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A review of Power Quality Problems-Voltage Sags for Different Faults

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Abstract— Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices whose performance is very sensitive to the quality of power supply. There are different power qualities issues like voltage sag, voltage swell, voltage interruption, harmonic distortion and under voltage and over voltage. The increased awareness on power quality has resulted in the need to quantify the voltage performance of a distribution system. Similar to what has been done on characterizing the reliability performance of voltage sag by magnitude, duration and phase angle jump. This paper introduces the concept of Review of Analysis of Voltage Sag/Dip for Symmetrical and Unsymmetrical Fault in Power System.

Index Terms— distribution system, Power quality, Symmetrical and unsymmetrical fault, voltage sag,

I. INTRODUCTION

Power Quality (PQ) related issues are of most concern nowadays. The widespread use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems. Due to their non-linearity, all these loads cause disturbances in the voltage waveform. Although many efforts have been taken by utilities, some consumers require a level of PQ higher than the level provided by modern electric networks. This implies that some measures must be taken in order to achieve higher levels of Power Quality.

II. Power Quality

Power quality is a consumer-driven issue, and the end user's point of reference takes precedence

From utility point: Power quality is defined as reliability and show statistics demonstrating that its system is 99.98% reliable.

From manufacturer's point: Power quality is defined as those characteristics of power supply that enables the equipment to work properly & maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency.

***III.* Sources And Effects of Power Quality Problems** The distortion in the quality of supply power can be introduced /enhanced at various stages; however some of the primary sources of distortion can be identified as below:

A. Power Electronic Devices

B. IT and Office Equipments
C. Arcing Devices
D. Load Switching
E. Large Motor Starting
F. Embedded Generation
G. Electromagnetic Radiations and Cables
H. Storm and Environment Related Causes etc.

While power disturbances can occur on all electrical system, the sensitivity of today's sophisticated electronic devices makes them more susceptible to the quality of power supply. For some sensitive devices a momentary disturbance can cause scrambled data, interrupted communication a frozen mouse, system crashes and equipment failure etc. A power voltage spike can damage.

IV. Power Quality Events

"*It include all possible situations in which the waveforms of the supply voltage or load current deviate from the sinusoidal waveform at rated frequency with amplitude corresponding to the rated rms value for all three phases of a three-phase system."*

Power quality phenomena can be divided in to two types, which need to be treated in a different way.

- A characteristic of voltage or current (frequency or power factor) is never exactly equal to its nominal or desired value. The small deviations from the nominal or desired value are called "voltage variations" or "current variations".
- Occasionally the voltage or current deviates significantly from its normal or ideal wave shape. These sudden deviations are called "events".

There are many Power Quality events or phenomena which only happen every once in a while. Some of them are discussed below.(According Table 1).

V.Voltage Sag

Voltage sags are a common power quality problem. Despite being a short duration (10ms to 1s) event during which a reduction in the RMS voltage magnitude takes place, a small reduction in the system voltage can cause serious consequences. The definition of voltage sags is often set based on two parameters: magnitude/depth and duration. However, these parameters are interpreted differently by various sources. Other important parameters that describe a voltage sag are:

- the point-on-wave where the voltage sag occurs, and

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- the phase angle changes during the voltage sag

A phase angle jump during a fault is due to the change of the X/R-ratio. The phase angle jump is a problem especially for power electronics using phase or zero-crossing switching.

A dip or sag, as defined by IEEE Standard 1159, IEEE Recommended Practice for Monitoring Electric Power Quality, is "a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage". Typical values are between 0.1 p.u. and 0.9 p.u. Typical fault clearing times range from three to thirty cycles depending on the fault current magnitude and the type of overcurrent detection and interruption.

Another definition as given in IEEE Std. 1159, 3.1.73 is "A variation of the RMS value of the voltage from nominal voltage for a time greater than 0.5 cycles of the power frequency but less than or equal to 1 minute. Usually further described using a modifier indicating the magnitude of voltage variation (e.g. sag, swell, or interruption) and possibly a modifier indicating the duration of the variation (e.g., instantaneous, momentary, or temporary)"

