MODELING OF THE TURN OF HIGH VOLTAGE OVERHEAD POWER TRANSMISSION LINES WITH UNDERGROUND CABLE ON FOUR BUSES OF TRANSMISSION LINES FOR IMPROVEMENT THE VOLTAGE PROFILE ON THE SYSTEM

(Case Study : Transmission Line 150 kV Region III Sub-system Yogyakarta)

Fitono Gulo[1], Syafriyudin[2], Mujiman[3]

[1]Student College, [2]Advisor Lecturer, [3]Co-Advisor Lecturer

Department of Electrical Engineering

Faculthy of Industrial Technology, Institute of Science and Technology AKPRIND Yogyakarta

Jl. Kalisahak 28 Komplek Balapan Tromol Pos 45 Yogyakarta 55222

Telp. (0274)563029 E-mail : fitobluesnet@gmail.com

ABSTRACT

Design and operation of electrical power system, economic factor, environmental factor, security factor and reliability factor should considered. Some kinds of electrical power system criterions are voltage drop and power losses caused by peak load. In the study is done two simulations experiments on the transmission line 150 kV sub-system region III Yogyakarta with the help of ETAP power station 7.0.0 using the Newton-raphson method to known the performance of underground cable for improvement the voltage profile on the system.

The result of simulation showed average voltage drop on the system at 1.79% for the mounting 4 branches underground cable or after the turn of overhead lines. This value is smaller than the voltage drop on the system without the underground cable is 1.83% so underground cable will contribute to the voltage and improvement the voltage profile on the system. Before the turn overhead lines with underground cable, the power losses and reactive power losses respectively 16.983 MW and 49.163 Mvar while after the turn of overhead lines with underground cable, the power losses and reactive power losses respectively 16.809 MW and 48.652 Mvar. Reduction of power losses and reactive power losses respectively 174 MW and 511 Mvar or in percent at 1.02% and 1.03%. The presence of underground cable, power losses on the branches will be smaller due to the supply of capacitive reactive power to the system.

Keywords : Charging Current, ETAP 7.0.0, Underground Cable and Voltage Profile

Introduction

In the development of the use of high voltage overhead power transmission lines less effective again for the network in the big cities and villages heavily populated because of many deficiencies and losses due to the influence of the surrounding environment. In terms of urban planning, the high voltage overhead power transmission lines don't have an aesthetics. In terms of protection, weather and climate as well as the influence of plants is a cause of trouble. To meet the power needs of an increasingly large, the most effective way is raising the voltage because it can reduce the power losses in the lines.

The use of high voltage undergroundcable power transmission line will significantly change the power flow due to loading current, the larger load current would improve the reactive power to the system that will affect to the load flow. The amount of reactive power generated will cause problems in the system that need to be controlled as possible (Mc Mahon, 1996).

Two branches of high voltage undergroundcable power transmission lines has been used in DIY and is a part of the four branches of underground cable that operating active in area III sub-system for transmitting the electrical power and complements existing network. Types of Low Pressure Oil Filled (LPOF) underground cable with large distance could lead of significant charging current (PT. PLN, 1999c).

The main case studies is replace the overhead lines existing with underground cable especially at overhead lines Godean-Bantul, overhead lines Kentungan-Bantul, overhead Kentungan-Godean and overhead Medari-Kentungan with the primary purpose of research to determine the performance of underground cable towards the voltage profile of the system.

Related Theory

Transmission line constant

Low Pressure Oil Filled (LPOF) is type of conductor used in the research. For the purpose of system analysis, a given transmission line can be repsented by its resistance, inductance or inductive reactance, capacitance or capacitive reactance, and leakage resistance which is usually negligible (Turan Gonen, 1988). The important parameters of the cable is capacitance which can be formulated as follows :

$$C = \frac{2\pi\varepsilon_o\varepsilon_r}{\ln\left(\frac{b}{a}\right)} F/m \qquad (1)$$

where :

$\varepsilon_o =$ vacuum permittivity (8.854 x 10^{-12} F/m)

$\varepsilon_r =$ relative permittivity (dielectric constant)

$a =$ radius of conductor

$b =$ radius of insulator

Underground cable transmission lines

The inductive reactance of an overhead high-voltage ac line is much greater than its capacitive reactance whereas the capacitive reactance of an underground high-voltage ac cable is much greater than its inductive reactance due to the fact that the three phase conductors are located very close to each other in the same cable. This var generation due to the capacitive charging currents, sets a practical limit to the possible noninterrupted length of an underground ac cable (Turan Gonen, 1998).

The generation of reactive power for underground cable

For high voltage underground cable power trasnsmission line has a large capacitance value, then in the analysis the charging current and capacitance should calculated. For purposes of the calculation analysis, the high voltage underground cable power transmission line can be modeled as shown in the figure below.

