Voltage Profile in a Low Voltage Distribution Network: A Case study of a typical network in New Zealand

Parash Acharya[1*], Alan Wood[2], and Andrew Lapthorn[2]

[1]Electric Power Engineering Centre (EPECentre), University of Canterbury
[2]Department of Electrical and Computer Engineering, University of Canterbury
[*]Presenting

EEA Conference & Exhibition 2018,20-22 June in Auckland

Abstract: This paper presents a study of a voltage profile in a typical distribution network within New Zealand. The impact of neutral shift on the bus voltages is studied. Two networks are selected for the analysis, one that is representative of most city/commercial networks, while the other network was selected randomly for the analysis. Real household load data was used for performing power flow analysis for these networks. An yearly power flow analysis for a typical city/commercial network is performed which consists of 46 Installation Connection Points (ICPs), with 19 residential and 27 non-residential loads. Similarly, the neutral shift analysis for unbalanced load is performed for the randomly selected network. For the same network, the change in voltage in each phase due to neutral voltage change is also analyzed. This work clarifies how much of the voltage variation in an LV network is attributable to neutral point voltage shift.

1 Introduction

In the future, more Distributed Generators (DGs) and Electric vehicles (EVs) connected to a Low Voltage (LV) network will affect the overall voltage profile of the network. The connection of such loads and generators in one of the phases will not only affect voltage profile of that particular phase but also of the other two phases. Such effects can be seen in the form of neutral point shifting or voltage unbalance. The return current flowing through a neutral conductor contribute towards a neutral-point shifting [1]. Harmonic currents also contribute towards large neutral current. Therefore, a four wire system (three phase with a neutral conductor) needs to be considered while performing a load flow analysis [2] [3]. This paper focuses on the power flow results with neutral point shift due to load unbalance.

A Matlab program was developed to run load flow in open-DSS for a LV distribution networks. A clustering of networks was performed in [4] and were classified into four major categories namely city , urban, rural and industrial . A power flow was run for one of these typical networks (named city/commercial and closest to cluster center) throughout the year. With a small number of Installation Connection Points (ICPs) compared to some other typical city networks, the processing time for running power flows throughout the year is reduced. Similarly, a detailed analysis of a randomly selected network is performed using a different set of real household loads. The voltage profile is only studied for one day load data of summer and winter. The power flow analysis is performed in Open-DSS using components such as transformer(with different connections), voltage source, line (both underground and overhead) and loads (of different types). An admittance (Y)-primitive matrix is formed for each of these components which are finally combined to obtain an overall Y-matrix of the network. The details of the model used for this study for all of these components can be found in [5], [6] and [7].

This paper presents the issue of voltage unbalance due to neutral point shifting in Section 2. The power flow results in a typical city/commercial LV network is presented in Section 3. Section 4 shows variation of voltages in different nodes which is mainly caused by neutral point shift. Finally, conclusions are drawn in Section 5.

2 Neutral Point Shift

A perfectly balanced load in each of the three phases and balanced source voltages will have the same neutral voltage at the load and at the source. With unbalanced lines and load, the neutral voltages at a load terminal will not be equal (neither in magnitude nor in phase) with that of the source neutral. This will make phase currents different and cause different voltage drops in the load phases. The neutral voltage will shift from a the supply neutral voltage to a different value. The amount of shift depends on the amount of unbalance.

One of the networks analysed is shown in Figure 1. For this network, the neutral shift in one of the buses (B2_2_3) due to load unbalance is shown in Figure 2. In Figure 2, all the neutral voltage angles at the load side are with respect to the transformer neutral. Even with a perfectly balanced three phase load within the network, there is a non-zero neutral voltage at the load terminal. This is due to the fact that different ICPs are connected with different line configurations which have different zero sequence impedances.

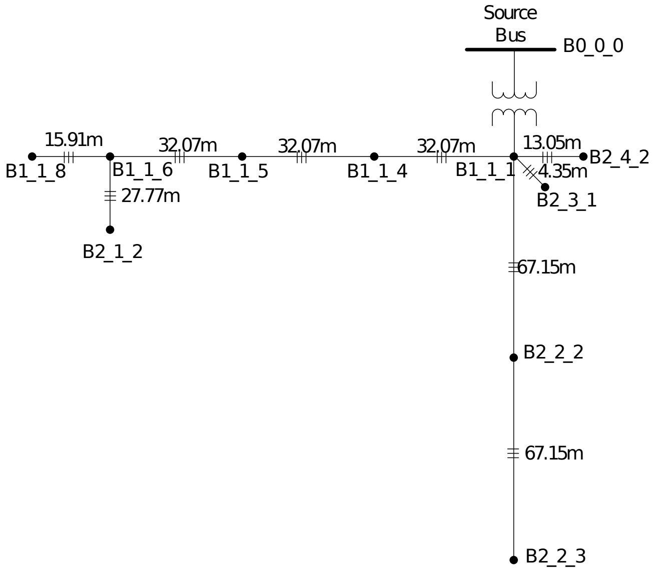


Figure 1: Single line diagram of a 10 Node randomly selected feeder along with the distances in metres

