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Research Article

Analysis of Various Types of Balanced Voltage Sags

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ABSTRACT

Voltage sags originating in AC supply systems can cause nuisance tripping of variable speed drives resulting in production loss and restarting delays.

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INTRODUCTION

Electric problems always occur regardless of time and place. This may cause an impact to the electric supply, thus may affect the manufacturing industry and impede the economic development in a country. The major electric problems that always occur in power systems are the power quality problems that have been discussed by the electrical engineers around the world since problems have become a major issue due to the rapid development of sophisticated and sensitive equipment in the manufacturing and production industries.

The sag according to their duration is categorized as shown in Table 1.

Due to different kinds of fault in power systems, different types of voltage sags can be produced. The voltage sags are classified according to the number of phases affected and the phase displacement, which are associated to the fault type. Voltage sags are divided into seven groups as Type A, B, C, D, E, F, and G.

Voltage sags can be either balanced or unbalanced, depending on the cause. The sag in this thesis is characterized by depth and duration.[1-5]

Geneva-based International Electrotechnical Commission (IEC) and Institute of Electrical and Electronic Engineers (IEEE) have proposed various power quality standards.[9] Table 2 summarizes some of these standards (Ghosh *et al*., 2002).

VOLTAGE SAG

Figure 1 shows the waveform for voltage sag. Sag is a decreased to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. Voltage sags (dips) are short-duration reduction in rms voltage caused by short-duration increase of the current, typically at another location than, where the voltage sag is measured. The most common cause of overcurrent leading to voltage sags are motor starting, transformer energizing, and faults. The capacitor energizing and switching of electronic load also lead to short duration overcurrent, but the duration of the overcurrent is too short to cause a significant reduction in the rms voltage. Voltage sags due to short circuit and earth faults are the cause for the vast majority of equipment problems. Electronic equipment become more susceptible to voltage sags; hence, the companies experience production stoppages.

Voltage sag analysis is a very complex issue since it involves a large variety of random factors such as:

- Type of short circuits - three-phase faults are responsible for larger voltage sag than single line-to-ground faults, although these ones are more frequent.
- Location of faults - transmission system faults are much more severe than distribution system, as a short circuit in a transmission grid is supposed to affect a larger area than the distribution system.
- Protective system performance - the duration of voltage sag is directly related to the protective system performance, i.e., the clearing times.
- Atmospheric discharges - surveys have shown that most of the voltage sag occurrences are associated with atmospheric discharges in transmission and distribution system (Mcgranaghan *et al*., 1995).

Every consumer is subject to a voltage sag occurrence since faults cannot be totally avoided. In fact, the greatest losses will fall on customers who own sensitive equipment such as programmable logic controllers (PLCs) and adjustable speed drives (ASDs). Some of the voltage sag effects on such equipment are as follows:

- PLCs malfunction causing industrial process totally or partially shut down.
- ASDs disconnection with consequent shutdown and production losses.
- Contactors and auxiliary relay dropout.
- Unexpected tripping of under voltage relays.

Figure 2 summarizes the results of the studies using the framework of IEEE 1159:1995/IEC 61000-2-1-IEEE Recommended Practice for Monitoring Electric Power Quality. It shows the percentage of fatal power quality events in different regions of the chart. The point to note here is that 98% of fatal power quality events are shorter than 15 s and most of them are voltage sags and 3% are voltage swells.

THEORITICAL AND SIMULATION ANALYSIS OF BALANCED VOLTAGE SAG

Type A Voltage Sag

Figure 3 shows the phasor diagram and complex equation of Type A sag. Type A is the only sag type that is balanced.

$$U_a = hU$$

$$U_b = -\frac{1}{2}hU - j\frac{\sqrt{3}}{2}hU$$

$$U_c = -\frac{1}{2}hU + j\frac{\sqrt{3}}{2}hU$$

In Type A sag, all the three phases drop in magnitude with the same amount and have 120° phase shift. In complex equations, “h” is the sag depth and “U” is the phase to ground AC voltage. This sag type is more severe than the other types. It is caused by balanced three-phase fault. It results in the reduction of the voltage on the DC link that is proportional to the AC source voltage. The under voltage and overcurrent protection on the DC link may trip the ASDs.

