LINE LOSSES, VOLTAGE DROP AND VOLTAGE UNBALANCE ON PARALLEL OVERHEAD DISTRIBUTION LINES

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Abstract

It has been a general practice by distribution utilities to parallel overhead distribution lines/feeders in a common right of way and the same pole as they terminate from a common substation. This paper studies the impact of modeling parallel overhead distribution lines. The modeling of this kind of circuits in the regulated status of electric distribution business is important as the modeling can impact line losses, voltage drop and voltage unbalance in the lines. A sample case was set-up and is simulated in two cases; parallel lines modeling and taking the parallel lines individually. The study utilized load flow calculations for analyzing line losses, voltage drops and voltage unbalance. The results showed that line losses are not affected by the kind of modeling applied to parallel overhead distribution lines but voltage drop and voltage unbalance yielded different results in the two cases simulated.

I. Introduction

For electric distribution utilities (DUs), it has been a general practice to parallel distribution lines/feeders in a common right of way and the same pole as they terminate from a common substation. The lines will be in parallel and will separate on different poles to serve the loads dedicated to each three-phase line.

The regulation of electric distribution business calls for accurate modeling and analysis of distribution networks. The resulting parameters from models and analysis will be used for performance regulation in operations and planning [1]. In [2], the regulating agency prescribed models that shall be used for distribution system losses segregation. In this case, distribution lines are to be three-phase models. The technical document ignores the practice of paralleling distribution lines. Though the modeling was intended for losses, there is a possibility that DUs may utilize the suggested models for benchmarking in all their planning and operations strategies based on the models described in the document since accompanying paper states an analytical tool, "Three-Phase Load Flow". Three phase load flow analysis is used for balanced or unbalanced distribution systems and can be utilized for voltage drop, capacitor placement, voltage regulator placement and setting, and voltage unbalance assessment, etc. Reference [3] addressed the need for modeling parallel distribution lines which would have 6x6 phase impedance matrix to account for the mutual coupling for all conductors in parallel.

This paper extends the work in [3] by analyzing the impact of modeling parallel distribution lines in terms of line losses, percent voltage drop and voltage unbalance. By studying these, we can examine on how modeling of distribution lines, modeled parallel or individually modeled, affect the said indices. The load flow algorithm discussed in [3] and [4] is employed whether the lines are in parallel or taken separately.

II. Case Building and Simulations

First and foremost, we created a case that can be utilized for the purposes of the paper. We adopted the pole configuration given in [3] and is illustrated Figure 1. Table 1 has the unbalanced loading assignments for the line phases. For the phase conductors, we used 4/0 ACSR, for the neutral conductors, 2/0 ACSR with length of the lines being 10 miles and 13.8 kV line to line voltage. When the lines are modeled separately, the lower set of three-phase line, Line 1, and the upper set of three-phase line, Line 2, will maintain the same configuration and both sets will be with neutral conductor of the same configuration. Case 1 simulates the overhead lines in parallel. Case 2 considers the distribution lines as separate in the simulations.

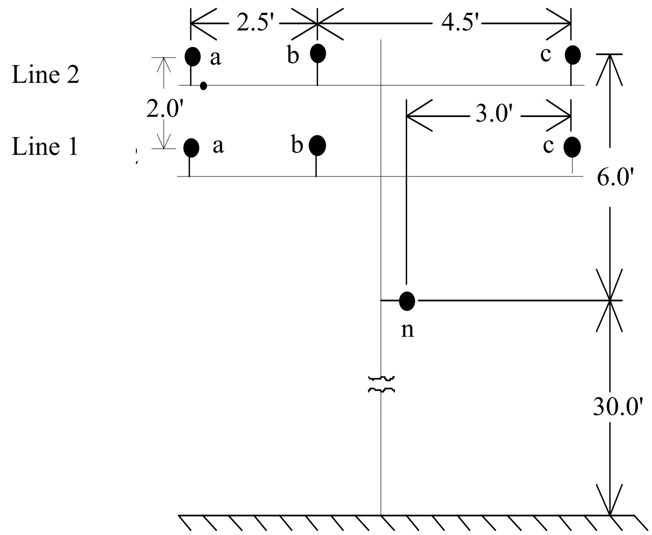

Figure 1. Parallel lines on a common distribution pole [3].

