VOLTAGE SAGS IN DISTRIBUTION SYSTEM

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ABSTRACT

Voltage sags, also known as dips, are increasingly important to industrial reliability. Modern process controls are often sensitive to voltage sags. the combination of a voltage sags and sensitive equipment may cause significant production outages. This paper describes the causes of the voltage sags in industrial plants, their effects on equipment operation, and possible solutions. One of solution is the type of transformer connection. In this paper, the effects of fault impedance and transformer connection on the voltage sag are given.

1. INTRODUCTION

Voltage sags can occur within facility and on the utility system. Those on power supply systems are most often due to systems faults or short circuits where the majority of sags drop to 80% to 90% of nominal voltage for about 10 cycles (0,167 s for 60 Hz systems) [1]. Voltage sags are the most important power quality problem facing many industrial customers. Equipment used in modern industrial plants (adjustable speed drives, robotics, logic controllers) is actually becoming more sensitive to voltage sags as the complexity of the equipment increases. It is important to understand the difference between an interruption (complete loss of voltage) and a voltage sag. Interruptions occur when a protective device actually interrupts the circuit serving a particular customer. This will normally only occur if there is a fault on that circuit.

Voltage sags occur during the period of a fault for faults over a wide part of the power system. Faults on parallel feeder circuits or on the transmission system will cause voltage sags but will not result in actual interruptions. Therefore, voltage sags are much more frequent than interruptions. If equipment is sensitive to these voltage sags, the frequency of problems will be much greater than if the equipment were only sensitive to interruptions [2]. Finally this paper offers ways for controlling the effects of the voltage sags.

2. CALCULATION OF VOLTAGE SAGS

A typical example of a voltage sag is shown in figure-1. Calculating the magnitude of the voltage sag for any specific fault (single phase-to-ground, phase-to-phase, three phase fault, etc.) is essential to the calculation process. It requires knowledge of network impedance, fault impedance, and fault location relative sensitive load. It is also necessary to know the type of transformer connection and pre-sag voltages.

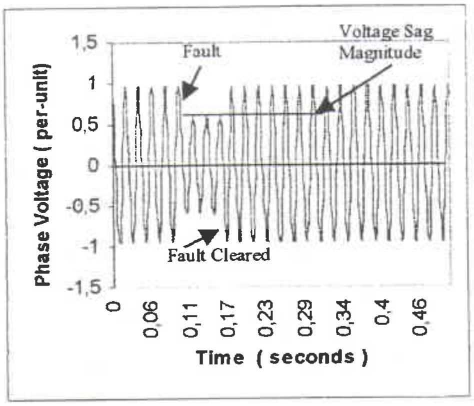

Figure-1. Typical Voltage Sag

Equations (1) to (2) show impedance divider calculations to predict voltage sag magnitudes. While fault current is following from the generator bus to bus-e , the voltage at the "d" is:

$$V_d = 1.0 \frac{jX_2}{jX_g + jX_{trf} + jX_1 + jX_2} \text{ (p.u)} \quad (1)$$

The voltage at the "c" is:

$$V_c = 1.0 \frac{jX_1 + jX_2}{jX_g + jX_{trf} + jX_1 + jX_2} \text{ (p.u)} \quad (2)$$

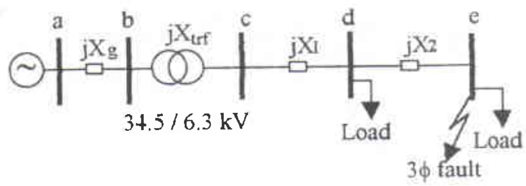

Figure-2. Simple System Impedance Diagram

The impedance divider concept also applies to the radial distribution system, however the calculations are more difficult. This normally requires a computer program for system fault analysis.

3. SYSTEM APPLICATION

Consider the simple radial distribution system in Figure-3. An industry on A is sensitive to voltage sags and wants to know the magnitude of voltage sags. For this example, consider all faults to be a single phase-to-ground only. The aim in this example is to the calculate the magnitude of voltage sag where secondary side of transformer that connected to sensitive load. The voltage sag magnitude is calculated for various type of transformer connections.

For a distribution system fault, the worst case occurs when the fault is near the customer transformer primary. The voltages on the customer bus will then be a functions of the customer transformer connections [3].

Three phase transformer stations that are connected delta - wye or wye - delta alter unbalanced voltage sags. Roughly, a phase to ground voltage sag turns into a phase to phase sag, less the zero sequence component, as it passes through any delta – wye transformer.