From Figure 2, it can be observed that at balanced load although there is reduced voltage at node B2_2_3 terminal due to the distance from the transformer, the voltages are still balanced. On the other hand, because of an unbalanced load, there is reduced voltage in one of the phase, the result of which can be observed in the form of increased voltage in other two phases. The neutral voltage angle at this node moves toward phase B, which reduces its voltage while Phase A and C experience an increased voltage.

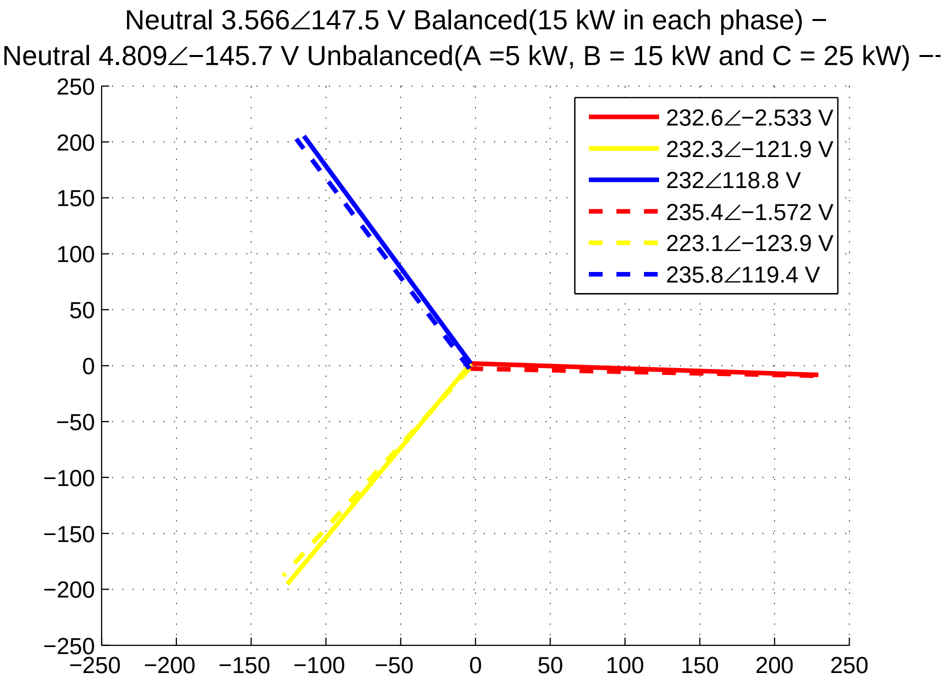


Figure 2: Neutral shift at bus B2_2_3 due to unbalanced load in the network (solid line = balanced load and dashed line = unbalanced load)

As seen in Figure 2, load unbalance results in a neutral shift which has impact on the magnitude change in all of the three phase voltages. This is why three wire model (using Kron's reduction) for wye line segment might not represent an accurate model of the line and hence for this study, a four wire line model is used.

3 Power Flow results in a typical network

Reference [4] proposed a typical city/commercial and closest to cluster center which is as shown in Figure 3. The network consists of 46 ICPs (19 residential and 27 non-residential loads).