Table 1. Loading assignments for phases of each line.

Line #	Phase	kVA	Power Factor
Line 1	A	240	0.95
	B	275	0.90
	C	300	0.85
Line 2	A	230	0.90
	B	280	0.85
	C	310	0.95

When the lines are modeled in parallel the phase impedance matrix will be in the form of equation (1). When the lines are modeled separately, the format of each line's phase impedance matrix will be like in equation (2).

$$Z_{\| abc} = \begin{bmatrix} Z11_{aa} & Z11_{ab} & Z11_{ac} & Z12_{aa} & Z12_{ab} & Z12_{ac} \\ Z11_{ba} & Z11_{bb} & Z11_{bc} & Z12_{ba} & Z12_{bb} & Z12_{bc} \\ Z11_{ca} & Z11_{cb} & Z11_{cc} & Z12_{ca} & Z12_{cb} & Z12_{cc} \\ Z21_{aa} & Z21_{ab} & Z21_{ca} & Z22_{aa} & Z22_{ab} & Z22_{ac} \\ Z21_{ba} & Z21_{bb} & Z21_{bc} & Z22_{ba} & Z22_{bb} & Z22_{bc} \\ Z21_{ca} & Z21_{cb} & Z21_{cc} & Z22_{ca} & Z22_{cb} & Z22_{cc} \end{bmatrix} \Omega \tag{1}$$

$$Z_{abc} = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \Omega \tag{2}$$

For the load flow simulations, the sending end voltage is assumed to be balanced as in the case of a regulated substation bus voltage. The load flow calculations followed the general figure for a three phase distribution line given in Figure 2. As stated in Section I, the load flow algorithm presented in [3] and [4] are used for the simulations.

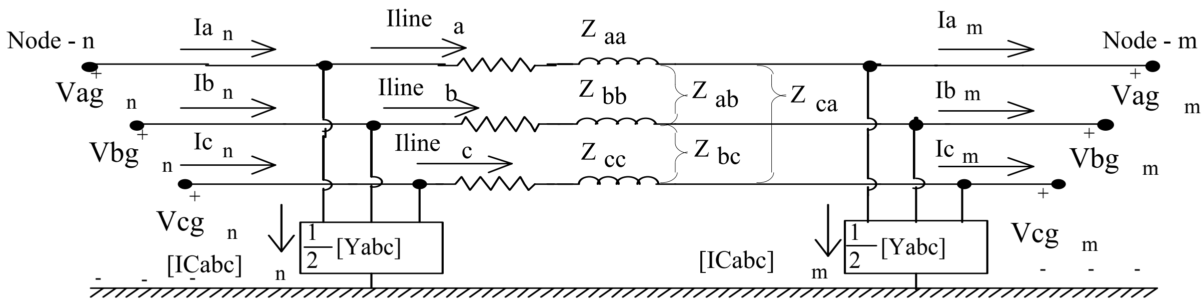

Figure 2. General figure for three-phase distribution lines.

For percent voltage drop assessment, equation (3) is utilized.

$$\%\ \text{Voltage Drop} = \frac{\text{Sending end voltage} - \text{Receiving end voltage}}{\text{Sending end voltage}}\ x\ 100 \quad (3)$$

For voltage unbalance assessment, the computation of unbalance factor was adopted from [1] and [5-7]. The following equations are used for solving voltage unbalance.

$$\text{Voltage Unbalance (IEC)} = \frac{\text{Negative sequence voltage}}{\text{Positive sequence voltage}}\ x\ 100 \quad (4)$$

$$\text{Voltage Unbalance (PDC)} = \frac{|\ \text{Maximum deviation from average}\ |}{|\ \text{Average of three phase voltages}\ |}\ x\ 100 \quad (5)$$

Equation (4) is solved because power quality (PQ) monitoring devices, based from an International Electrotechnical Commission (IEC) standard [6], are utilizing the said equation for processing voltage unbalance, while equation (5), is used by the regulator for performance standards in [1].

III. Analysis of Results

A. Line Loss Evaluation

In Table 2, the computed line losses in both cases are almost equal. Losses along distribution lines are I^2R, where I is the current flowing in the line and R being the line resistance, by knowing this the calculated values of line losses from the load flow analysis should be equal or near to each other in both simulation cases. This can be expected since the line currents in both cases are equal. The discrepancy can be due to the unequal mutual coupling between conductors and the added neutral conductor in Line 2 in separate lines simulation.

