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Research Article

Analysis of Unsymmetrical Voltage Sag Propagation Trough Distribution Transformer

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Abstract: In this study critical problem of voltage sag propagation through transformer winding in distribution network is taken into account. The sage propagation problem depends on the unsymmetrical fault type and winding connections of the distribution transformer. The characterization of the sage propagation is effected due to the zero sequence components. The detection of the voltage sage through sequence detection method is used to solve the problem. The obtained results reflect the characterization of voltage sag propagated from primary to the secondary winding of transformer during various connection schemes. The method adopted would be useful to analysis the power supply network for power quality in distribution transmission network.

Keywords: Power quality, unsymmetrical fault and sequence analyzer, voltage sag

INTRODUCTION

The power quality is an important issue in a power system. The sag in power distribution network due to unsymmetrical faults in transformer windings deviate the wave shape of the supply voltage or load current from the rated sinusoidal wave form and rated frequency (Kiran *et al*., 2014). Power quality is big issue that is increasing day by day rapidly. The loads in the distribution networks are very much sensitive of the sag that degrades the power quality at higher level (Kamble and Thorat, 2014). Voltage sag is very important issue of power quality it defines as reduction in RMS value of voltage between 0.1 to 0.9 p.u., at the power frequency with duration from 0.5 cycles to 1 min. The main cause of voltage sag in power system is caused by short circuit faults and energizing the heavy load machines. Voltage sag may be symmetrical or unsymmetrical depends on the fault type which may occur hundreds kilometer away from the customers point of presence (Kiran *et al*., 2014). There are so many methods for voltage sag detection in power system, such as wavelet transform methods and sequence detection method (Pawar and Kakre, 2014).

In power system about 90% complains of voltage sag problem are being recorded which are propagated through the transformer (Bhutto *et al*., 2013a). In Matlab/Simulink power quality events are simulated to analyze various disturbances like voltage sag, transients and interruptions. Power system faults may occur due to the lightning flash over and short circuit, which carries the huge amount of current (Tan and Ramachandaramurthy, 2013; Bhutto *et al*., 2013b). When fault occurs in power system voltage sag appears and propagates through the transformer winding. Due to the fault, magnitude of the voltage and the time duration may disturb with phase jump at some angle (Bhutto *et al*., 2013c). Voltage sag is better parameter to assess the performance of future smart grid for reliable intelligent operation of power system particularly in the distribution network (Zeng *et al*., 2013). The voltage sag characterization and analysis is very important for designing an efficient protection systems and controllers for electrical machines such as synchronous and asynchronous. The VDR and STATCOM are used to control power quality (Cortýs *et al*., 2013; Li *et al*., 2013; Xin-ke *et al*., 2013) in the distribution network.

In this study, the sag voltage propagation at primary and secondary sides of transformer is examined with suitable transformer connections using sequence analyzer.

MATERIALS AND METHODS

Figure 1 the one line diagram of power system network with two buses is shown. When fault occurs on bus then voltage will be zero at primary of transformer on faulty phase other two phases may not be disturbed. On other hand at secondary side of the transformer the magnitude of propagated sag voltage is not zero in magnitude:

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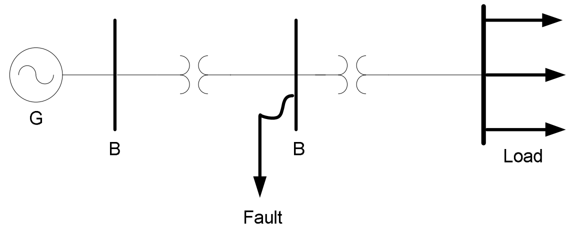