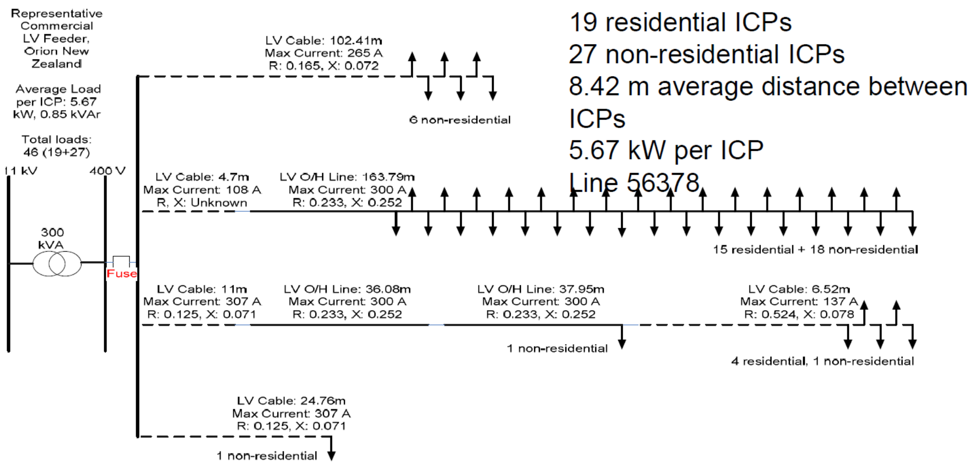
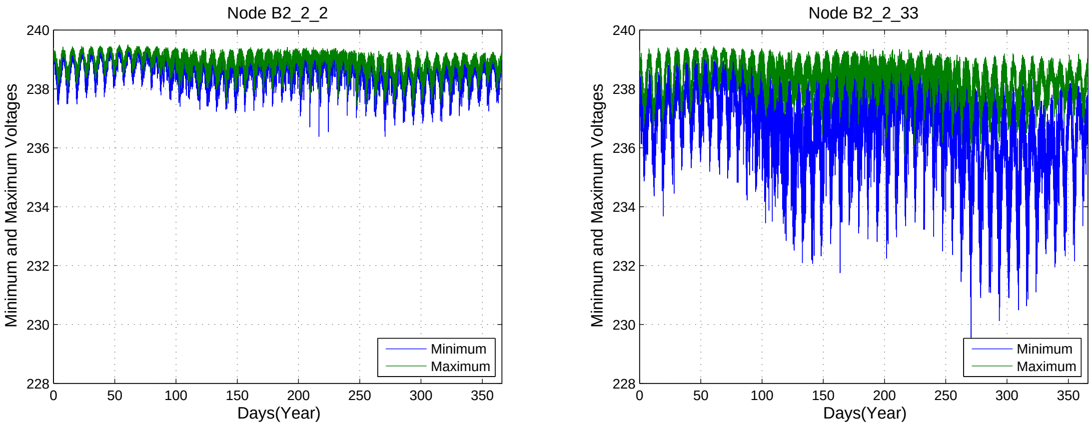


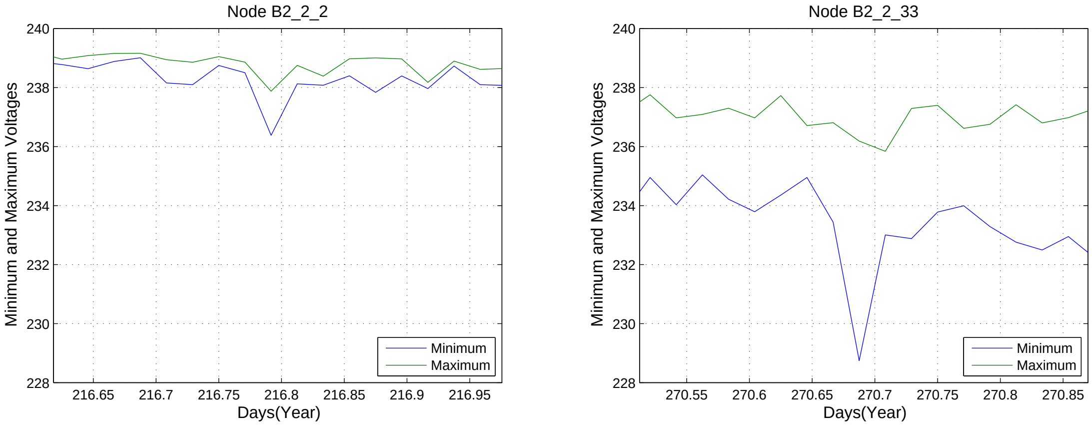
Figure 3: City/Commercial Network which is closest to the cluster centre