Table 2. Computed line losses.

Case #	Remarks	Line #	Line Loss (kW)	Total (kW)
1	Parallel Case	Line 1	20.1971	42.4461
		Line 2	22.4671	
2	Separate Case	Line 1	20.8261	42.3635
		Line 2	21.5374	

B. Voltage Drop and Voltage Unbalance Evaluation

Table 3 presents the results of calculated voltages, voltage drop and voltage unbalance. Based from the results, voltage drops for the two overhead lines differ from one another. The phase voltages tend to increase or decrease depending on the modeling of parallel lines' case simulated. Likewise, the voltage unbalance in the receiving end of the line yielded different results. Voltage unbalances were noticeably higher, whether using the formula of IEC or PDC, in the case of parallel lines simulation. The PDC voltage unbalance levels are slightly lower than the unbalance assessment as per IEC standard. The difference in voltage drops and voltage unbalance levels is primarily due to the unequal mutual coupling between conductors in the modeling of parallel lines. It can be said that the approach to modeling overhead distribution lines in parallel will have an impact to voltage drop and voltage unbalance.

Table 3. Computed voltages, voltage drops and voltage unbalance.

Case #	Remarks	Line #	Phase Voltage		% Voltage Drop	Voltage Unbalance	
						PDC	IEC
1	Parallel Case	Line 1	Vab	13,450.63	2.532	1.370	1.381
			Vbc	13,193.85	4.392		
			Vca	13,162.11	4.622		
		Line 2	Vab	13,443.37	2.584	1.307	1.331
			Vbc	13,156.83	4.661		
			Vca	13,209.74	4.277		
2	Separate Case	Line 1	Vab	13,404.20	2.868	1.038	1.091
			Vbc	13,325.60	3.438		
			Vca	13,157.85	4.653		
		Line 2	Vab	13,434.61	2.648	1.052	1.203
			Vbc	13,157.52	4.656		
			Vca	13,300.29	3.621		

IV. Conclusions

This paper investigated the impact of modeling overhead distribution lines in parallel with line losses, percent voltage drop and voltage unbalance. Two simulation cases, parallel lines and individual line modeling, were presented to evaluate the said parameters.

Line losses are almost the same for the simulated cases. It can be concluded that the modeling parallel distribution lines as parallel or separate lines will not impact line losses assessment.

The resulting voltage drops and voltage unbalances were of different values for both cases. Voltage drops tend to increase or decrease when comparing the simulation cases' results. The voltage unbalances in the lines were higher in the parallel lines simulation than in the other case. The IEC standard of computing voltage unbalance yielded slightly higher values than the PDC requirement. The modeling of parallel overhead distribution lines will have an effect on voltage drops and voltage unbalances based from the results. The voltages at the receiving end of parallel distribution lines are affected by the unequal mutual coupling between the line conductors.

References

[1] Philippine Distribution Code, Energy Regulatory Commission, San Miguel Avenue, Pasig City, Philippines, available on line- www.erc.gov.ph.

[2] *Models and Methodology for Segregating Distribution System Losses*, Annex A of Guidelines for the Application and Approval of Caps on the Recoverable Rate of Distribution System Losses, Energy Regulatory Commission, San Miguel Avenue, Pasig City, Philippines, available on line- www.erc.gov.ph.

[3] W. H. Kersting, *The Modeling and Analysis of Parallel Distribution Lines,* presented at the IEEE Rural Electric Power Conference 2005.

[4] W. H. Kersting, Distribution System Modeling and Analysis, CRC Press, Boca Rotan, Florida, 2001.

[5] J. A. L. Ghijselen and A. P.M. Van den Bossche, *Exact Voltage Unbalance Assessment Without Phase Measurement*, IEEE Transactions on Power Systems, Vol. 20, No. 1, February 2005.

[6] T. A. Short, Electric Power Distribution Handbook, CRC Press, Boca Rotan, Florida, 2004

[7] T. Gonen, Electric Power Distribution System Engineering, McGraw-Hill Book Company, New York, 1986

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