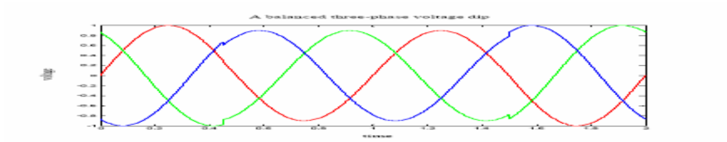

Fig.1 (a) A balance 3-phase voltage sag

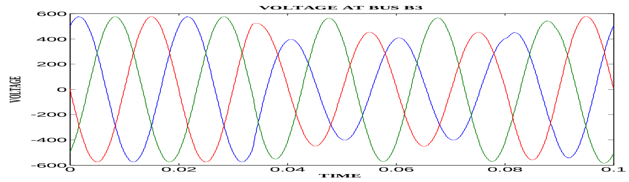

Fig.1 (b) An unbalanced 3-phase voltage sag

A voltage sag is basically classified as balanced or unbalanced sag and depending on sag magnitude severity deep and shallow sag as shown below in fig. 2(a), (b).

1) Deep sag: A deep sag is a with a low magnitude as shown in fig. 2(a)

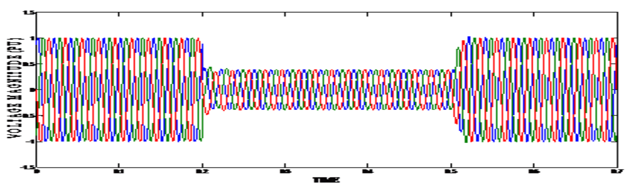

Fig. 2(a) Deep Sag

2) ***Shallow Sag:*** A shallow sag is a with a large magnitude as shown in fig. 2(b)

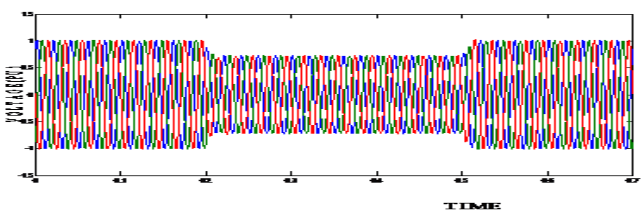

Fig. 2(b) Shallow Sag

VI. General Overview of Causes and Effects on Voltage on Power System.

There are various causes of voltage sags in a power system. Bollen [1] has provided a brief review of the causes of voltage sags which are as follows.

A. Voltage sags due to faults

Voltage sags due to faults can be critical to the operation of a power plant, and hence, are of major concern. Depending on the nature of the fault (e.g., symmetrical or unsymmetrical), the magnitudes of voltage sags can be equal in each phase or unequal respectively.

For a fault in the transmission system, customers do not experience interruption, since transmission systems are looped/networked .One-cycle rms voltage for the voltage sag can be seen as in Fig.3.

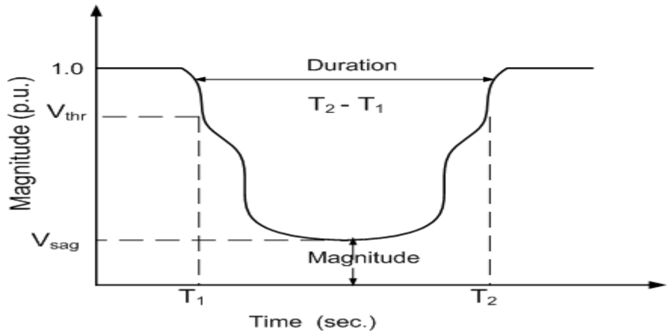

Fig.3. RMS voltage for the voltage sag

Factors affecting the sag magnitude due to faults at a certain point in the system are:

- Distance to the fault
- Fault impedance
- Type of fault
- Pre-sag voltage level
- System configuration
  - System impedance
  - Transformer connections

B. Voltage sags due to induction motor starting

Since induction motors are balanced 3φ loads, voltage sags due to their starting are symmetrical. Each phase draws approximately the same in-rush current. The magnitude of voltage sag depends on:

- Characteristics of the induction motor
- Strength of the system at the point where motor is connected.

C. Voltage sags due to transformer energizing

The causes for voltage sags due to transformer energizing are:

- Normal system operation, which includes manual energizing of a transformer.
- Reclosing actions

The voltage sags are unsymmetrical in nature, often depicted as a sudden drop in system voltage followed by a slow recovery. The main reason for transformer energizing is the over-fluxing of the transformer core which leads to saturation. Sometimes, for long duration voltage sags, more transformers

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are driven into saturation. This is called Sympathetic Interaction.