The load flow analysis is performed for the network as shown in Figure 3 using randomly selected 46 ICPs yearly load data of 2015 from the same region in NZ. The maximum and minimum voltages (out of three phase voltages) for every half hour throughout the year at two different ICPs (one near and one far from the transformer in feeder 2) is plotted in Figure 4. This shows that the variation of minimum voltage is higher for the node far from the transformer. Very few of the minimum voltages lie below 230 V. This is a city network whose ICPs lies very close to each other reducing overall resistance of the network. The voltage profile can be worse in a rural network whose ICPs are far away from each other. In future, the author will identify the weak networks (in terms of voltage profile) and perform further analysis. A zoomed version of Figure 4 is plotted in Figure 5 focussing on the minimum voltage during one year period. For the node B2_2_33 lying far from the transformer, the minimum voltage falls below 230 V. None of the voltages at node B2_2_2 (close to the transformer) fall below 236 V. It is noteworthy that the instance of minimum voltage on one phase is not correlated with low voltage in other two phases, implying that this is associated with a neutral voltage change.



(a) Node near to the transformer (b) Node far away from the transformer

Figure 4: Minimum and Maximum Voltages at two different nodes



(a) Node near to the transformer (b) Node far away from the transformer

Figure 5: Minimum and Maximum Voltages at two different nodes (zoomed at lowest voltage)

4 Variation of voltages with respect to neutral voltages

Further analysis for the network as shown in Figure 1 was performed using randomly selected household data for two days (one for summer and other for winter). The loads used at various nodes for two different days (January 1 and July 15) are as shown in Figures 6 and 7 in which three different colours represent the load connected to various phases.