Table 1: Types of voltage sag

Categories	Typical magnitude
Instantaneous sag	0.1–0.9 pu
Momentary sag	0.1–0.9 pu
Temporary sag	0.1–0.9 pu

Type B Sag

$$U_a = hU$$

$$U_b = -\frac{1}{2}U - j\frac{\sqrt{3}}{2}U$$

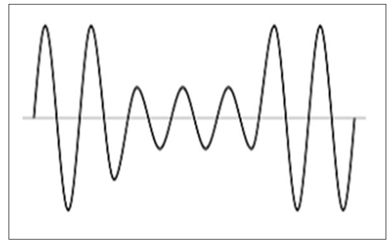

Figure 1: Waveform for voltage sag

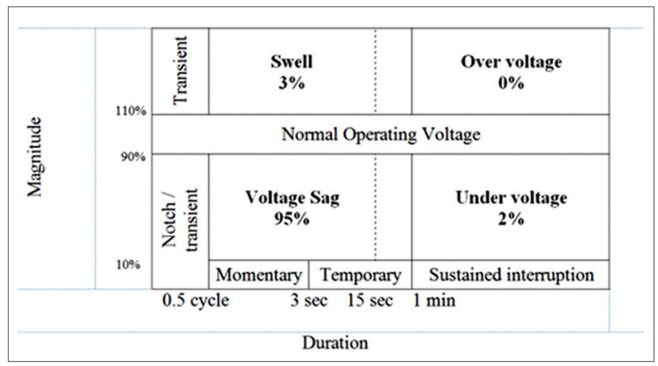

Figure 2: Institute of Electrical and Electronic Engineers 1159:1995

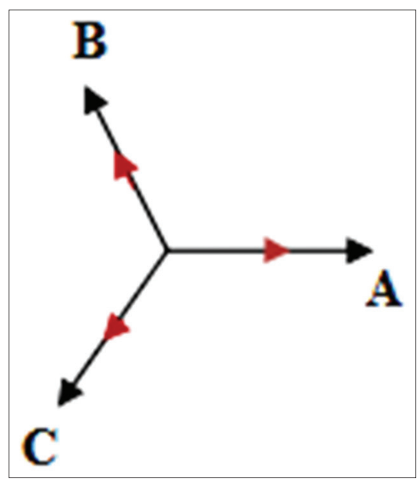

Figure 3: Phasor diagram of Type A sag

Table 2: Power quality standards of IEEE and IEC[8]

Phenomena	Standards
Classification of power quality	IEC 61000-2-5: 1995, IEC 61000-2-1: 1990, IEEE 1159:1995
Voltage sag/swell and interruptions	IEC 61009-2-1: 1990, IEEE 1159: 1995
Harmonics	IEC 61000-2-1: 1990, IEEE 519: 1992, IEC 61000-4-7: 1991
Transients	IEC 61000-2-1: 1990, IEEE c62.41: (1991), IEEE 1159: 1995, IEC 816: 1984
Voltage flicker	IEC 61000-4-15: 1997

IEC: International Electrotechnical Commission, IEEE: Institute of Electrical and Electronic Engineers