VII. Characterization of Voltage Sag.

A. Sag Magnitude

To quantify the sag magnitude, the voltage divider model of radial distribution system shown in following fig.4 can be used.

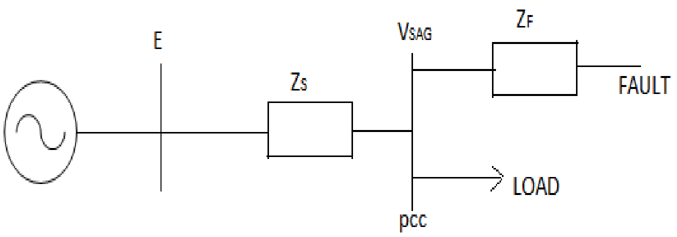

Fig.4. Voltage Divider Model for voltage sag.

Above fig. shows two impedances: Z_S is the source impedance at the point of common coupling; and Z_F is the impedance between the point of common coupling and the fault. The point of common coupling (pcc) is the point from which both the fault and the load are fed. In the voltage divider model, the load current before as well as during the fault is neglected. Voltage at the pcc and though voltage at the equipment terminal, can be found from

$$V_{sag} = \frac{Z_F}{Z_S+Z_F}E$$

We will assume that the pre-event voltage is exactly 1 pu, thus *E*=1. This result in the following expression for the sag magnitude

$$V_{sag} = \frac{Z_F}{Z_S+Z_F}$$

$$= \frac{z.L}{Z_S+z.L}$$

Any fault impedance should be included in the feeder impedance Z_F (1) that the sag becomes deeper for faults electrically closer to the customer (when Z_s becomes larger). Where z is the impedance per unit length and L is the length of feeder.

B. Fault-clearing Time

The duration of sag is mainly determined by the fault clearing time, but it may be longer than the fault clearing time. Generally duration of sag are the number of cycles below threshold during the event. Generally faults in transmission systems are cleared faster than faults in distribution systems. In transmission system the critical fault clearing time is rather small. Transmission and sub transmission systems are normally operated as a grid, requiring distance protection or differential protection, both of which are rather fast. The principal form of protection in distribution system overcurrent protection. This requires often some time grading which increases the fault-cleaning time.

An over view of the fault-cleaning time of various protective devices is given in reference.

- Current-limiting fuses: less than one cycle
- Expulsion fuses: 10-100ms
- Distance relay with fast breaker : 50-100ms
- Distance relay in zone 1:100-200ms
- Distance relay in zone 2:200-500ms
- Differential relay :100-300ms
- Overcurrent relay : 200-2000ms

1. Phase Angle jump

The Phase-angle jump manifests itself as a shift in zero crossing of the instantaneous voltage. Phase - angle jumps as (shown in fig.5) during three phase faults are due to a difference in the X/R ratio between the source and the feeder. Phase angle jump angle=9.72°. (for fig.5 shown below) the phase angle jump can be calculated as

$$\Delta\Phi = arc\,(\bar{V}_{sag}) = \arctan\left(\frac{X_F}{R_F}\right) - \arctan\left(\frac{X_S+X_F}{R_S+R_F}\right)$$

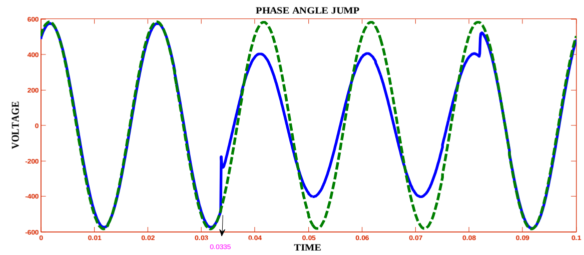

Fig.5. Phase angle jump

VII. Unbalance Sag Due To Unsymmetrical Fault.

For unsymmetrical fault the voltage divider in fig. 4 can be used but it has to be split into its three component: a positive sequence network, a negative sequence network and a zero sequence network.