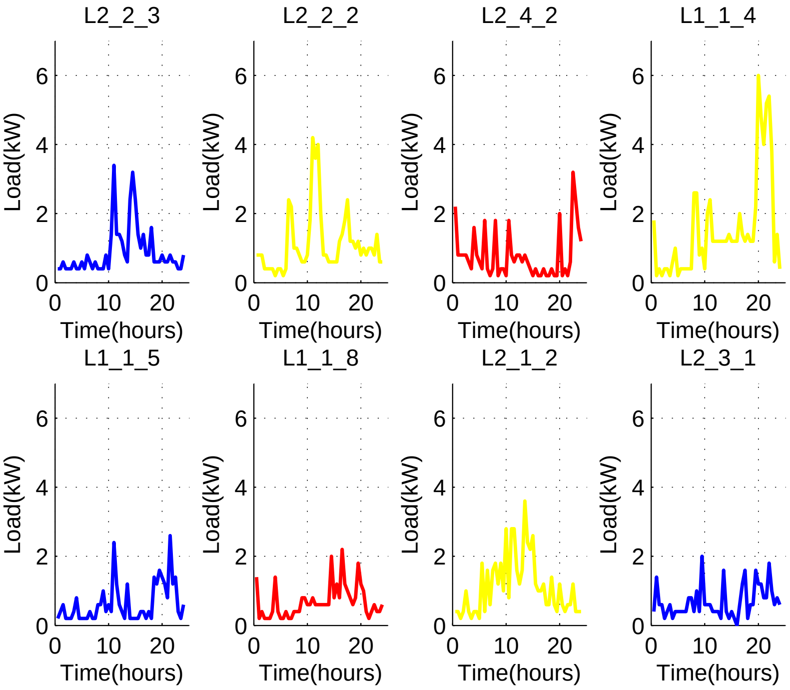


Figure 6: Load at different nodes for January 1

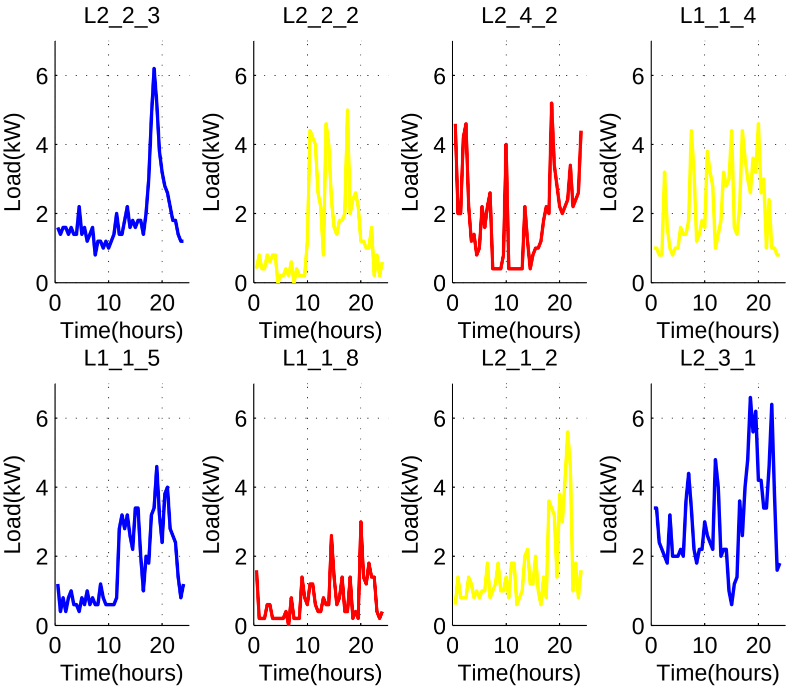


Figure 7: Load at different nodes for July 15

The maximum voltage difference between phases versus neutral voltages at two nodes are plotted in Figures 8 and 9 which shows that the difference due to neutral voltage change is strongly correlated at the nodes far away from the transformer. The magnitude of the neutral voltage is also relatively high for the networks that has higher unbalanced load (in this case July 15 load). These graphs show that the voltage difference between phases is between 70-90% due to neutral voltage shift at the far end of the feeder.

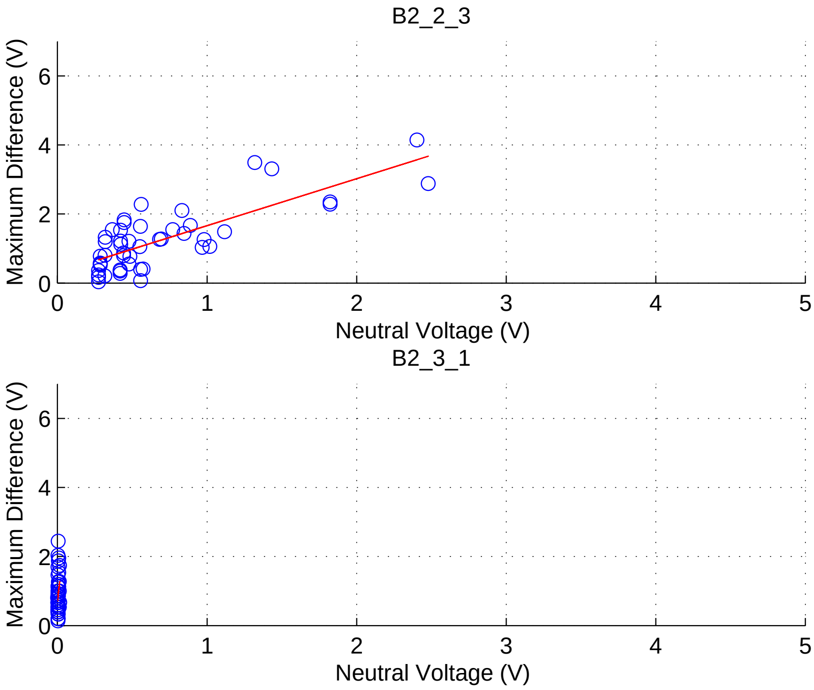


Figure 8: Maximum Voltage difference versus neutral voltages at different nodes for January 1