For system in figure-3, table-1 and figure-4,5,6,7 show the effect transformer connections have on a typical remote fault clearing voltage sag caused by a phase to ground fault. It can be clearly seen that the importance of including the effects of transformers in the calculations of the voltage sags.

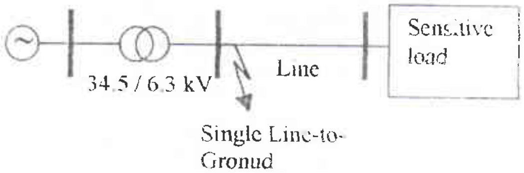

Figure-3. Typical Distribution System one Line Diagram.

Table-1. Transformer Secondary Voltages With An SLGF On The Primary (Fault Impedance = 0.0 ohm)

Transformer Connection	Phase to Phase V_{ab}	V_{bc}	V_{ca}	Phase to Neutral V_a	V_b	V_c
Δ – Y (grounded)	0.88	0.88	0.33	0.53	1.00	0.53
Y (grounded) – Δ	0.34	0.80	0.80	0.50	0.50	1.00
Y – Y	0.58	1.00	0.58	0.33	0.88	0.88
Y (grounded) – Y (grounded)	0.58	1.00	0.58	0.00	1.00	1.00

Table-2. Transformer Secondary Voltages With An SLGF On The Primary (Fault Impedance = 1.0 ohm)

Transformer Connection	Phase to Phase V_{ab}	V_{bc}	V_{ca}	Phase to Neutral V_a	V_b	V_c
Δ – Y (grounded)	0.88	0.89	0.38	0.58	1.00	0.61
Y (grounded) – Δ	0.36	0.87	0.89	0.57	0.55	1.00
Y – Y	0.59	1.00	0.61	0.38	0.89	0.89
Y (grounded) – Y (grounded)	0.58	1.00	0.61	0.08	1.00	1.00

Table-3. Transformer Secondary Voltages With An SLGF On The Primary (Fault Impedance = 5.0 ohm)

Transformer Connection	Phase to Phase V_{ab}	V_{bc}	V_{ca}	Phase to Neutral V_a	V_b	V_c
Δ – Y (grounded)	0.88	0.92	0.53	0.63	1.00	0.72
Y (grounded) – Δ	0.48	0.87	0.93	0.68	0.62	1.00
Y – Y	0.63	1.00	0.71	0.52	0.92	0.93
Y (grounded) – Y (grounded)	0.63	1.00	0.71	0.29	1.00	1.00

When fault impedance is equal to zero, we have a direct short circuit, which is called a bolted fault. Although such direct short circuit result in the highest value of fault current and are therefore the most conservative values to use when determining the effects of anticipated faults, the fault impedance is seldom zero.

Most faults are the result of insulator flashover, where the impedance between the line and ground depends on the resistance of the arc, of the tower itself, and of the tower footing if ground wires are not used [4]. Fault impedance is very important to sag magnitude calculations especially on lower voltage systems. The additional fault impedance generally makes sags less severe than zero impedance faults. Table-2 and table-3 show the effect of fault impedance on the voltage sag for the system in figure-3.