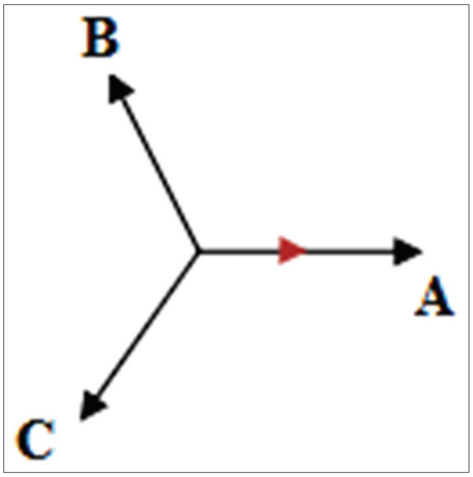

Figure 4: Phasor diagram of Type B sag

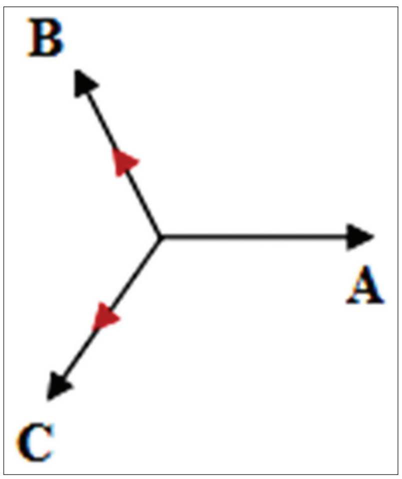

Figure 5: Phasor diagram of Type E sag

$$U_c = -\frac{1}{2}U + j\frac{\sqrt{3}}{2}U$$

Single-phase faults can produce Type B. In this type, one phase has reduced voltage magnitude and the other two phases have same voltage with phase shift of 120°. This is shown in Figure 4. This is the most frequently occurring fault about 80% of the cases.

Type E Sag

$$U_a = U$$

$$U_b = -\frac{1}{2}hU - j\frac{\sqrt{3}}{2}hU$$

$$U_c = -\frac{1}{2}hU + j\frac{\sqrt{3}}{2}hU$$

Type E sags are caused by two phase-to-ground fault. Two phases have reduced voltage magnitude, and no phase angle jump is seen in Figure 5. The effect of Type E and Type G sags is identical because they only differ in zero sequence voltage.

Type A sag is a balanced symmetrical three-phase fault. Hence, the three phases have same reduced voltage magnitudes with phase shift of 120° as seen in Figure 6.

In the supply voltage, 50% sag depth and 30% balanced instantaneous swell are generated between 0.3 and 0.5 s and 0.7 and 0.8 s, respectively.

In Figure 6, the 3Φ supply voltage and line to phase voltage with 50% sag depth of 10 cycles and swell of 5 cycles are presented. The line to phase voltage magnitude is 230V, between 0 and 0.3 s (without fault).

As per complex equations seen in Figure 3 for 50% sag depth, the first phase magnitude is calculated as (115, 0°) and the other two phases are calculated as, $U_b = -57.5-j99.6$, in polar form (115, −120°) and $U_c = -57.5+j99.6$, in polar

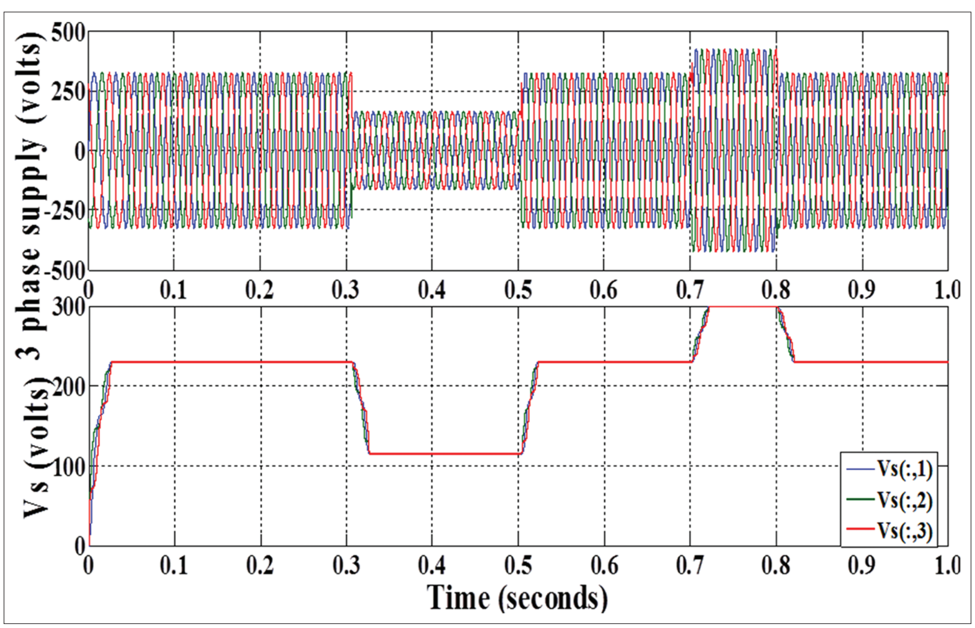

Figure 6: Three-phase supply and line to phase voltage with 50% Type A sag and 30% balanced instantaneous swell