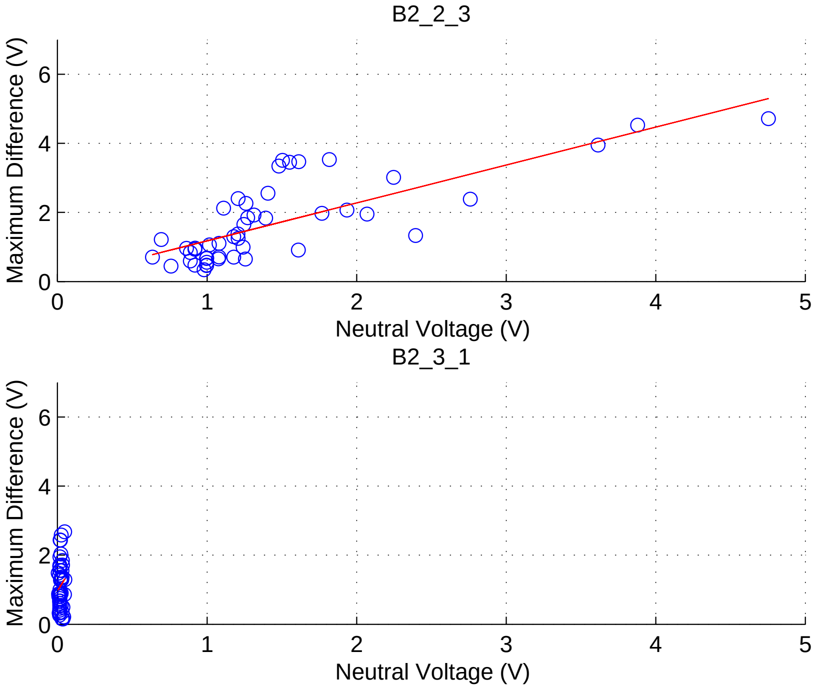
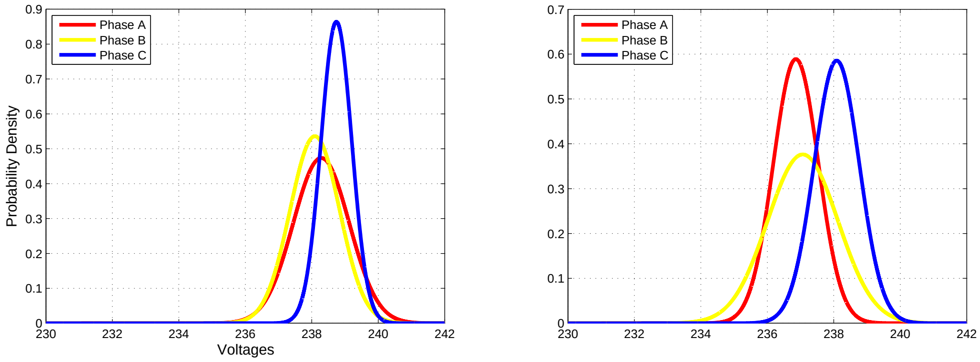


Figure 9: Maximum Voltage difference versus neutral voltages at different nodes for July 15

A normally fitted distribution probability density function for three phase voltages of two days are plotted in Figure 10. From this Figure, it can be observed that the variation of voltages at all the nodes for these two days lies in between 230 V and 240 V while a greater variation can be observed on July 15. A common practice in distribution network is to connect tap changing transformers in order to maintain the voltage. With reference to Figure 10, the tap changing transformers shift the voltages either to the left (if some of the nodes are over-voltage) or towards right (if some of the nodes are under voltage) but do not control the spread of voltages. Hence, an approach for controlling these nodal voltages without using tap-changing transformers may be preferred.



(a) Three Phase Voltages for January 1 (b) Three Phase Voltages for July 15

Figure 10: Probability density of three phase voltages and neutral voltage on January 1 load

5 Conclusions

When performing power flow analysis for the city/commercial network through out the year, only few voltages at the nodes (far away from the transformer) reached below 230 V, which showed that these are strong networks. With greater variation of load in three phase voltages there will be larger neutral voltage drop at the nodes far away from the transformer. This analysis shows that neutral voltage shift is a strong contributor to voltage variation in LV distribution network, and this should be taken into account in voltage control strategies. Three phase tap changing transformers might not be a proper solution when there is large variation of voltages due to higher unbalanced load between phases. More analysis need to be done for identifying the weak networks and the impacts of connecting DGs and EVs for such networks.

References

[1] L. Degroote, B. Renders, B. Meersman, and L. Vandevelde, "Neutral-point shifting and voltage unbalance due to single-phase dg units in low voltage distribution networks," in *IEEE Bucharest Power Tech Conference*, June 2009.

[2] J. Desmet, D. Putman, F. Hulster, and R. Belmans, "Thermal analaysis of the influence of nonlinear, unbalanced and asmetrical loads on current conducting capacity of lv-cables," in *IEEE Power Tech Conference*, June 2003.

[3] L. Sainz, J. Pedra, and J. Mesas, "Study of three phase conductor current in three-phase networks with single-phase converters," in *IEEE Transaction on Power Delivery*, ser. 3, vol. 21, 2006, pp. 1466–1475.

[4] J. Watson, N. Watson, D.Santos-Martin, A. Wood, and S. Lemon, "Impact of solar photovoltaics on the low-voltage distribution network in new zealand," *IET Generation, Transmission and Distribution*, 2015.

[5] W. H. Kersting, *Distribution System Modeling and Analysis*. CRC Press, 2001, vol. 1.

[6] F. Alvardo, "Formation of y-node using the primitive y-node concept," in *IEEE Transactions on Power Apparatus and Systems*, ser. 12, vol. PAS-101, December 1982, pp. 4563–4571.

[7] R. C. Dugan and S. Santoso, "An example of 3-phase transformer modeling for distribution system analysis." IEEE, September 2003, pp. 1028–1032.