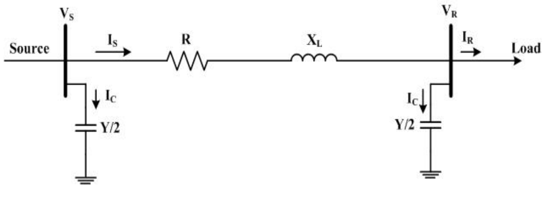


Figure 1. High voltage underground cable power transmission line model

The magnitude of the current at the load side :

$$I_R = \frac{P + jQ}{\sqrt{3}.V_R} \quad (2)$$

The voltage at the sending side :

$$V_S = V_{R(L-N)} + I_R.Y \quad (3)$$

The magnitude of charging current :

$$I_C = 2\pi f.C.V_{R(L-N)} \quad (4)$$

The source current :

$$I_S = I_C + I_R \quad (5)$$

The capacitance reactance :

$$X_C = \frac{V_{R(L-N)}}{I_C} \quad (6)$$

Load flow analysis

The load flow also known as power flow solution of an electrical power system provides voltages at all the buses, power flows and losses in the lines at specific levels of power generation and loads (K.S Sastry Musti, 2012).

Therefore each bus in a power system is associated with four quantities and they are real power, reactive power, magnitude of voltage and phase angle of voltage. In a load flow problem two quantities/out of four are specified for each bus and the remaining two quantities are obtained by solving the load flow equations (Narendra Kumar, 2010).

Load flow using Newton Raphson method

Newton-Raphson (NR) method is more efficient and practical for large power system. Here load flow problem is formulated in polar form.

$$P_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k) \quad (7)$$

$$Q_i = -\sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (8)$$

Equations (7) and (8) constitute a set of nonlinier algebraic equations in terms of the independent variables, voltage magnitude in per unit and phase angles in radians, we can easily observe that two equations for each load bus given by equations (7) and (8) and one equation for each voltage controlled bus, given by equation (7) Expanding equations (7) and (8) in taylor-series and neglecting higher order terms, can be written is short form :

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (10)$$

Load flow concept on transmission line with underground cable

In the calculations of load flow and power losses in the transmission line can be explained by taking the example of the model four bus consists of three branches using overhead lines connecting the bus 1, 2 and 3 and one branches using underground cable connecting the bus 3 and 4 as shown in Figure 2. The magnitude of admitance each branches of transmission lines is expressed with y_{12}, y_{13}, y_{23} and y_{34} while the shunt capacitance value on the bus is y_{10}, y_{20}, y_{30} and y_{40}.

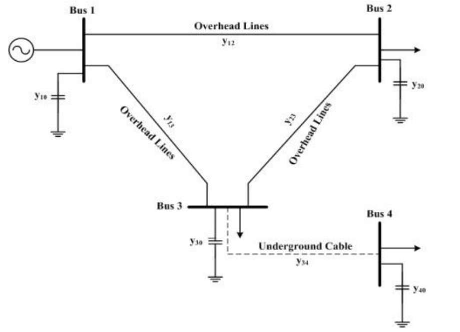


Figure 2. Transmission line models for load flow calculation

In matrix, the magnitude of the current flowing on the branches :

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} \quad (11)$$

or

$$I_{bus} = Y_{bus}.V_{bus} \quad (12)$$

Figure 2. showed the underground cable mounted with radially ie at bus 3 to bus 4 has a value of shunt capacitance y_{40} and admitace y_{34} large enough, then the current at bus 3 and bus 4 increasing.

Research Method

In the study will reviewing the effect of underground cable at a voltage level of 150 kV against the voltage profile of the system. The data obtained then processed using ETAP 7.0.0 power station program. The performance of underground cable will be tasted by means of simulation after that data analysis. The result of analysis will be compared in the form of graph representation or table and calculation analysis so the performance of underground cable transmission line can be known towards voltage profile of the system. For more details, the process of the research will be described in the flow chart as follows

