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Three-phase-to-ground fault and its impact on voltage magnitude

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Abstract: According to growth of electricity demand and the increased number of non-linear loads in power grids, providing a high quality electrical power should be considered. In this paper voltage sag of the power quality issue is studied. Voltage sag due to power system fault, three-phase-to-ground is created in distribution line model, their effect on the voltage magnitude variation by varying fault resistance for each phase are examined. A simple and practical method is proposed for voltage sag detection, by calculating RMS voltage over a window for particular time period. The case study contains a single-machine including distribution line, which is simulated in MATLAB/Simulink environment. The presented simulation results validate sag, decrease of voltage magnitude for decrease in the fault resistance for three-phase-to-ground fault.
Key Words: Power Quality, Sag, Ground Fault

1. INTRODUCTION

Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as. “The concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment” [1]. Voltage sag is defined and explained as below. A voltage sag is a short duration reduction in rms voltage which can be caused by a short circuit, overload or starting of electric motors [2]. A voltage sag happens when the rms voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute [2][3]. Some references defines the duration of a sag for a period of 0.5 cycle to a few seconds [4][5], and longer duration of low voltage would be called a "sustained sag" [4]. In this paper, the line fault model is simulated to obtain the voltage sags. Voltage sags typically are due to starting on large loads, such as an electric motor or an arc furnace. Induction motors draw starting currents ranging between 600 and 800% of their nominal full load currents [1]. Utility faults are also responsible for voltage sags. Approximately 70% of the utility-related faults occur in overhead power lines. Some common causes of utility faults are lightning strikes, contact with trees or birds and animals, and failure of insulators [1]. Voltage sags are considered one of the most harmful power quality disturbances, because they adversely affect the satisfactory operation of several types of end-user equipment. A fault in a transmission line affects sensitive equipment up to hundreds of kilometers away from the fault.

The paper is organized as follows: In section 2, the voltage sag characteristics are discussed. Section 3 is dedicated to the factors that affect voltage sag. Simulation and results are presented in section 4 and 5.

2. VOLTAGE SAG CHARACTERISTICS

Voltage sag is defined as a decrease in rms voltage at the power frequency for durations of 0.5 cycles to 1 minute. This definition specifies two important parameters for voltage sag: the rms voltage and duration. The standard also notes that to give a numerical value to a sag, the recommended usage is a sag 70%, which means that the voltage is reduced down to 70% of the normal value, thus a remaining voltage of 30%. Sag magnitude is defined as the remaining voltage during the event. The power systems faults not only cause a drop in voltage magnitude but also cause change in the phase-angle of the voltage. The parameters used to characterize voltage sag are magnitude, duration and point-on-wave sag initiation.

2.1 Voltage Sag Magnitude

The magnitude of voltage sag can determine in a number of ways. The most common approach to obtain the sag magnitude is to use rms voltage. There are other alternatives, e.g. fundamental rms voltage and peak voltage. Hence the magnitude of the sag is considered as the residual voltage or remaining voltage during the event. In the case of a three- phase system, voltage sag can also be characterized by the minimum RMS-voltage during the sag. If the sag is symmetrical i.e. equally deep in all three phases, if the sag is unsymmetrical, i.e. the sag is not equally deep in all three phases, the phase with the lowest remaining voltage is used to characterize the sag [6].

The magnitude of voltage sags at a certain point in the system depends mainly on the type and the resistance of the fault, the distance to the fault and the system configuration. The calculation of the sag magnitude for a fault somewhere within a radial distribution system requires the point of common coupling (pcc) between the fault and the load. Fig.1 shows the voltage divider model. Where Z_S is the source impedance at the pcc and Z_F is the impedance between the pcc and the fault. In the voltage divider model, the load current before as well as during the fault is neglected. There is no voltage drop between the load and the pcc. The voltage sag at the pcc equals the voltage at the equipment terminals, the voltage sag can be found from the (1).

$$V_{Sag} = \frac{Z_F}{Z_S + Z_F} E (1)$$

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.

$$V_{Sag} = \frac{Z_F}{Z_S + Z_F} (2)$$

For fault closer to the pcc the sag becomes deeper smallZ_F. The sag becomes deeper for weaker supplies largerZ_S [7].