Fig. 1: One line diagram of power system

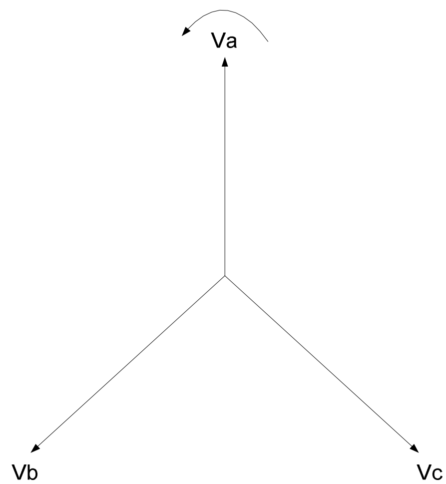

Fig. 2: Three phase vector

$$Va = V_1 + V_2 + V_0 \quad (1)$$

$$Vb = a^2V_1 + aV_2 + V_0 \quad (2)$$

$$Vc = aV_1 + a^2V_2 + V_0 \quad (3)$$

In order to analysis the some kind of voltage sag propagation in distribution network by using mathematical formulation from theories of three phase faults. It is very easy to calculate the all type of sag and phase jump by using sequence components (Tao *et al*., 2012). In three phase system Va, Vb and Vc are three phase voltages displaced at 0^o, 120^o and 240^oor -120^o.

Effects of transformer connections on the propagation of voltage sag: The propagation of voltage sag influenced by the transformer winding connections is shown in Fig. 2. The major role of zero sequence components whenever transformer connection winding does not allow to flow zero sequence components can still has influence on phase magnitude and phase jump.

It is clear view of sag voltage propagation through transformer connection (Y-Y) in Fig. 3. When Line to Ground (LG) fault is occur in power system before transformer (Y-Y) it view that when fault on phase A at primary side of transformer voltage will decrease up to 0 p.u., value other B and C phase may not effected but due to transformer connection sag voltage propagate on secondary side of transformer at every phase depend on transformer connection, here stat-star connection of transformer used for analysis of sag voltage at secondary side it is clear view of propagated sag voltage with different magnitude at phase a 0.33 p.u., at phase b 0.8 p.u., and at phase c 0.8 p.u., Analysis of sag voltage propagation on different types of faults and transformer connection has different voltage sag at primary and secondary (Tao *et al*., 2012).

RESULTS AND DISCUSSION

In the section the simulation results are presented by using sequence analyzer in Simulink. In this we have considered the various connections three phase transformer to study the voltage sag propagation under unsymmetrical faults say line to ground faults. In each configuration the sags are characterized and detected with help of the sequence components say positive negative and zero components.

Line to ground fault with star-star connection: When line to Ground Fault (LG) occurs in power system network, voltage sag appears on the primary and the secondary side of transformer as shown in Fig. 3 and 4 respectively. In these graphs the time in seconds is the time of sag duration and versus the voltage.

The plots of Fig. 4 represent the sag voltage at the primary of the transformer after the line to ground fault. The sag voltage propagates to the secondary of the transformer on the each phase as shown in Fig. 5.

In these figures, it can be clearly observed that, when fault occurs at the primary of the transformer in start-star configuration then the sag voltage propagates to each phase of the secondary of the transformer. The RMS value of sag voltage is higher on affected phase. Table 1 shows the phase voltage calculated on the primary and on the secondary sides of transformer by using sequence analyzer. At the primary side on the faulty phase the RMS value of the voltage is zero i.e., $V_a = 0$. While other phases of primary side are unaffected. The impact of sag voltage propagation on the secondary is shown in Fig. 5. The statistic of the affected phases in RMS values is given in the Table 1.

Line to ground fault in star-delta connection: In this configuration the impact of the voltage sag propagation on the secondary is studied when line to Ground Fault (LG) occurs at primary side. The voltage sag appears on its primary and secondary side as shown in Fig. 3 and 6 respectively.