form (115, +120°). Simulation result also shows between 0.3 and 0.5 s (sag duration), the voltage magnitude is 115 V and the phase angle between any two phases is 120°. During swell condition, the voltage sag is 299 V between 0.7 and 0.8 s. This voltage is fed to the ASD.

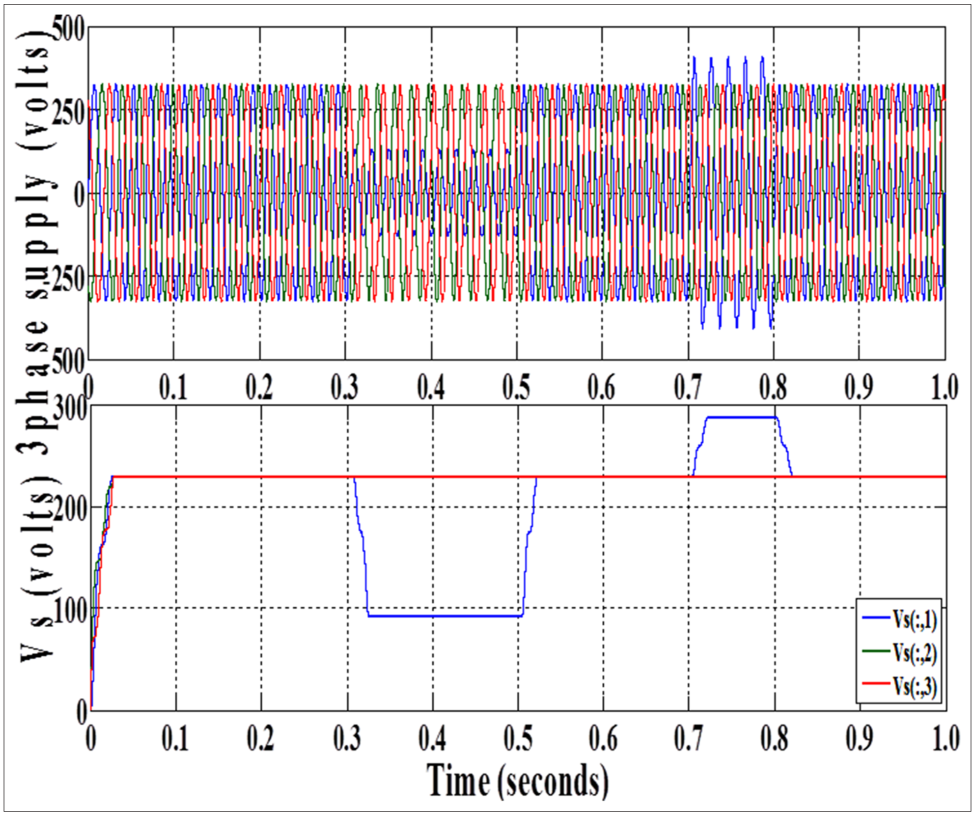

Figure 7: Three-phase supply and line to phase voltage with 60% Type B sag and 25% balanced single-phase swell

