OVERHEAD MEDIUM VOLTAGE TWISTED INSULATED CABLE MODELS FOR THREE-PHASE POWER FLOW ANALYSIS

Lukmanul Hakim[1], Alex Munandar[2], Diah Permata[1], Herri Gusmedi[1], Khairudin[1] and Umi Murdika[1]
[1]Jurusan Teknik Elektro, Universitas Lampung, Bandar Lampung, Indonesia
[2]PT. PLN (Persero) Distribusi Jakarta Raya Area Bintaro, Indonesia
E-Mail: plgsekip@eng.unila.ac.id

ABSTRACT

This paper proposes a modified Carson method for modeling 20 kV overhead medium voltage twisted insulated cables (MVTIC) commonly found in the distribution systems in Lampung Province, Indonesia. Different cable sizes are considered in this work. Results are then compared to those obtained from OpenDSS and ETAP (with SPLN library). The sequence impedances obtained from the method are then utilized in the developed three-phase power flow software to analyze a real medium voltage distribution feeder consisting 119 buses and serving rural area.

Keywords: overhead cable modified carson, distribution system.

INTRODUCTION

The need of performing three phase power flow analysis has led the Power System Laboratory of Universitas Lampung to develop a computer program for calculating three phase power flow based on Newton-Raphson method [1] called UnilaPF. In the previous implementation, three phase distribution line admittance was constructed from sequence impedance input to the program. Consequently, it requires user to obtain the sequence impedance of each line segment prior to using the program. This data is not always available and therefore, a more generic model which reflects the physical construction of the distribution line is required to ease the user in using the program.

In addition to the commonly-found overhead conductor for distribution line, a medium voltage cable constructed from three single-phase conductors is also used in distribution feeder. However, application of the modified Carson's method to obtain the sequence impedance of such cable line has not been reported previously. According to the modified Carson method, sequence impedance is affected by distance between the conductor (D), frequency of system (f), and soil resistivity (ρ).

The modified Carson method, developed by W. H. Kersting [2] is considered to be simple to implement in a computer program, yet sufficiently models the distribution line of interest. In this work, a modified Carson method is proposed to model the overhead medium voltage twisted insulated cable (MVTIC) commonly found in the 20-kV distribution systems in Lampung Province, Indonesia. Different cable sizes are examined and the results are then compared to those from OpenDSS [3] and ETAP [4].

MODEL IMPLEMENTATION

The medium voltage overhead twisted insulated cable (SPLN 43-5 / IEC 60502-2) [5] is commonly found in the distribution system in Indonesia where bare conductors are not preferable for use. This cable is constructed by twisting three single-phase cables with center point 1, 2, and 3 as in figure 1 with a messenger wire in the middle of the twist. This messenger wires may or may not be grounded and consequently, in this work we develop the two models to accommodate these two configurations.

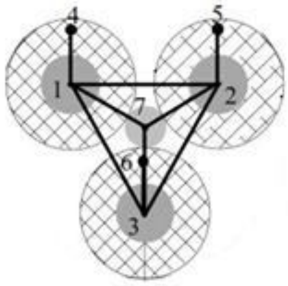


Figure-1. Cross section of a MVTIC with messenger wire.

The modified carson method

Kersting simplified Carson method by only use first term of P and first two terms of Q. This method is known as Modified Carson Method [2]. The approach is adopted in this work.

$$z_{ii} = \left(r_i + 4\cdot\omega\cdot P\cdot G\right) + j2\cdot\omega\cdot G\left(\ln\frac{1}{GMR_i} + \ln\left(S_{ii}\right) + 2\cdot Q\right)$$

$$z_{ij} = 4\cdot\omega\cdot P\cdot G + j2\cdot\omega\cdot G\left(\ln\frac{1}{D_{ij}} + \ln\left(S_{ij}\right) + 2\cdot Q\right) \tag{1}$$

Where:

$$P = \frac{\pi}{8} \tag{2}$$

$$Q = -0.0386 + \frac{1}{2} \cdot \ln\frac{2}{k_{ij}} \tag{3}$$

$$G = 0.1609347 \times 10^{-3}$$

Phase impedance matrix (Z_{abc}) can be constructed by using equation below [2]:

$$Z_{ii}=r_i+\pi^2 \mathrm{f}\ \mathrm{G}+\mathrm{j}4\pi \mathrm{f}\ \mathrm{G}(ln\frac{1}{GMR_i}+7.6786 - \frac{1}{2}\ln\frac{\rho}{f}) \qquad (4)$$

$$Z_{ij}= \pi^2 \mathrm{f}\ \mathrm{G}+\mathrm{j}4\pi \mathrm{f}\ \mathrm{G}(ln\frac{1}{D_{ij}}+7.6786 - \frac{1}{2}\ln\frac{\rho}{f}) \qquad (5)$$

Frequency (f) used in this equation is 50 Hz (working frequency in Indonesia) and soil resistivity (ρ) is assumed to be 100 Ω.m which is common for soil along the studied distribution feeder.