Table2- Classification of voltage sag and its effect on individual phasor

Type	Nature	Type of Fault	Observations in Phasor: Change in magnitude	Observations in Phasor: Change in Phase
Type A	Balanced	Three Phase Short Circuit	Equal Drop in all phases	None
Type B	Unbalanced	SLGF/ Phase to phase (LL)	Drop in one phasor	None
Type C	Unbalanced	SLGF/ Phase to phase (LL)	Drop in two phasors	In both phasors
Type D	Unbalanced	SLGF/ Phase to phase (LL)	Drop in all phases	In two phasors
Type E	Unbalanced	LLG	Drop in two phasors	In two phasors
Type F	Unbalanced	LLG	Drop in all phases	In two phasors
Type G	Unbalanced	LLG	Drop in all phases	In two phasors

1. Single-Phase Faults

For a single-phase fault, the three sequence networks shown in fig. 6(a) should be connected in series at the fault position.

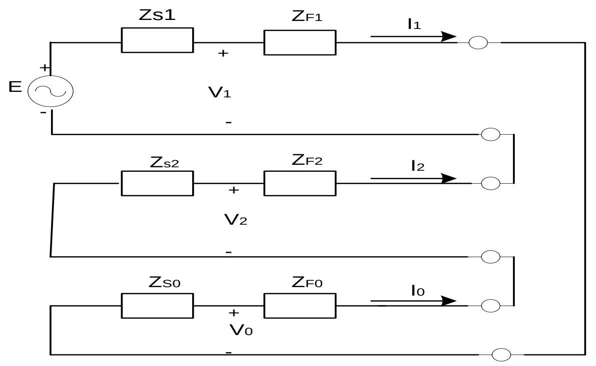

Fig. 6(a) Equivalent circuit for a single phase faults

For the faulted phase voltage V_a we get

$$V_a = \frac{Z_{F1}+Z_{F2}+Z_{F0}}{(Z_{F1}+Z_{F2}+Z_{F0})+(Z_{S1}+Z_{S2}+Z_{S0})}$$

The voltage between the two non-faulted phases is

$$V_b - V_c = (a^2 - a)\left[1 - \frac{Z_{S1}-Z_{S2}}{(Z_{F1}+Z_{F2}+Z_{F0})+(Z_{S1}+Z_{S2}+Z_{S0})}\right]$$

2. Phase-to-Phase Fault

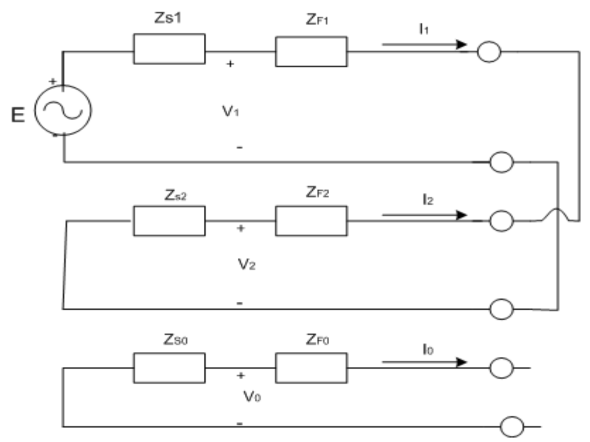

Fig. 6(b) Equivalent circuit for a phase-to-phase fault.

For a phase-to-phase fault the positive and negative-sequence network are connected in parallel as shown in fig. 6(b). The resulting circuit for a phase-to-phase fault in phase b and c in which zero sequence components is zero.

The voltage between the faulted phases

$$V_b - V_c = (a^2 - a)\frac{Z_{F1}+Z_{F2}}{(Z_{F1}+Z_{F2})+(Z_{S1}+Z_{S2})}$$

2. Two-phase-to-Ground Faults

The only asymmetrical fault type remaining is the two-phase-to-ground fault as shown in fig. 6(c) .For a two phase-to-ground fault the three sequence networks are connected in parallel.

The voltage between the un faulted phases and ground

$$V_a = 1 + \frac{(Z_{S2}-Z_{S1})(Z_{S0}-Z_{F0})}{D} + \frac{(Z_{S0}-Z_{S1})(Z_{S2}+Z_{F2})}{D}$$