Table 1: Voltage sag at primary and secondary of T/F on Y-y connection

Primary side of transformer (Star connected)	Secondary side of transformer (Star connected)	Secondary side of transformer (Delta connected)
$V_{a1} = 0.666\angle -1.158$	$V_{a1} = 0.6643\angle -3.9117$	$V_{a1} = 0.664\angle -33.91$
$V_{a2} = 0.332\angle 179.25$	$V_{a2} = 0.3312\angle 176.507$	$V_{a2} = 0.33\angle -153.49$
$V_{a0} = 0.332\angle 179.825$	$V_{a0} = 0$	$V_{a0} = 0$
$V_a = 0$	$V_a = 0.33\angle -4.32$	$V_a = 0.57\angle -63.81$
$V_b = 1\angle -120$	$V_b = 0.87\angle -104.7$	$V_b = 0.57\angle -124$
$V_c = 0.99\angle 120$	$V_c = 0.87\angle 97.14$	$V_c = 0.99\angle 86.2$

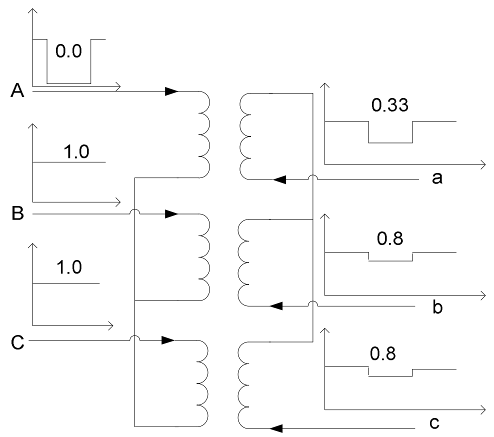

Fig. 3: Voltage sag propagation due to the line to ground fault (Tao *et al*., 2012)

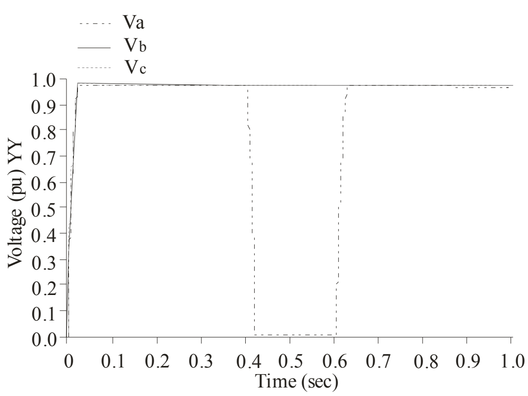

Fig. 4: Sag voltages at primary by using Y-Y connection

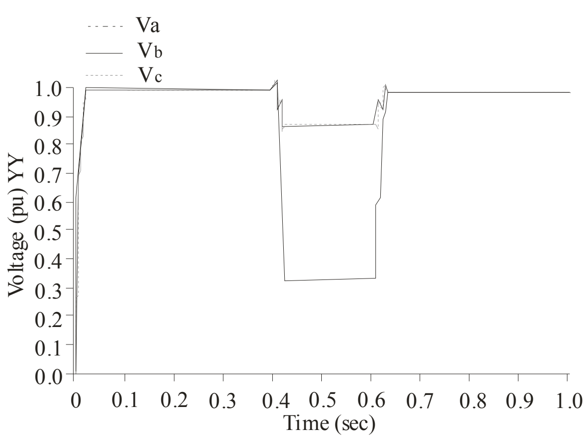

Fig. 5: Sag voltage propagation at secondary side in Y-Y connection

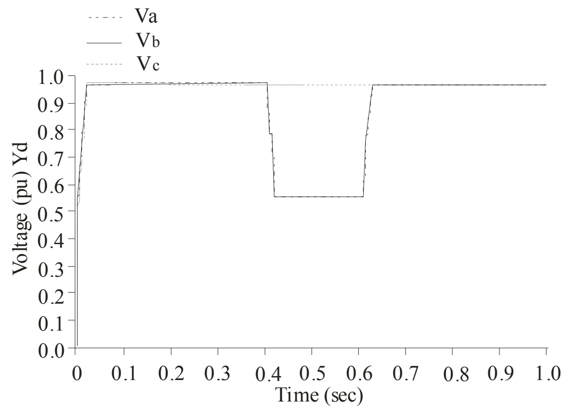

Fig. 6: Sag voltage at secondary side by using Y-d connection

It is clearly observed from above results of Fig. 6 that RMS value wave form of voltage that, in this case the two phases are affected by the voltage sag propagation with same impact. The statistic of the propagation is given in Table 1.