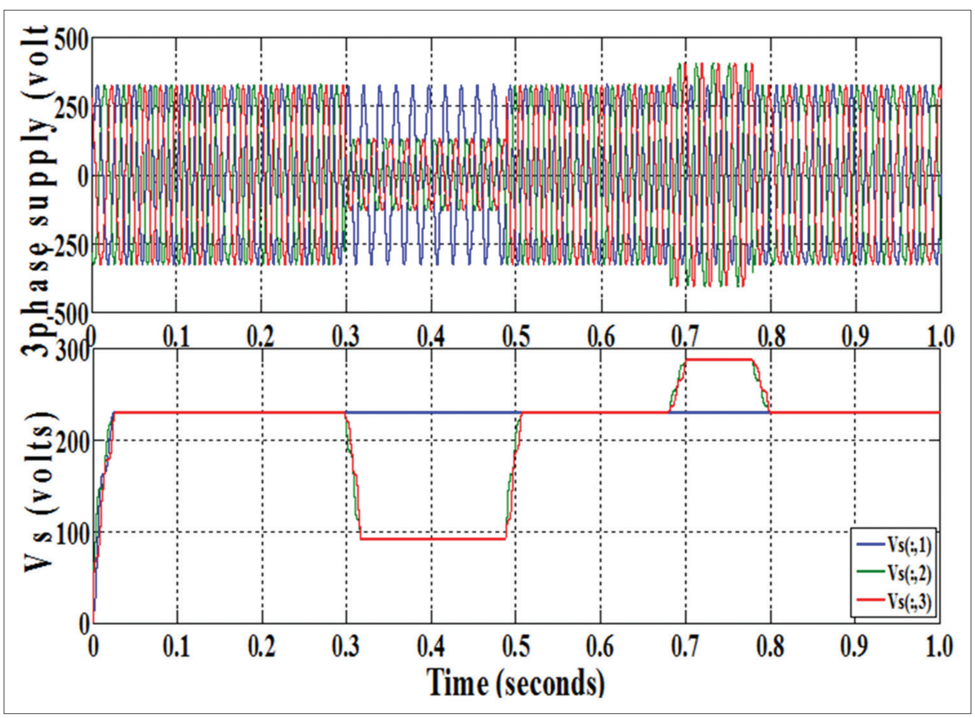

Figure 8: Three-phase supply and line to phase voltage with 60% Type E sag and 25% two-phase swell

Single-phase faults can produce Type B sag. Type B sag is a symmetrical unbalanced sag. In this type, one phase has reduced voltage magnitude and the other two phases maintain same voltage with phase shift of 120° as shown in Figure 4.

In the supply voltage, 60% sag depth and 25% balanced instantaneous swell are generated between 0.3 and 0.5 s and 0.7 and 0.8 s, respectively.

In Figure 7, the first phase has reduced voltage magnitude of U_a = (92, 0°) and the other two phases have voltage magnitudes, as per complex equation [Figure 3], $U_b = -115-j80$, in polar form (230, −120°) and $U_c = -115+j80$, in polar form (230, +120°). The phase angle between any two phases is 120°. The balanced swell of 30% (299 V) in one phase has been generated between 0.7 and 0.8 s and this voltage containing sag and swell is fed to the ASD.

Type E sag is a symmetrical unbalanced voltage swell. Type E sags are caused by two phase-to-ground fault. Two phases have reduced voltage magnitude, and there is no phase angle jump.

10 cycles of 60% sag depth between 0.3 and 0.5 s and 5 cycles of 25% balanced two-phase swell between 0.7 and 0.8 s are generated in the 3Φ supply and are shown in Figure 8.

In Type E sag, the first phase has constant voltage magnitude and the other two phases have minimum reduced voltages. As per the complex equations referred in Figure 5, for 60% sag depth, the first phase voltage magnitude is 230V, and the other two phases are calculated as, $U_b = -46-j79.6$, in polar form (92, −120°) and $U_c = -46+j79.6$, in polar form (92, +120°). In simulation result, between 0.3 and 0.5 s, first phase voltage magnitude is 230 V and the other two-phase magnitudes are 115 V with the phase angle of 120°. A 25% balanced two-phase swell of 287.5 V has been generated between 0.7 and 0.8 s, and this voltage is fed to the three-phase rectifier of an ASD.

CONCLUSION

Among seven types of sags, Type A sag is the worst case in all types of voltage sag because the induction motor parameters are affected more during this type of sag. Type A, Type B, and Type E are symmetrical voltage sags. The effect of motor's performance is similar to Type A sag with changes only in the magnitudes.

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