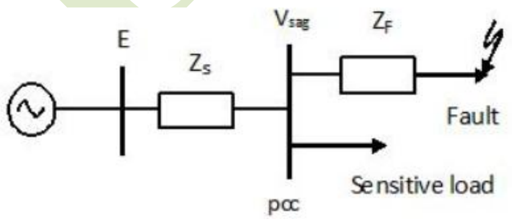

Figure 1. Voltage Divider Model

2.2 Voltage Sag Duration

The duration of voltage sag is mainly determined by the fault–clearing time. The duration of a voltage sag is the amount of time during which the voltage magnitude is below threshold is typically chosen as 90% of the nominal voltage magnitude. For measurements in the three-phases systems the three rms voltages have to be considered to determine duration of the sag. The voltage sag starts when at least one of the rms voltages drops below the sag-starting threshold. The sag ends when all three voltages have recovered above the sag- ending threshold [7].

2.3 Point on Wave

To obtain a accurate value for the sag duration one needs to be able to determine “start” and “ending” of the sag with a higher precision. For this one needs to find the so-called “point-on-wave of sag initiation” and the “point-on-wave of voltage recovery”

The point-on-wave initiation is the phase angle of the fundamental wave at which the voltage sag starts. This angle corresponds to the angle at which the short-circuit fault occurs. As most faults are associated with a flashover, they are more likely to occur near voltage maximum than voltage zero. Point on wave initiation and ending are phase angles at which instantaneous voltage starts and ends to experience reduction in voltage magnitude, i.e. between which the corresponding rms voltage is below the defined threshold limit (usually defined as 90% and 10% of the nominal voltage, respectively). Point-on-wave initiation corresponds to phase angle of the pre-sag voltage, measured from the last positive-going zero crossing of the pre-sag voltage, at which transition from the pre-sag to during sag voltage is initiated. Similarly, point-on-wave of ending corresponds to phase angle of the post-sag voltage. Measured with respect to the positive-going zero crossing of the post-sag voltage, at which transition from during-sag to post-sag voltage, respectively, and not to during-sag voltage is to avoid complications introduced by the phase shifts and transients that usually occur at the sag initiation and at the sag ending. Both point-on-wave values are usually expressed in degrees or radians [7], [9].

3. FACTORS THAT AFFECT VOLTAGE SAG

Specifically, at the equipment terminals, these factors affect the voltage sag type [7]

3.1 Fault type

Voltage sags are primarily caused by system faults. Each fault type has a different effect to the voltages at the fault point, which subsequently defined the voltage sag types.

- Single-Line-to-Ground (SLG) Fault
- Line-to-Line (LL) Fault
- Double-Line-to-Ground (LLG) Fault
- Three Phase (3P) Fault

3.2 Transformer Winding Connection

Transformer winding connections are classified into three types to explain the transfer of three-phase unbalanced voltage sags, as well as the change in voltage sag type, from one voltage level to another.

- Type 1 – Transformers that do not change anything to the voltages. The primary voltages (per unit) are equal to the secondary per unit voltages. The only transformer configuration that falls under this type is the Wye Grounded-Wye grounded (YgYg).
- Type 2 – Transformers that remove the zero-sequence voltage. Basically, the secondary voltage (pu) is equal to the primary voltage (pu) minus the zero-sequence component. The Delta-delta (Dd), Delta-zigzag (Dz) and the Wye-wye (with both windings ungrounded or with only one star point grounded) belong to this type.

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- Type 3 – Transformers that changes line and phase voltages. Delta-wye (Dy), Wye-delta (Yd) and the Wye-zigzag (Yz) fit under this type.

3.3 Load Connection

- Wye-connected load
- Delta-connected load

4. Modeling and Simulation

4.1 Component Modules

The proposed virtual model simulates the 22KV/415V distribution network. Figure 2 shows the simulated component modules. The first module on the left most represents a power module , 3-Phase 22KV Bus supplied by a source, connected to sensitive load on the right most block via 22/0.415KV transformer, line faults are simulated and sag is created at junction A.

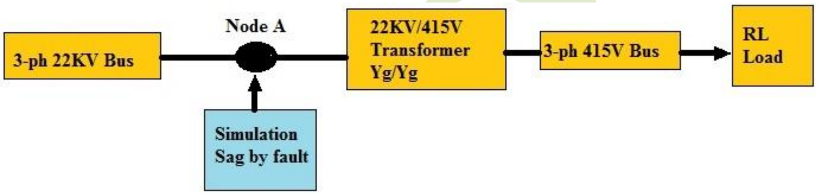

Figure 2.Component Modules

4.2 Simulink Model

The whole model of system under study is shown in Fig.3. The system contains a three phase source connected to a RL load through a distribution line. A three phase fault is placed in between the Yg-Yg distribution transformer and the Bus1. The system parameters are listed in appendix TABLE 1.