Line to ground fault with star ground-star ground (YG-yg) connection: When LG occurs in power distribution network, voltage sag appears on primary and secondary side as shown in Fig. 3 and 7 respectively.

In this configuration of the transformer connection there is no any impact of sag propagation on the secondary of the transformer. Because in this type of connection the zero sequence components are not involved that is why the same sag is propagated from primary to the secondary. The analyzer results are shown in Table 2.

Line to ground fault with star ground-delta connection: In star ground to delta connection, when the line to Ground Fault (LG) occurs voltage sag appears on primary and secondary side as shown in Fig. 8 and 9 respectively. The analyzer results are given in Table 2.

Line to ground fault with delta-star connection: Figure 10 represents the voltage sag propagation effect on both the winding during the LG fault. The impact on the primary is similar to the Fig. 3. The analytical results of the sequence analyzer are given in Table 3 representing the RMS values of the sag propagation voltage.

Table 2: Voltage Sag at primary and secondary of T/F on YG-yg and YG-d connections

Primary side of transformer	Secondary side of transformer on YG-yg connection	Secondary side of transformer on YG-d connection
$V_{a1} = 0.666\angle -1.158$	$V_{a1} = 0.664\angle -33.9115$	$V_{a1} = 0.6641\angle -4$
$V_{a2} = 0.332\angle 179.25$	$V_{a2} = 0.3312\angle -153.49$	$V_{a2} = 0.3314\angle 176.7$
$V_{a0} = 0.332\angle 179.825$	$V_{a0} = 0$	$V_{a0} = 0.334\angle 176.7$
$V_a = 0$	$V_a = 0.57\angle -63.81$	$V_a = 0$
$V_b = 1\angle -120$	$V_b = 0.57\angle -124$	$V_b = 0.99\angle -123$
$V_c = 0.99\angle 120$	$V_c = 0.99\angle 86.2$	$V_c = 0.99\angle 116.3$

