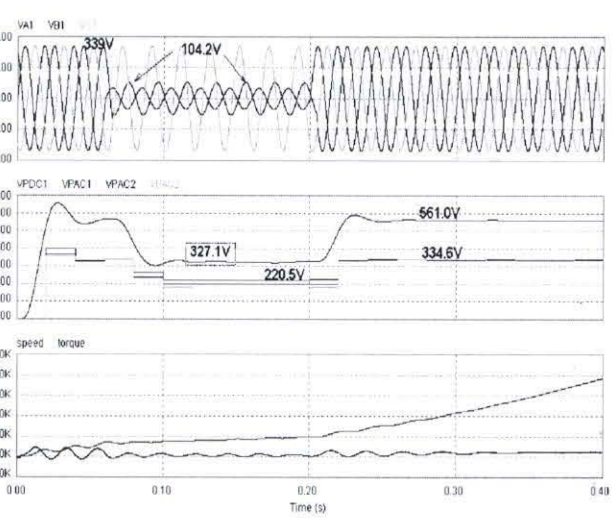

Figure 10: Simulation result of 20 % two-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b) average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

Figure 8, 9 and 10 show that as the percentage of voltage drop increased the voltage during sagging at the output of bridge and inverter are reduced. For motor speed waveforms, as the voltage magnitude in third phase decreases, sensitivity of the drive increases (rate of motor speed is reduced).

V. SIMULATION OF SINGLE-PHASE VOLTAGE SAG (TYPE B)

By referring to figure 4, the simulation results under single-phase with percentage variation voltage sag are shown in figure 11, 12 and 13.

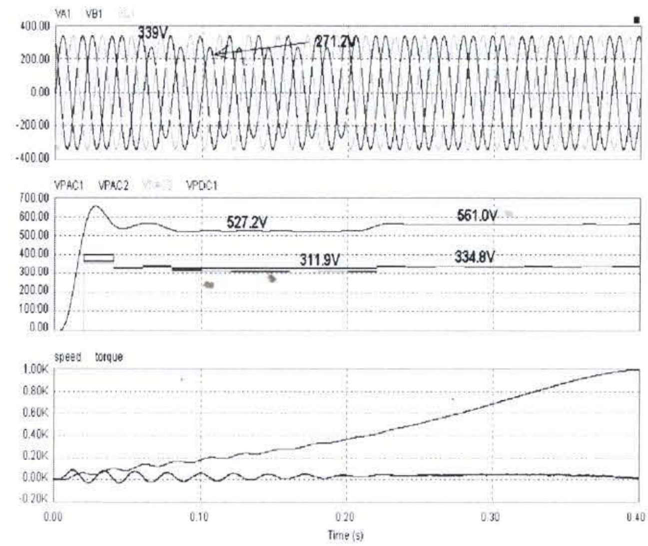

Figure 11: Simulation result of 80 % single-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b) average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

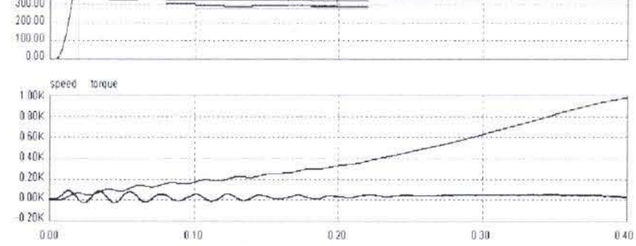

Figure 12: Simulation result of 50 % single-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b) average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

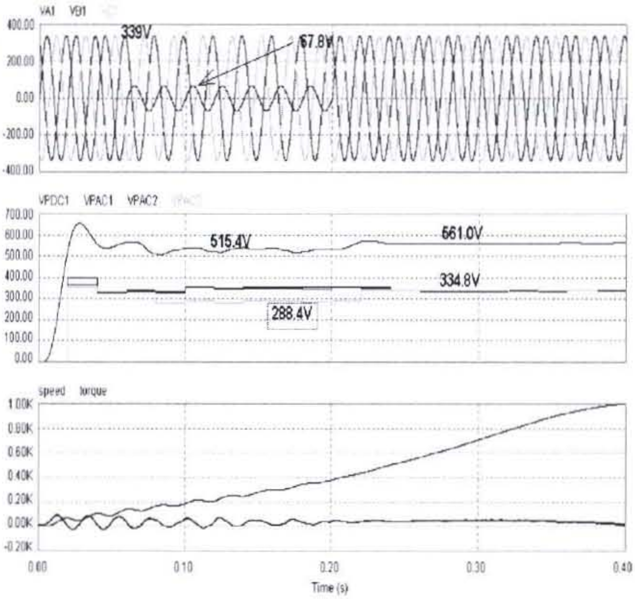

Figure 13: Simulation result of 20 % single-phase voltage sag: (a) Line voltages, VA1, VB1and VC1; (b) average dc voltage, VPDC1 and rms ac voltages, VPAC1, VPAC2 and VPAC3; and (c) Motor speed and torque.

The result obtained are similar to those previously for type A and E where the highest dc voltage and inverter voltage drop are obtained for lower voltage sags during voltage sags.

Refer to figure 11, 12 and 13; it is observed that as the percentage of voltage drop increased, the voltage during sagging at the output of bridge and inverter are reduced. The rate of motor speed getting lower as the percentage of voltage drop increased during sagging.

VI. CONCLUSION

From simulation of three phase VSI system, the measured voltages of average bridge output and rms inverter output are approximately the same from calculated voltage. As expected in simulation of three-phase sags (type A), the sag depth (percentage of voltage sag) is proportional with average bridge and inverter output where the deeper the sag, the lower the magnitude voltages.

The simulation of two-phase sag (type E) and single-phase sags (type B) shows the same results as three-phase sag but the voltage magnitude drop for both bridge and inverter output are lower than the voltage magnitude drop of three-phase sag simulation. These also conclude that lower sag would cause lower voltage level at both output of bridge rectifier and inverter.

During the voltage sag, it is shown clearly evident that the speed drops off as the bridge output voltage and inverter output voltage level drops. Therefore, it is clearly evident that the inverter output voltage variation under voltage sag influence the motor speed rate. Moreover, the higher percentage drop of nominal voltage for certain types of sag, will produced lower speed and it takes longer time to reach steady-state.

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