To simulate the dynamic performance, the three phase fault considered for the duration 0.05 seconds (0.05-0.1 seconds).

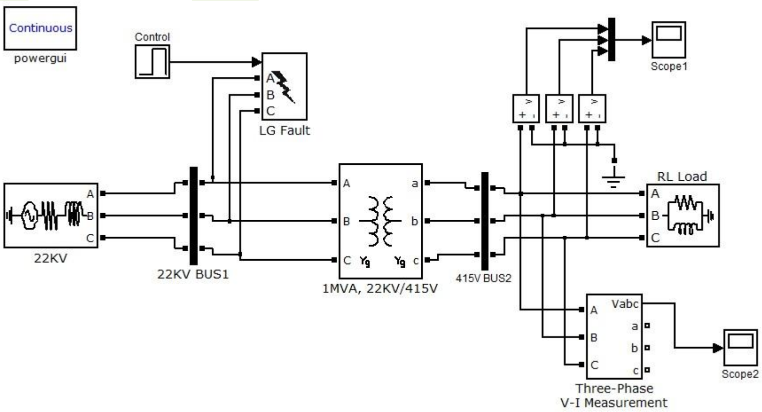

Figure 3.Simulation model

5. EXAMINING SIMULATION RESULTS

Fig 4, 5, 6 and 7 depicts sag. Significant sag is observable during the fault for the duration 0.05 to 0.1 seconds. As shown in Fig 4, the voltage magnitude is about .2 per unit for the fault resistance 10ohm. In Fig 5, the voltage magnitude is about .6 per unit for the fault resistance 40ohm. In Fig 6, the voltage magnitude is about .9 per unit for the fault resistance 120ohm.