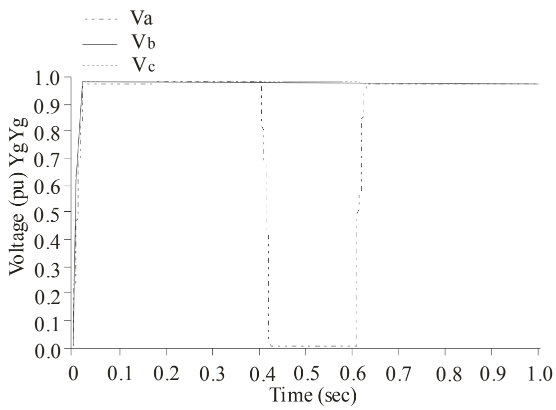

Fig. 7: Sag voltage at secondary side by using YG-yg connection

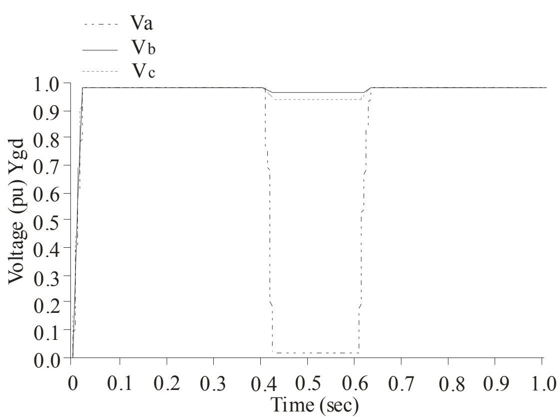

Fig. 8: Sag voltages at primary by using YG-d connection

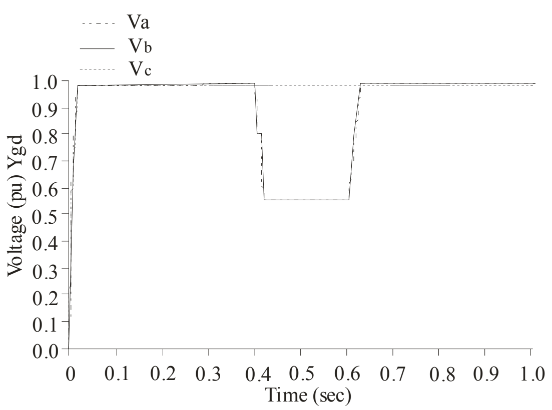

Fig. 9: Sag Voltage at secondary side by using YG-d connection

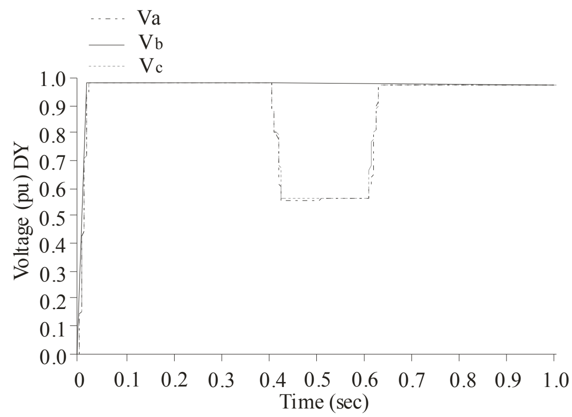

Fig. 10: Sag voltage at secondary side by using D-y connection

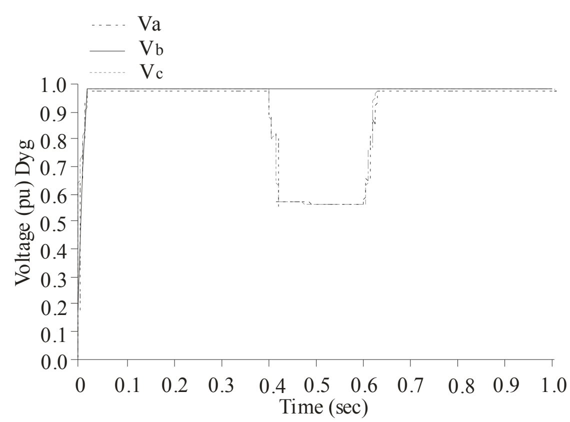

Fig. 11: Sag voltage at secondary by using D-yg connection

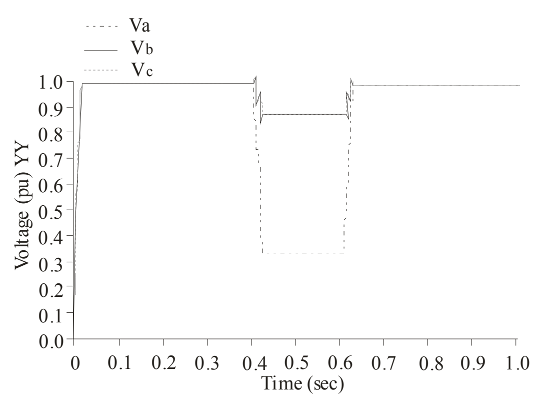

Fig. 12: Sag voltage at secondary side by using D-d connection

Table 3: Voltage sag at primary and secondary of T/F on D-y, D-yg and D-d connections