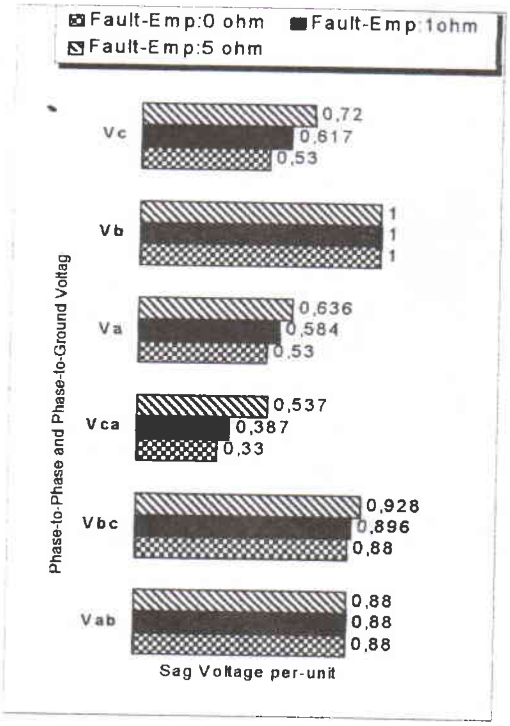

Figure-4. Delta/wye-grounded Connected Transformer

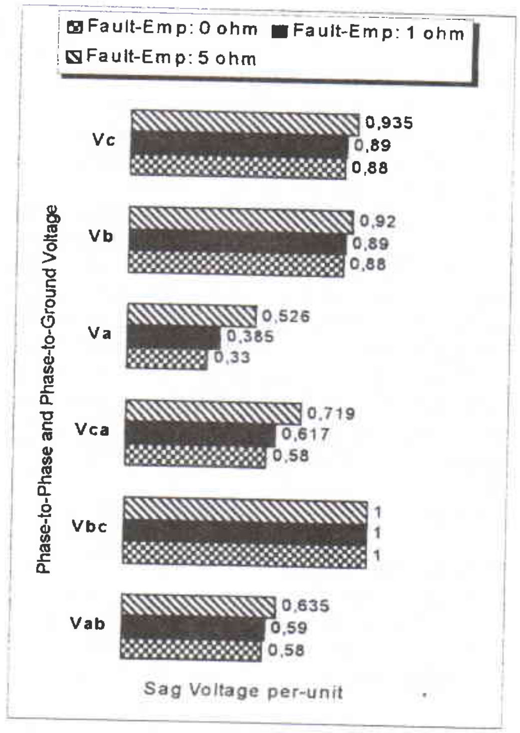

Figure-6. Wye/wye Connected Transformer

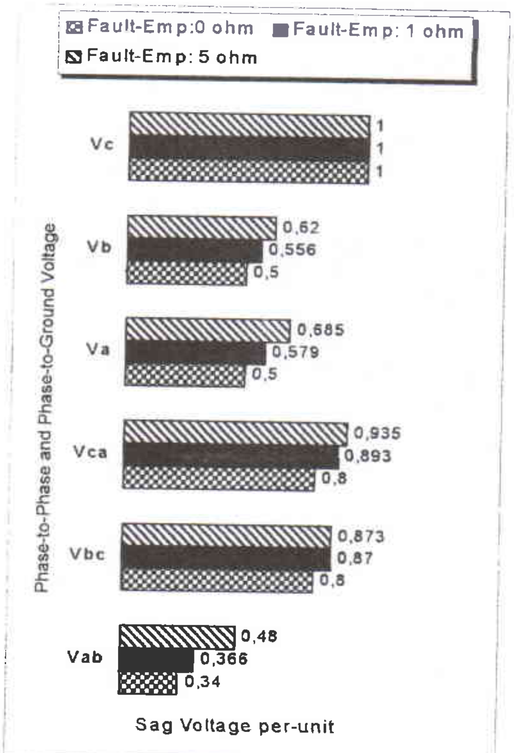

Figure-5. Wye-grounded/delta Connected Transformer

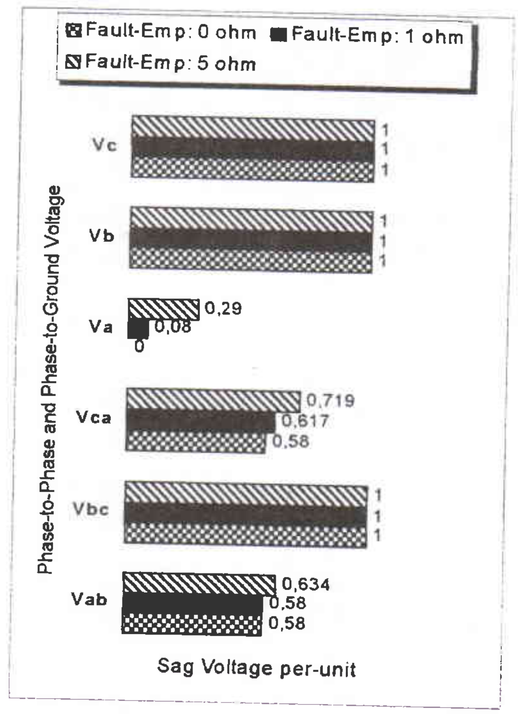

Figure-7. Wye-grounded/wye-grounded Connected Transformer

3. CONCLUSIONS

A single line-to-ground fault on the primary side of a distribution transformer will result in a voltage sag to no lower than 33% of normal voltage on any phase-to-phase connection. In cases of wye-grounded / wye-grounded connected and wye-grouned/wye connected transformer, the voltage of phase faulted is zero. However, in cases of other transformer, connections types, the voltage of phase faulted is not zero. This results show the impedance of including the effects of transformers in the calculations. It also offers one small opportunity for controlling the effect of voltage sag. As the fault impedance increases, magnitude of voltage sag increases for all of transformer connection type. Hence, the effect of the voltage sag on the sensitive loads con be decreased.

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