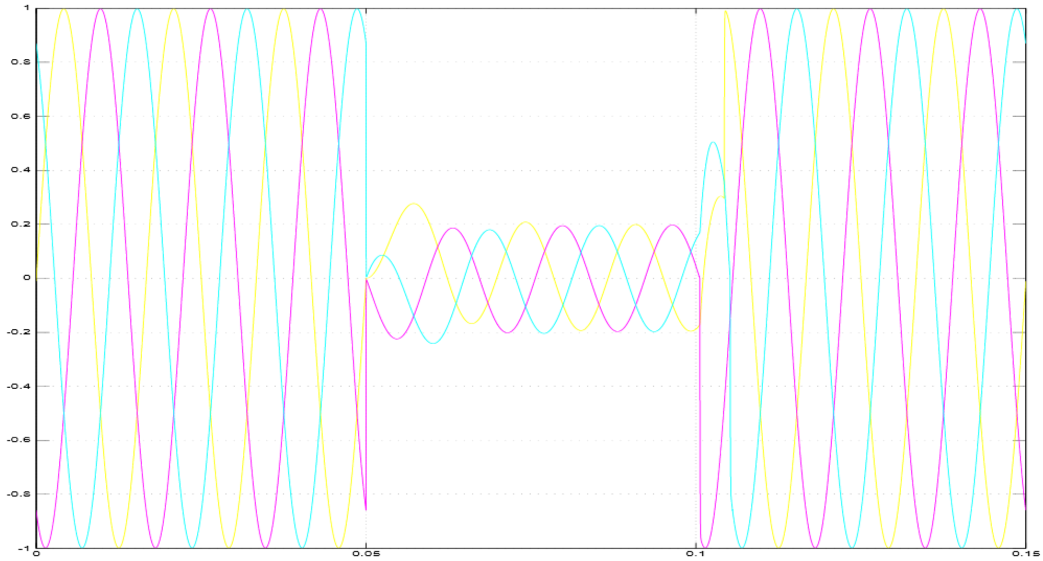

Figure 4.Three phase load voltage sag waveform for Ron 10ohm

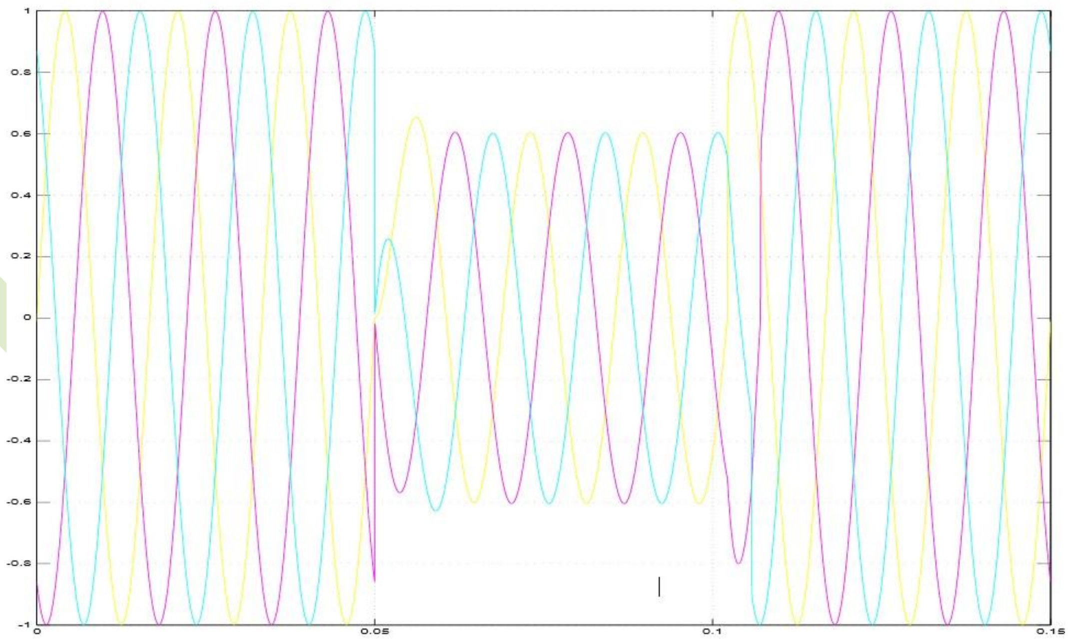

Fig 5. Three phase load voltage sag waveform for Ron 40ohm

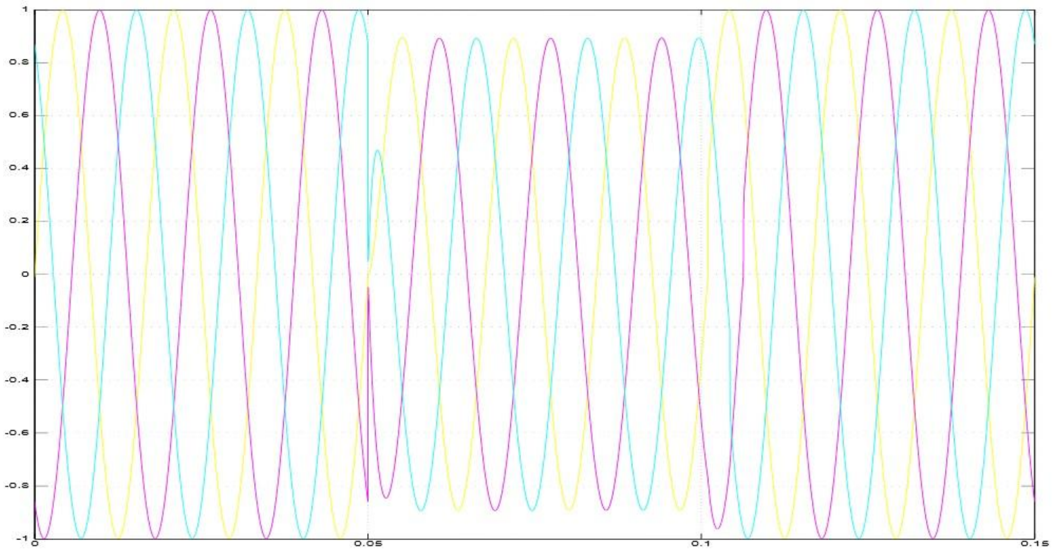

Fig 6. Three phase load voltage sag waveform for Ron 120ohm

6. CONCLUSION

Voltage sags have been mainly characterized by magnitude and duration. In this paper, the voltage sag presented. Simulation results validate sag for three-phase-to-ground fault. The magnitude of voltage sags at a certain point in the system depends mainly on the resistance of the fault. Higher the resistance lower is the magnitude of sag voltage.

PPENDIX

TABEL 1. SIMULATION SYSTEM PARAMETERS

Parameters	Values
Three phase source	
Rated voltage	11 kV
Rated Frequency	60 HZ
X/R	10
Base Voltage	11 kV
Short-circuit level	10 MVA
Transformer	
Nominal Power	1MVA

Parameters	Values
Rated Voltage	11/0.415 kV
Three-phase fault	
Type	ABC-G
Ground resistance	10, 40, 120 ohm

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