Primary side of transformer	Secondary side of transformer on D-y connection	Secondary side of transformer on D-yg connection	Secondary side of transformer on D-d connection
$V_{a1} = 0.666\angle -1.158$	$V_{a1} = 0.6643\angle 26.087$	$V_{a1} = 0.6643\angle 26.087$	$V_{a1} = 0.6643\angle -1.9117$
$V_{a2} = 0.332\angle 179.25$	$V_{a2} = 0.3312\angle 146.5$	$V_{a2} = 0.3312\angle 146.5$	$V_{a2} = 0.3312\angle 176.507$
$V_{a0} = 0.332\angle 179.825$	$V_{a0} = 0$	$V_{a0} = 0$	$V_{a0} = 0$
$V_a = 0$	$V_a = 0.57\angle 56$	$V_a = 0.57\angle 56$	$V_a = 0.33\angle -4.32$
$V_b = 1\angle -120$	$V_b = 0.99\angle -93.7$	$V_b = 0.99\angle -93.7$	$V_b = 0.87\angle -104.7$
$V_c = 0.99\angle 120$	$V_c = 0.57\angle 116.19$	$V_c = 0.57\angle 116.19$	$V_c = 0.87\angle 97.14$

Table 4: Voltage sag at secondary side of transformer on different connections

Type fault	Transformer connections Star/Delta	Propagation of voltage sag at secondary of transformer V_a (pu)	V_b (pu)	V_c (pu)
Line-to-ground fault (L-G)	Y-Y	$V_a = 0.33\angle -4.32$	$V_b = 0.87\angle -104.7$	$V_c = 0.87\angle 97.140$
	Y-d	$V_a = 0.57\angle -63.8$	$V_b = 0.57\angle -129.0$	$V_c = 0.99\angle 86.200$
	YG-y	$V_a = 0.57\angle -63.8$	$V_b = 0.57\angle -124.0$	$V_c = 0.99\angle 86.200$
	YG-yg	$V_a = 0$	$V_b = 0.99\angle -123.0$	$V_c = 0.99\angle 116.30$
	D-y	$V_a = 0.57\angle 56$	$V_b = 0.99\angle -93.70$	$V_c = 0.57\angle 116.19$
	D-d	$V_a = 0.33\angle -4.32$	$V_b = 0.87\angle -104.7$	$V_c = 0.87\angle 97.140$
	D-yg	$V_a = 0.57\angle 56$	$V_b = 0.99\angle -93.70$	$V_c = 0.57\angle 116.19$

Line to ground fault with delta-star ground connection: When line to Ground Fault (LG) occurs in power network, voltage sag appears on primary and propagated to the secondary side is shown in Fig. 11. The characteristics of the sag voltage obtained through analyzer are given in Table 3.

Line to ground fault with delta- delta connection: Figure 12 shows the impact of the sag propagation on secondary side of the transformer, when the transformer connection is delta-delta and analyzer results are given in Table 3.

When fault occurs on distribution network voltage sag propagation occur from primary to the secondary of transformer. It has been analyzed on fault type and also on different transformer connection with different RMS wave form and also mathematically calculated by using the sequence analyzer as shown in the Table 4. On the basis of above results and discussion, it is proved that the proposed sequence analyzing method for voltage sag characterization is more effective as compared to the other technique used in the literature. The proposed voltage sag characterization technique applied to YG-yg transformer connection, the same voltage sag propagates to the secondary of transformer with the subtraction of the zero sequence component as given in Table 4.

CONCLUSION

This research the intensive analysis of transformer with different types of connections for voltage sag propagation in low voltage distribution network is studied. The results obtained using sequence analyzer demonstrates the importance of voltage propagation on low voltage distribution transformer used for sensitive loads. The analysis is useful for protection design and controlling of voltage sag propagation problems in power system to insuring power quality. It has also observed that when zero-sequence components involve then the voltage sag propagation will be different on secondary side of the transformer. If zero sequence components have not involved then same voltage sag propagate from primary to the secondary of the transformer. In addition, it also has been observed that when fault occurs the phase shifts at secondary side transformer as well.

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