In this work, three different conductor sizes are considered, i.e. 120 mm2, 150 mm2, and 240 mm2. Prior to calculating sequence impedance of the distribution line, GMR (in feet) and resistance (in ohm/mile) are determined as follows:

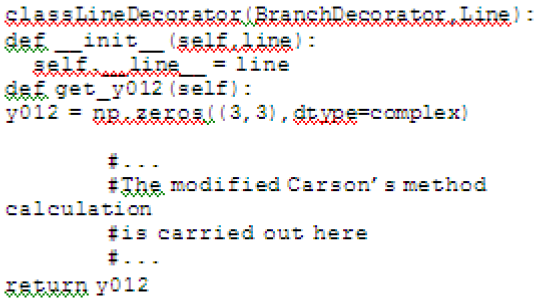
For 120 mm^2 cable:
D_S = 1.011811 inch
T = 11.811 mils
GMR_S = (D_S – (T/1000))/24
GMR_S = 0.0417 ft
R_S = 7.9385 x 10^8 x (ρ/(D_S x T)
R_S = 1.2754 ohm/mile

For 150 mm^2 cable:
D_S = 1.0551181 inch
T = 11.811 mils
GMR_S = 0.0435 ft
R_S = 1.2231 ohm/mile

For 240 mm^2 cable:
D_S = 1.2165354 inch
T = 11.811 mils
GMR_S = 0.0502 ft
RS = 1.0608 ohm/mile

Software model

In our implementation [1], a decorator class is used to contain the mathematical model of each power system component in addition to component class that contains all physical attributes of the component. This allows flexibility for future development and accommodates modular improvement. After a line has been decorated by the LineDecoratorClass, the decorated line can be called during formation of system bus admittance matrix. The decorated line will return a sequence admittance matrix of size 3x3 complex type matrix.



```
classLineDecorator(BranchDecorator,Line):
def __init__(self,line):
  self.__line__ = line
def get_y012(self):
y012 = np.zeros((3,3),dtype=complex)

        #...
        #The modified Carson's method
calculation
        #is carried out here
        #...
return y012
```

Figure-2. Code snippet of the implementation in UnilaPF.

RESULTS AND DISCUSSIONS

This research considers three sizes of medium voltage cables, i.e. 120 mm2, 150 mm2, and 240 mm2. Cable used in this research is NFA2XSEY-T [6]. In this research the cables are modeled into two models, they are:

1. Medium voltage cable with ungrounded messenger wire.
2. Medium voltage cable with grounded messenger wire.

The calculated sequence impedance for both configurations is compared between UnilaPF and OpenDSS for the ungrounded messenger wire and UnilaPF – ETAP for the grounded messenger wire. For ETAP simulation, with the help from local distribution company, standard MVTIC library from PLN is provided in the ETAP file.

Comparison of sequence impedances - ungrounded messenger wire

Table 1 and 2 show comparison of sequence impedances calculated by both UnilaPF and OpenDSS. For zero sequence impedance, the difference is observed to be in significant magnitude compared with the positive sequence impedance.

Table-1. Zero sequence impedance (ohm/km).

Program	Cross sectional area		
	120 mm^2	**150 mm^2**	**240 mm^2**
UnilaPF	0.926 + *j*0.318	0.857 + *j*0.297	0.707 + *j*0.24
OpenDSS	1.09 + *j*0.564	1.03 + *j*0.54	0.82 + *j*0.476

Table-2. Positive sequence impedance (ohm/km).

Program	Cross sectional area		
	120 mm^2	**150 mm^2**	**240 mm^2**
UnilaPF	0.267 + *j*0.167	0.22 + *j*0.162	0.141 + *j*0.154
OpenDSS	0.261 + *j*0.168	0.215 + *j*0.16	0.135 + *j*0.155

Comparison of sequence impedances – grounded messenger wire

Table-3. Zero sequence impedance (ohm/km).

Program	Cross sectional area		
	120 mm^2	**150 mm^2**	**240 mm^2**
UnilaPF	0.907 + *j*0.323	0.84 + *j*0.302	0.693 + *j*0.247
ETAP/SPLN	0.975+*j*0.272	0.795 + *j*0.265	0.483 + *j*0.245

Table-4. Positive sequence impedance (ohm/km).