With

$D = (Z_{S0}+Z_{F0})(Z_{S1}+Z_{F1}+Z_{S2}+Z_{F2})+(Z_{S1}+Z_{F1})(Z_{S2}+Z_{F2})$

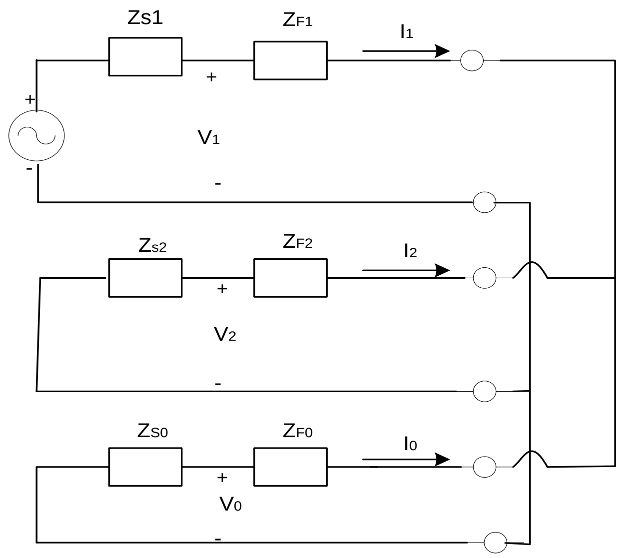

Fig 6(c) Equivalent circuit for two phase-to- ground fault

Table 3- Origin of Three-Phase Unbalanced Sags

Fault Type	**Star-connected load**	**Delta – connected load**
Three Phase	Type A	Type A
Two-phase-to-ground	Type E	Type F
Phase-to-phase	Type C	Type F
Single-phase	Type B	Type C

IX. Result and Conclusion

An extensive review of the Analysis of Voltage Dip/Sag for Symmetrical and Unsymmetrical Fault in Power System typically in the distribution system has been presented to provide a perspective on this type of power quality problems typically voltage sag. It has found that the voltage sag depends on factors such as fault impedance, feeder impedance, cross sectional area and length of conductor. Also it has been observed that phase - angle jumps during three phase faults are due to a difference in the X/R ratio between the source and the feeder. Thus the presented review helps in better understanding of the phenomenon of the balanced and unbalanced voltage sag issue related to the power system.

X.Discussions

It has been observed that the sag depends upon the type of fault , balanced sag occurs due to symmetrical fault while unbalanced sag occurs due to unsymmetrical fault. The sag duration depends upon the fault clearing time of the protective devices. The difference between X/R ratio of the source and the feeder influences the phase angle jump.

XI. References

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iii. *Ray Arnold "Solutions to Power Quality Problems" power engineering journal 2001 pages: 65-73.*

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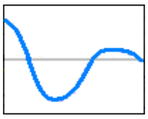
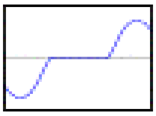
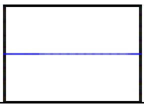
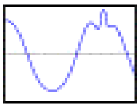
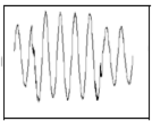
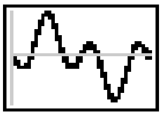
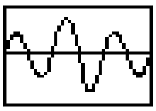
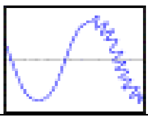
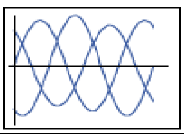
Table 1 – Most common Power Quality problem

1.Voltage sag (or dip) 	**Description:** A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0,5 cycle to 1 minute. **Causes:** Faults on the transmission or distribution network (most of the times on parallel feeders). Faults in consumer's installation. Connection of heavy loads and start-up of large motors.
2. Very short interruptions 	**Description**: Total interruption of electrical supply for duration from few milliseconds to one or two seconds. **Causes**: Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.
3. Long interruptions 	**Description:** Total interruption of electrical supply for duration greater than 1 to 2 seconds **Causes:** Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines or poles, fire, human error, bad coordination or failure of protection devices.
4. Voltage spike 	**Description:** Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage. **Causes:** Lightning, switching of lines or power factor correction capacitors, disconnection of heavy loads.
5. Voltage swell 	**Description:** Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds. **Causes:** Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours).
6. Harmonic distortion 	**Description:** Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency. **Causes:** *Classic sources*: electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors. *Modern sources*: all non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.
7. Voltage fluctuation 	**Description:** Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz. **Causes:** Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads.
8. Noise 	**Description:** Superimposing of high frequency signals on the waveform of the power-system frequency. **Causes:** Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.
9. Voltage Unbalance 	**Description:** A voltage variation in a three-phase system in which the three voltage magnitudes or the phase angle differences between them are not equal. **Causes:** Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault).