Classification of Voltage Sag Propagation under Double Line to Ground Fault on a Low Voltage Distribution Power Network

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Abstract-The key issue of the voltage-sag propagation on the different types of winding connections for the low voltage transformer in the distribution power network is considered in this study. The issues of voltage sag propagation depend upon the type of the asymmetrical fault and the connection of the transformer windings. In this paper, the double line to ground fault is adopted for the voltage sag characterization. The depiction of the sage propagation is an outcome of the zero sequence components. Voltage sag propagation detection can be used to improve the power quality of the system. The obtained results reveal the characteristics of the voltage drop propagation from the primary to the secondary winding of the transformer throughout different connection. The implemented method will help analyze the Power Quality (PQ) problem in terms of voltage sag of the distributed transmission networks of the power system.

Keywords-voltage sag; power quality; double line to ground fault

I. Introduction

Power Quality (PQ) is an important issue in electrical systems [1]. Due to the existence of symmetric faults in the transformer windings, the sinking of the distribution network will deviate from the waveform of the power supply voltage, which depends on the nominal sine waveform and the nominal frequency [2, 3]. Many industrial and home customers often have equipment that is sensitive to electrical interference [4]. Therefore, it is important to understand the quality of the supplied power [5, 6]. If sufficient power supply voltage is not provided, electrical appliances may or may not be sued at all. End users have increased their awareness of voltage quality and challenge network operators to obtain appropriate information and provide them with better power supply quality [3]. Nowadays, PQ has become a major aspect of the Power Distribution System (PDS), due to reasons such as the presence of sensitive and nonlinear loads in the distribution system [7, 8]. The main problem is the quality of energy in terms of voltage constancy in the PDS. Voltage sag, defined as a sharp decrease in the amplitude of the supply voltage, is a PQ problem that can cause loss of susceptible loads in the PDS. In recent years, many defects due to low voltage, such as electrical equipment failure, production line loss, and complete equipment failure, have been studied [9-12]. The voltage sag defined by IEEE is the decrease of the RMS voltage value between 0.1 and 0.9pu [10]. Voltage sag can interfere with the operation of sensitive equipment. These circumstances may lead to huge cost-effective fatalities by disturbing the industrial manufacture process [13, 14].

II. Discription and System Modeling

The variation in voltage, current, or frequency may cause equipment failure/malfunction. According to IEEE 1159-1995 standard, the sag reduces the voltage between 0.1 to 0.9pu. As

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shown in Figure 1, the RMS at the power frequency ranges from 0.5 to 1 minute. Figure 2 shows a one line schematic diagram power network with two buses. If a bus failure occurs, the voltage on the primary transformer would be in a fault state, and on the other hand, on the secondary of the transformer has not a zero level of the voltage. It can be said that voltage sag can propagate from primary to secondary.

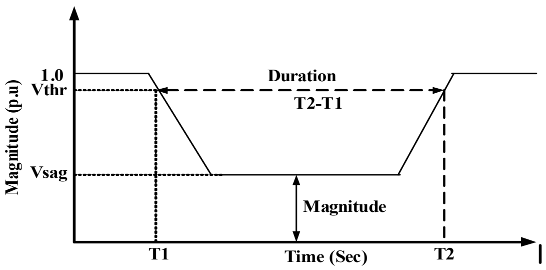

Fig. 1. Sag voltage discription.

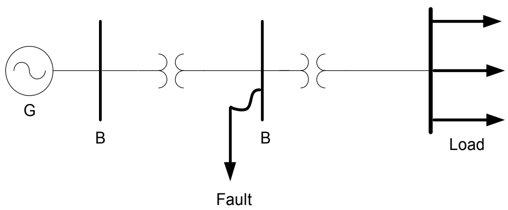

Fig. 2. One line diagram of the power system.

A. Simulink Model of the Distribution Network for Voltage Sag Propagation

This study aims to classify the voltage sag propagation under double line to ground fault on a low voltage distribution power network. The power system has four stages: generation, transmission, distribution, and utilization. In the model shown in Figure 3, one distribution feeder of 11kV from the feeder voltage has been sent to the load side and between them there is transformer. When fault occurs on the primary side of the transformer, the voltage will sag at the primary side and also propagate on the secondary side depending on various factors, i.e. fault type, winding connection, winding impedance, and fault impedance. Voltage sag was measured with a measurement block and calculated from the sequence analyzer on the primary and secondary side of transformer.

1) Three Phase Source Block

This block is formed in Simulink where three phase voltage displaced with reference degree is present. Here, 11kV voltage is selected and reference angle is selected.

2) Voltage Current Measurement Block

This block is formed where the three phase of voltage and current are measured and shown with a connected scope.

3) Three Phase Fault Block

This block is formed where the fault type (line to ground fault, double line fault, double lone to ground fault, and three phase faults) is selected.

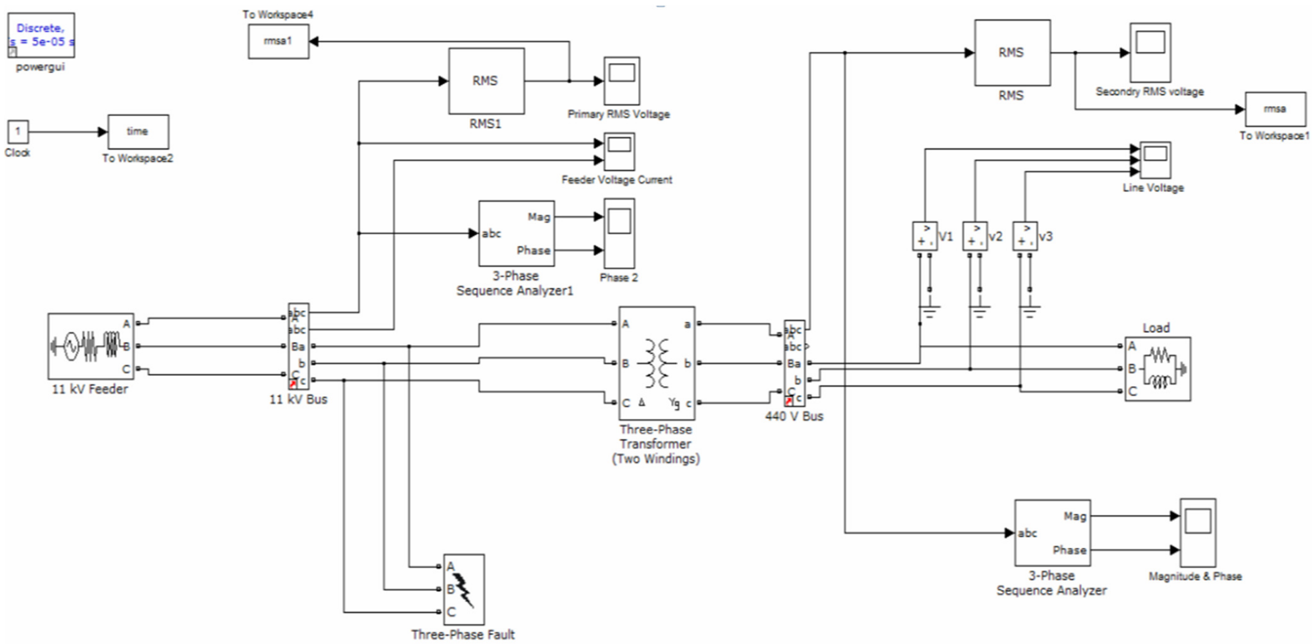

Fig. 3. The Matlab/Simulink model for the classification of voltage sag propagation of the distribution network.

4) RMS Voltage Block

This block measures the RMS value.

5) Two Winding Transformer

In this block, winding connections are selected with suitable winding resistance and inductance.

6) RLC Load Block

In this block, active and reactive powers are selected.

7) Sequence Analyzer Block

In this block, sequence component values and phase angles are measured and shown.

The discrete time ($5\ e^{-5}$) solver is used in the Simulink model.

B. Modeling for Sequence Analyzer's Symmetrical and Unsymmetrical Faults

In a power system, two kinds of faults occur, due to a variety of reasons, namely the symmetrical and the unsymmetrical faults. In symmetrical faults, all phases are short circuited, so all phases have the same amount of voltage, i.e. zero or maximum. In an unsymmetrical fault, two phases are short circuited with one another or to the ground: line to line, phase to line, and phase-phase to ground faults (LL, LG, and LLL).

C. Sequence Components

Fault calculation may be conducted with the sequence components. There are three sequence components (positive, negative, and zero sequence components) used in the analysis of the power system's faults and its stability. The sequence components are used to analyze the voltage sag propagation under unsymmetrical faults.

1) Positive Sequence Components

Positive sequence components have the same magnitude and displaced phase angle as the normal phase voltage or current, as shown in Figure 4.

2) Negative Sequence Components

Negative sequence components have the same magnitude but opposite phase displacement with normal phase voltage or current as shown in Figure 5.

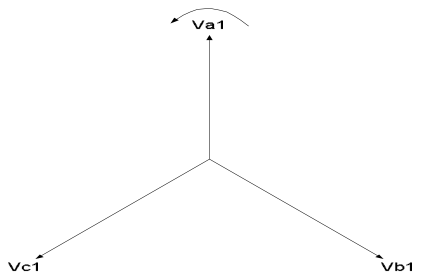

Fig. 4. Positive sequence components.

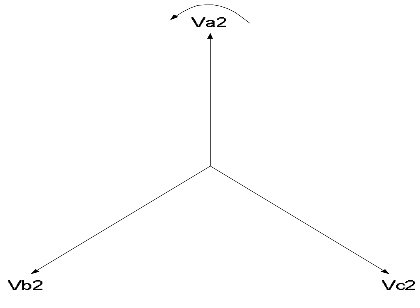

Fig. 5. Negative sequence components.

3) Zero Sequence Components

Zero sequence components have the same magnitude and angle as shown in Figure 6.

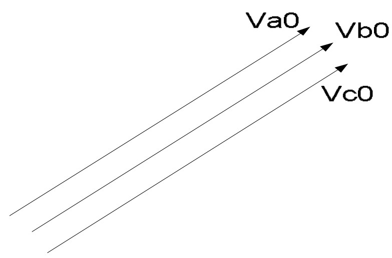

Fig. 6. Zero sequence components.

D. Phase Voltages Calculation by Sequence Components

In a three phase system Va, Vb, and Vc are the three phase voltages displaced at 0^0, 120^0 and 240^0or-120^0. Equations (1)-(3) [15] describe the system:

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

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

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

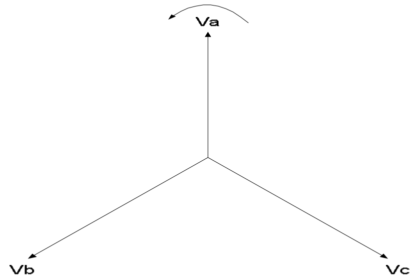

Fig. 7. A three phase vector.

III. RESULTS AND DISCUSSION

In this section, the Simulink sequence analyzer is used to display the simulation results. In this article, the different types of the connection of the three-phase transformers are considered and the voltage sag propagation on the distribution power network under double line to ground fault is analyzed. Sequence components (positive and zero components) are implemented to characterize the voltage sag. When the fault appears on the power system, then the voltage sag also occurs on each side of the transformer, but due to the transformer winding connection, the voltage sag will expand. Voltage sag analysis is performed by changing the fault resistance on the primary side of the transformer to monitor the propagation voltage on the secondary side by modifying the fault resistance, selecting double line to ground fault for voltage sag analysis, and selecting start-delta connection for comparative analysis.

A. LLG Fault with Y-Y Connection

In this section, the LLG with Y-Y connection of the transformer is used to test the voltage sag propagation on the power network. When an LLG fault takes place in the power network, voltage sag emerges on the primary and secondary sides, as shown in Figures 8 and 9. It can be clearly seen from the RMS value waveform that when a fault occurs on the primary to the secondary side of the transformer, then the voltage drop can appear as a different RMS value. The RMS values under LLG fault with different types of transformer connection were simulated in the Matlab model by using the phase sequence analyzer (Table I).

TABLE I. SAG VOLTAGE ON THE PRIMARY AND SECONDARY OF T/F WITH Y-Y CONNECTION

T/F Primary Side	T/F Secondary Side
Va1=0.333∠−1.3	*Va1*=0.332∠−4.059
Va2=0.333∠−121.28	*Va2*=0.3325∠−124.09
Va0=0.332∠−120.11	*Va0*= 0
Va = 0	*Va*= 0.332∠−64
Vb = 0	*Vb*=0.332∠−64
Vc = 0.99∠119.17	*Vc* = 0.66∠115.92

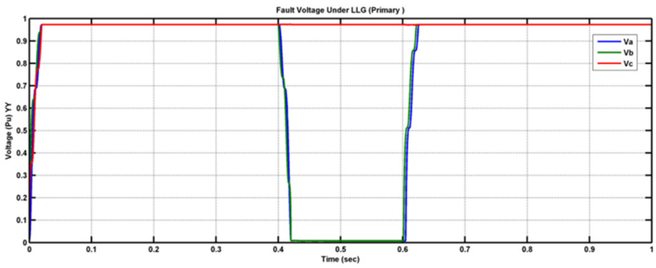

Fig. 8. Sag voltage at the primary side by using Y-Y connection.

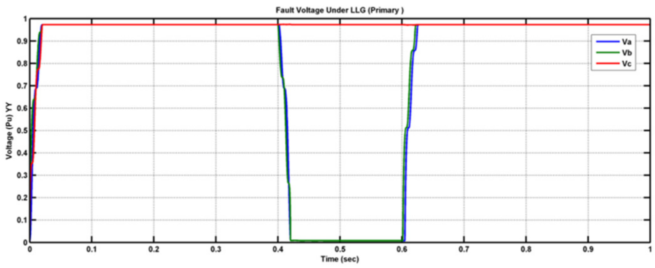

Fig. 9. Sag voltage at the secondary side by using Y-Y connection.

B. LLG Fault with Y-Delta Connection

When a LLG fault occurs in the power network, voltage sag would come out on both sides of the transformer as illustrated in Figures 10-11. The RMS value waveforms obviously state that once the primary side of the transformer fails, at different RMS values, the voltage sag of the transformer will drop to the secondary side. This is simulated in the model and can be passed. The phase sequence analyzer performs the calculations, as shown in Table II.

C. LLG Fault with YG-YG Connection

LLG fault with YG-YG connection is considered in this section. When a LLG fault takes place in the distribution network, there will be voltage sag on the primary and secondary sides as shown in Figures 12-13.

TABLE II. PRIMARY AND SECONDARY OF T/F ON Y-D CONNECTION VOLTAGE SAG

T/F Primary Side	T/F Secondary Side
Va1=0.333∠−1.3	*Va1=0.332∠−34.05*
Va2=0.333∠−121.28	*Va2*=0.3325∠−94.039
Va0=0.3321∠−120.11	Va0= 0
Va = 0	*Va* = 0.57∠-64
Vb = 0	Vb=0
Vc = 0.99∠ 119.17	*Vc*=0.57∠ 115.98

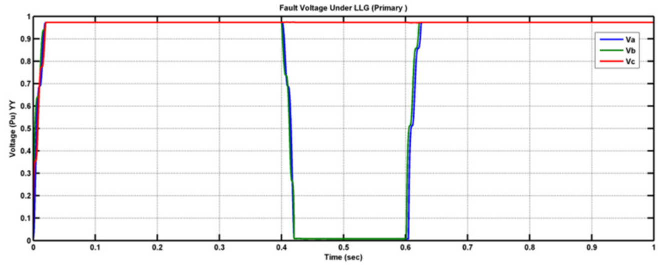

Fig. 10. Y-D connection sag voltage at the primary side.

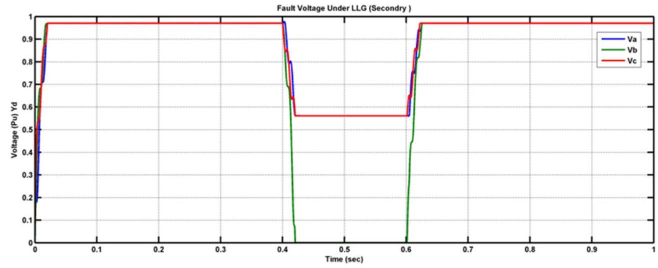

Fig. 11. Y-D connection sag voltage at the secondary side.

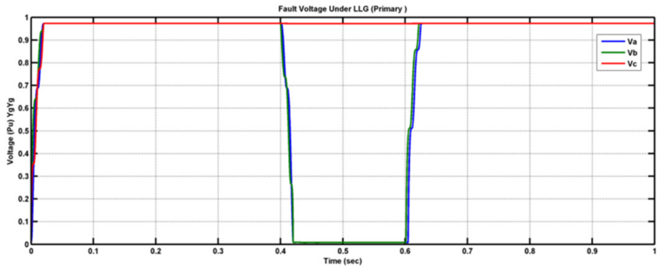

Fig. 12. YG-YG connection sag voltage at the primary side.

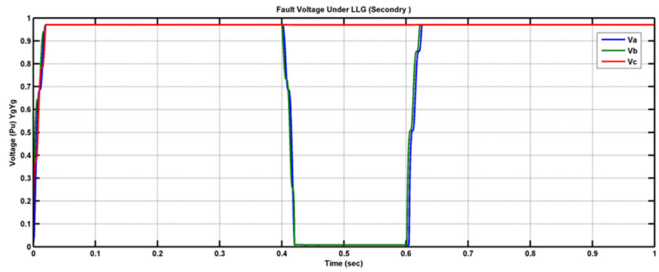

Fig. 13. YG-YG connection sag voltage at the secondary side.

From the RMS value waveform, it is observed that when the primary of the transformer fails, at different RMS value, the voltage sag of the transformer will also drop to the secondary side. The phase sequence analyzer performance is shown in Table III.

TABLE III. PRIMARY AND SECONDARY OF T/F ON YG-YG CONNECTION VOLTAGE SAG

T/F Primary Side	T/F Secondary Side
Va1 = 0.333∠-1.3	*Va1*= 0.332∠-4.25
Va2= 0.333∠-121.28	*Va2*= 0.332∠-124.23
Va0 = 0.3321∠120.11	*Va0*= 0.332∠-117.15
Va = 0	*Va*= 0
Vb = 0	*Vb*=0
Vc = 0.99∠119.17	*Vc*= 0.99∠116.2

D. LLG with YG-Delta Connection

Following, the LLG with YG-Delta connection has been tested for voltage sag propagation. When an LLG fault occurs, the voltage sag on the primary and secondary would appear on the transformer. It can be observed from the waveform of the RMS values in Figures 14-15 that when the primary of the transformer is under fault condition, then the voltage sags would be dropped to the secondary side of the transformer at different RMS values. Table IV represents the voltage sags on both sides of the transformer under phase sequence analyzer performance.

TABLE IV. PRIMARY AND SECONDARY OF T/F ON YG-D CONNECTION VOLTAGE SAG

T/F Primary Side	T/F Secondary Side
Va1=0.333∠−1.3	*Va1*=0.332∠−34.05
Va2=0.333∠−121.28	*Va2*=0.3325∠−94.039
Va0=0.3321∠120.11	*Va0*= 0
Va = 0	*Va*= 0.57∠-67
Vb = 0	*Vb*=0
Vc = 0.99∠119.17	*Vc*=0.57∠115.98

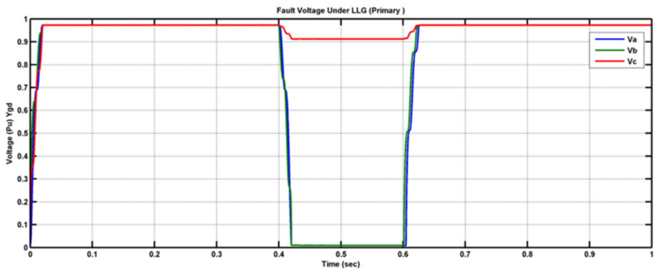

Fig. 14. YG-delta connection sag voltage at the primary side.

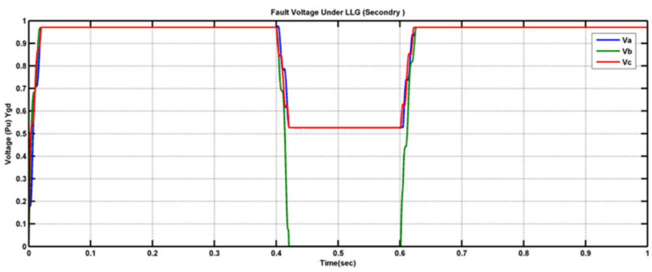

Fig. 15. YG-delta connection sag voltage at the secondary side.

E. Double Line to Ground Fault with Delta-Star connection

The RMS values of an LLG fault are shown in Figures 16-17. The voltage sags on the primary and secondary sides are again calculated with the sequence analyzer in the Matlab model. The calculated RMS values are shown in Table V.

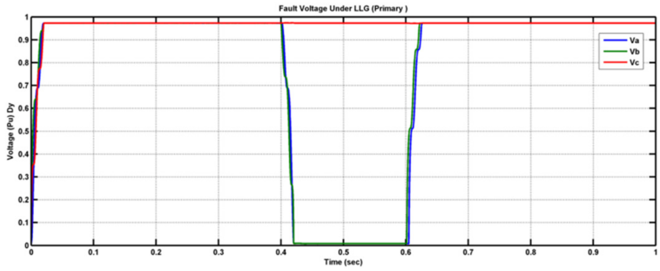

Fig. 16. D-Y connection sag voltage at the primary side.

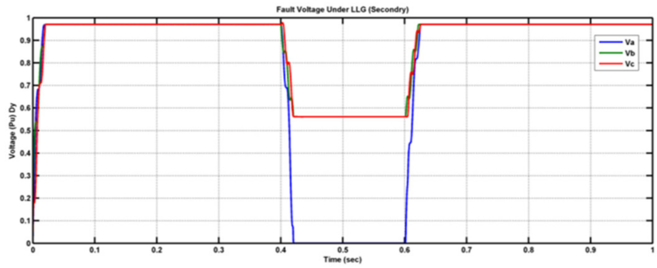

Fig. 17. D-Y connection sag voltage at the secondary side.

TABLE V. PRIMARY AND SECONDARY OF T/F ON D-Y CONNECTION VOLTAGE SAG

T/F Primary Side	T/F Secondary Side
Va1=0.333∠−1.3	*Va1*=0.332∠25.945
Va2=0.333∠−121.28	*Va2*=0.3325∠−154
Va0=0.3321∠120.11	*Va0*= 0
Va = 0	*Va*= 0
Vb = 0	*Vb=0.57∠ -64*
Vc = 0.99∠119.17	*Vc=0.57∠115.98*

F. Double Line to Ground Fault with Delta-Delta Connection

The RMS values of an LLG fault are shown in Figures 18-19. The voltage sags on the primary and secondary sides are again calculated with the sequence analyzer in the Matlab model. The calculated RMS values are shown in Table VI.

TABLE VI. PRIMARY AND SECONDARY OF T/F ON D-D CONNECTION COLTAGE SAG

T/F Primary Side	T/F Secondary Side
Va1=0.333∠−1.3	*Va1=0.332∠-4.059*
Va2=0.333∠−121.28	*Va2=0.3325∠−124.09*
Va0=0.3321∠120.11	*Va0*= 0
Va = 0	*Va*= 0.332<-64
Vb = 0	*Vb= 0.332 ∠-64*
Vc = 0.99∠199.17	*Vc* = 0.66∠115.92

G. LLG Fault with D-YG Connection

The RMS values of an LLG fault are shown in Figures 20-21. The voltage sags on the primary and secondary sides are again calculated with the sequence analyzer in the Matlab model. The calculated RMS values are shown in Table VII.

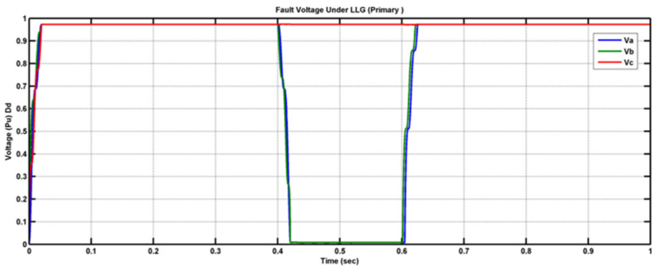

Fig. 18. D-D connection sag voltage at the primary side.

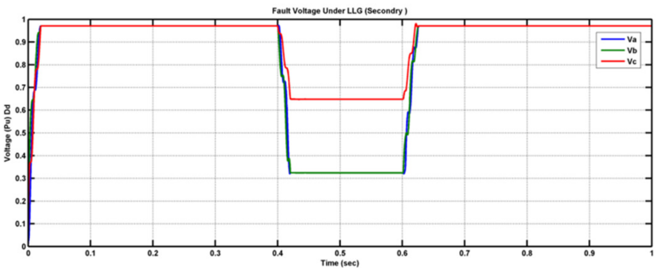

Fig. 19. D-D connection sag voltage at the secondary side.

TABLE VII. PRIMARY AND SECONDARY OF T/F ON D-YG CONNECTION VOLTAGE SAG

T/F Primary Side	T/F Secondary Side
Va1=0.333∠−1.3	*Va1=0.332∠ 25.945*
Va2=0.333∠−121.28	*Va2=0.3325∠−154*
Va0=0.3321∠120.11	*Va0=* 0
Va = 0	*Va*= 0
Vb = 0	*Vb= 0.57 ∠ -64*
Vc = 0.99∠119.17	*Vc=0.57∠115.98*

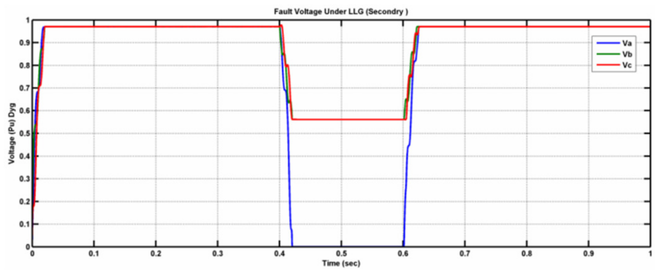

Fig. 20. D-YG connection sag voltage at the primary side.

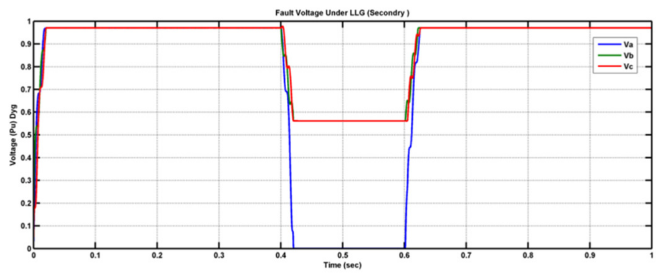

Fig. 21. D-YG connection sag voltage at the secondary side.

IV. CONCLUSION

This paper conducts in-depth research on the voltage sag propagation under double line to ground fault (LLG) with different transformer connections, which are used for low-voltage in distribution power networks. The results have been acquired with the use of the sequence analyzer. The obtained results show the voltage sag classification, which propagates from the primary to the secondary of the transformer. The voltage sag characterizations are important in order to check the power quality under fault condition of the distribution network. This study's results may be found helpful when designing proper protection schemes and ways to improve the voltage sag under fault conditions at various levels of the power system. It is worth noting that when a zero-sequence component is included, then voltage sag propagation would be different on the secondary side of the transformer. If the zero sequence components are not included, the same voltage sag would propagate from the primary to the secondary of the transformer. In addition, it can be observed that a phase shift would appear when a fault occurs on the secondary side of the transformer.

REFERENCES

[1] A. H. Soomro, A. S. Larik, M. A. Mahar, A. A. Sahito, and I. A. Sohu, "Simulation-based Analysis of a Dynamic Voltage Restorer under Different Voltage Sags with the Utilization of a PI Controller," *Engineering, Technology & Applied Science Research*, vol. 10, no. 4, pp. 5889–5895, Aug. 2020, https://doi.org/10.48084/etasr.3524.

[2] A. K. Junejo, G. M. Bhutto, A. S. Saand, and M. U. Keerio, "Analysis of Unsymmetrical Voltage Sag Propagation Trough Distribution Transformer," *Research Journal of Applied Sciences, Engineering and Technology*, vol. 13, no. 5, pp. 403-408–408, 2016, https://doi.org/10.19026/rjaset.13.2958.

[3] P. S. Kiran, B. Nookesh, M. N. Bhavani, B. A. Kumar, and G. Mani, "Voltage Sag Mitigation Using Pulse Width Modulation Switched Autotransformer through Matlab Simulation," *International Journal of Engineering Research and Applications*, vol. 4, no. 4, pp. 33–36, Apr. 2014, https://doi.org/10.19026/rjaset.13.2958.

[4] F. Jandan, S. Khokhar, Z. A. Memon, and S. a. A. Shah, "Wavelet Based Simulation and Analysis of Single and Multiple Power Quality Disturbances," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 3909–3914, Apr. 2019, https://doi.org/10.48084/etasr.2409.

[5] A. A. Malak, G. M. Bhutto, E. A. Buriro, and M. A. Koondhar, "Mathematical Analysis of Voltage Dip propagation in CIGRE (International council of large electric system) Low Voltage Distribution Test Network," *Journal of Applied and Emerging Sciences*, vol. 10, no. 2, pp. 109–116, Dec. 2020, https://doi.org/10.36785/jaes.v10i2.405.

[6] E. A. Al-Ammar, A. Ul-Haq, A. Iqbal, M. Jalal, and A. Anjum, "SRF based versatile control technique for DVR to mitigate voltage sag problem in distribution system," *Ain Shams Engineering Journal*, vol. 11, no. 1, pp. 99–108, Mar. 2020, https://doi.org/10.1016/j.asej.2019.09.001.

[7] M. Ramachandran, A. M. C. Mary, M. Muthukumaran, J. Ganesan, A. Krishnaveni, and D. E. Selvaraj, "A Review on Basic Concepts and Important Standards of Power Quality in Power System," *International Journal of Science and Engineering Applications*, vol. 4, no. 5, pp. 299–303, Oct. 2015, https://doi.org/10.7753/IJSEA0405.1013.

[8] M. M. Ghahderijani, M. Castilla, L. G. de Vicuña, A. Camacho, and J. T. Martínez, "Voltage sag mitigation in a PV-based industrial microgrid during grid faults," in *2017 IEEE 26th International Symposium on Industrial Electronics (ISIE)*, Edinburgh, UK, Jun. 2017, pp. 186–191, https://doi.org/10.1109/ISIE.2017.8001245.

[9] S. Thirukkovai, J. Venkatesan, and D. S. M. Girirajkumar, "Voltage Sag/Swell Mitigation Using UPQC," *International Journal of Scientific & Engineering Research*, vol. 5, no. 4, pp. 161–167, Apr. 2014.

[10] S. I, A. J, and K. K. V. Kumar, "Sag/Swell Migration Using Multi Converter Unified Power Quality Conditioner," *International Journal of Advances in Engineering & Technology*, vol. 1, no. 5, pp. 437–440, Nov. 2011.

[11] J. Chen, L. Qi, G. Jin, and Y. Xue, "Analysis of the effect on propagation of voltage sag considering different winding connection modes of transformer," presented at the 2016 International Conference on Advanced Electronic Science and Technology (AEST 2016), Nov. 2016, pp. 547–556, https://doi.org/10.2991/aest-16.2016.74.

[12] O. H. Eyüboğlu, B. Dindar, and Ö. Gül, "Series Resonance Type Fault Current Limiter for Fault Current Limitation and Voltage Sag Mitigation in Electrical Distribution Network," in *2020 2nd Global Power, Energy and Communication Conference (GPECOM)*, Izmir, Turkey, Oct. 2020, pp. 256–261, https://doi.org/10.1109/GPECOM49333.2020.9247878.

[13] "IEEE Recommended Practice for Monitoring Electric Power Quality," *IEEE Std 1159-2019 (Revision of IEEE Std 1159-2009)*, pp. 1–98, Aug. 2019, https://doi.org/10.1109/IEEESTD.2019.8796486.

[14] S. S. Rao, *Switchgear Protection and Power Systems*, 13th ed. Delhi, India: Khanna Publishers, 2008.

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