Program	Cross sectional area		
	120 mm^2	150 mm^2	240 mm^2
UnilaPF	0.267 + *j*0.167	0.22 + *j*0.162	0.141 + *j*0.154
ETAP/SPLN	0.325 + *j*0.109	0.265 + *j*0.106	0.161 + *j*0.098

From Tables 3 and 4, differences between the modified Carson's method and ETAP/SLPN can be observed. These differences are due to simplification of the modified Carson's method. By using the obtained sequence impedances above, a comparison of three phase power flow results are provided in the next section. In our implementation of the modified Carson's method, the use of grounded messenger wire only affects the zero sequence impedance.

Three phase power flow results

In order to ensure that differences in the sequence impedance have insignificant effect to the overall power flow analysis. In this section, comparisons on active power losses and voltage profile are provided. The test system is an actual distribution feeder of 119-bus. This feeder supplies rural area and MVTIC is installed along the first 30 kms express feeder. As shown in Figures 3 and 4, in terms of active power losses, the effect is not significant.

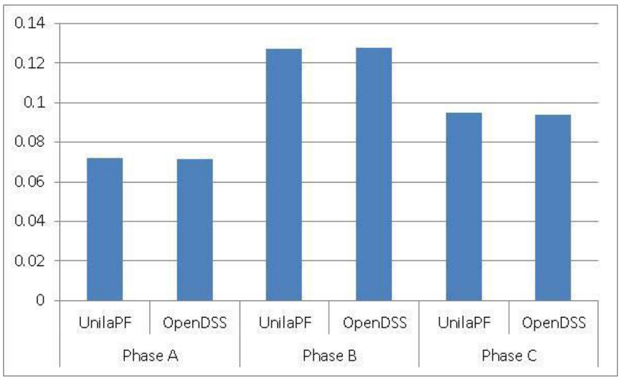


Figure-3. Active power losses for ungrounded messenger wire case.

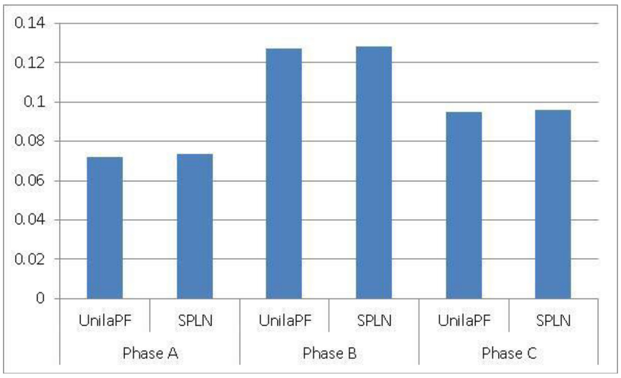


Figure-4. Active power losses for grounded messenger wire case.

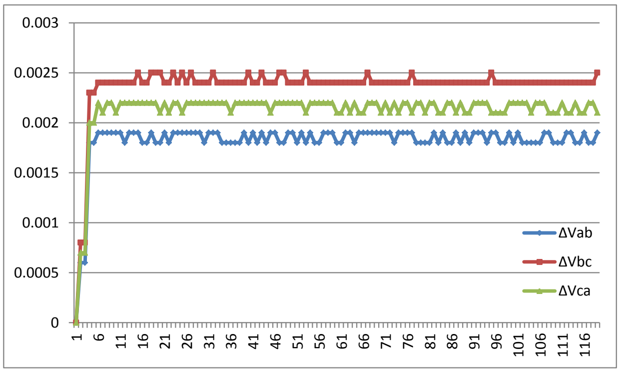


Figure-5. A plot of 3-phase line to line voltage difference of 119-bus.

Another test to verify that the results obtained are satisfactory is by comparing the voltage magnitude difference from a 3-phase power flow calculation of both sequence impedances calculated by UnilaPF using the modified Carson's method and sequence impedances based on ETAP/SPLN. Figure-5 shows that the differences are less than 0.0025 p.u. for line to line voltage magnitudes of 119-bus feeder line with mixed medium voltage overhead 3-phase line and overhead twisted insulated cable. This small figure of voltage magnitude difference is acceptable for a power flow analysis.

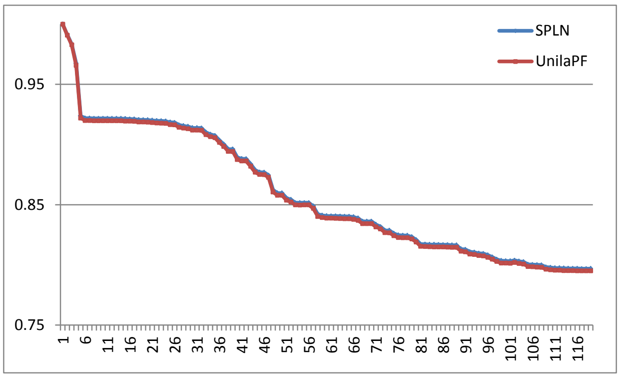


Figure-6. Line to line V_{AB} voltage profile (in p.u.).

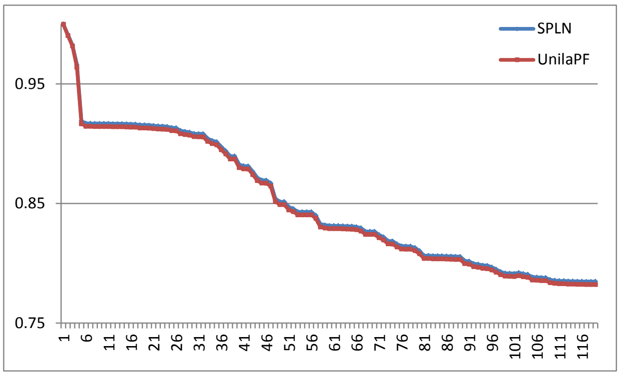


Figure-7. Line to line V_{BC} voltage profile (in p.u.).

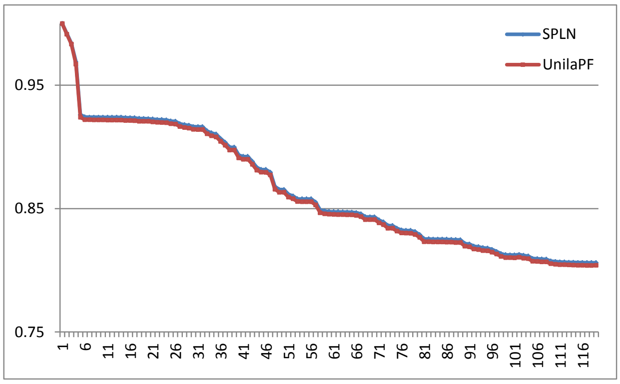


Figure-8. Line to line V_{CA} voltage profile (in p.u.).

Full line to line voltage profile plots of the 119-bus feeder are shown in Figures 6, 7, and 8 for VAB, VBC, and VCA respectively. Because the difference is minimal in terms of voltage magnitude resulted from power flow calculations of difference sequence impedances (the ones obtained from the modified Carson's method in UnilaPF and the ones from ETAP/SPLN unbalanced power flow), the two are overlapped. Having these, the adopted method is able to provide solutions very similar to sequence impedance provided by ETAP/SPLN.

CONCLUSIONS

In this work, the modified Carson's method is adopted to calculate sequence impedance in our implementation of 3-phase power flow software called UnilaPF. The sequence impedances obtained from this implementation are compared with the ones calculated by OpenDSS and the ones provided by ETAP/SPLN (with PLN Standard Overhead Cable Library). In addition, power flow results are also compared and these show that the adopted method is able to provide solutions similar to ETAP with SPLN overhead line library. Future research will be directed toward improvement of the method especially in accommodating underground cable found in the distribution feeder in Indonesia.

ACKNOWLEDGEMENT

This research work was supported by Ministry of Research, Technology and Higher Education, Republic of Indonesia through Research Grant Penelitian Fundamental 2015/2016.

REFERENCES

[1] L. Hakim, M. Wahidi, U. Murdika, F. Milano, J. Kubokawa, N. Yorino, "A three-phase power flow analysis for electrical power distribution system with low voltage profile," in Proc. 2nd Int'l. Conf. on Information Technology, Computer and Electrical Engineering (ICITACEE), Semarang, 16-18 Oct. 2015, pp. 303-308.

[2] W.H. Kersting, "Distribution System Modeling and Analysis 3rd Ed.," CRC Press, 2012.

[3] R. C. Dugan, T. E. McDermott, "An open source platform for collaborating on smart grid research", IEEE PES General Meeting 2011, San Diego, 24 - 29 July 2011, pp. 1-7.

[4] ETAP, "Distribution Network Analysis – Distribution Load Flow," available: http://etap.com/distribution/load-flow.htm?lang=en-US.

[5] SPLN 43-5-2:1995, "KabelPilinUdaraBerisolasi XLPE danBerselubung PVC Berpenggantung Kawat Baja dengan TeganganPengenal 12/20 (24) kV (Overhead Twisted Cable with XLPE Insulated, PVC Sheathed and Steel Messenger Wire Rated Voltage at 12/20 (24) kV".

[6] Kabelindo, "Medium Voltage XLPE Insulated Cable," PT. KabelindoMurni, Tbk. 2015.