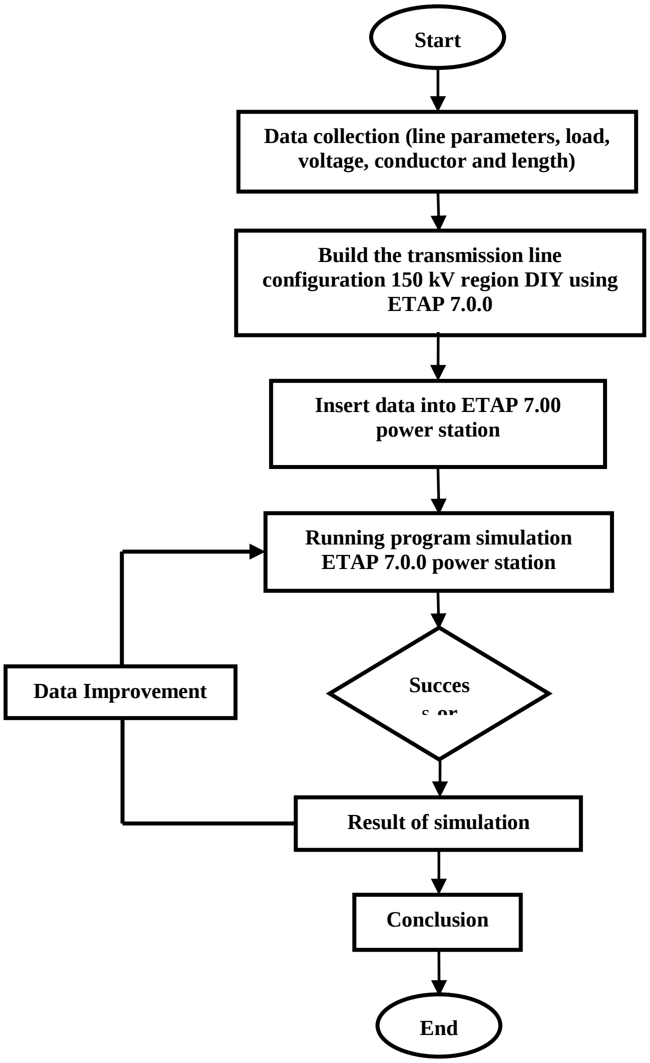


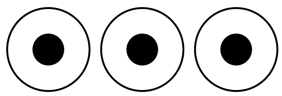
Figure 3. Flow chart research process

Discussion and Result of Research

Voltage profile of the system

Voltage profile before the turn of overhead lines with underground cable is state condition of the system. The first simulation experiment aims to determine the voltage profile of the system before the turn of overhead lines with underground cable so the performance of underground cable can be known by comparison. In this case study, overhead lines which is replaced with underground cable done only on the transmission line in the city as much as 4 branches with assumed the length and type of conductor used is same where for the high voltage underground cable power transmission line using conductor of Cu 240 mm^2. Technical specifications of cable as follows :

Table 1. Technical specifications of cable

Num.	Reviews	Spesifications
1.	Nominal Voltage	150 kV
2.	Number of Cores	1
3.	Structural of Composition Cross Sectional Area	3 horizontal  240 mm^2
4.	Conductor Material Design Diameter	 Copper Hollow Circular 24.4 mm
5.	Insulation	Imoregnated kraft paper tape
6.	Cooling	Oil

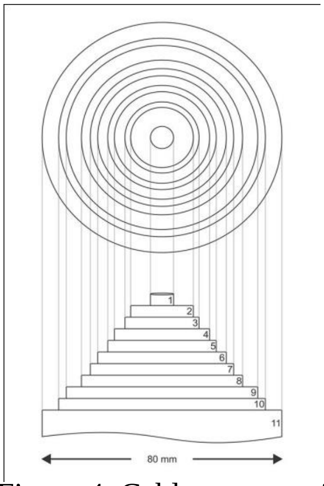


Figure 4. Cable construction

Description :

1. Oil duct
2. Conductor
3. Conductor screen
4. Insulation
5. Core screen
6. Metal sheath
7. Reinforcement
8. Sealing compound
9. Anti-corrosion sheath
10. Anti-termite protection
11. Outer covering

The result of two simulations showed before the turn of overhead lines, the power losses and reactive power losses is 16.983 MW and 49.163 Mvar while after the turn of overhead lines, the power losses and reactive power losses is 16.809 MW and 48.652 Mvar. Reduction of power losses and reactive power losses after the turn of overhead line respectively is 174 MW and 511 Mvar or in percent is 1.02% and 1.03%.

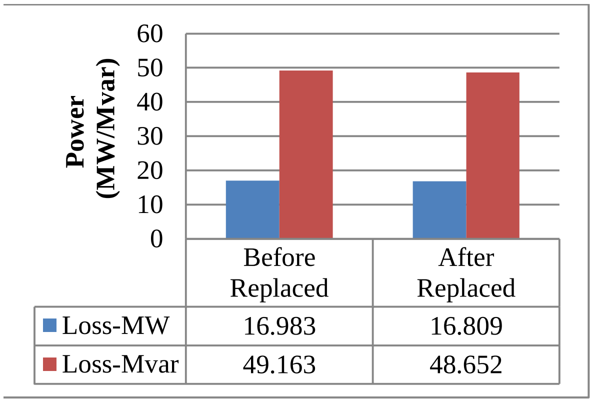


Figure 5. Comparison graph of power losses and reactive power losses

Table 2. General datas of project system

Study ID	Before Replaced	After Replaced
STUDY CASE ID	LOAD FLOW	LOAD FLOW
BUSES	11	11
BRANCHES	17	17
POWER GRIDS	2	2
LOADS	17	17
LOAD-MW	496.498	497.195
LOAD-Mvar	230.878	230.754
LOSS-MW	16.983	16.809
LOSS-Mvar	49.163	48.652

Total of power loss in the system before the turn of overhead lines ie power losses 16983 MW and reactive power losses 49163.1 Mvar while the average voltage drop in the system is 1.83%. Total of power loss in the system after the turn of overhead lines ie power losses 16809.4 MW and reactive power losses 48652.5 Mvar while the average voltage drop in the system is 1.79%. Comparison of voltage drop in the system before and after the turn of overhead lines underground cable as in the table and chart below.

Table 3. Voltage drop on the system

Branch of Transmission Lines	Before Replaced	After Replaced
ID	% Drop Voltage	% Drop Voltage
UDRGND CB BANTL-WBJAN	0.09	0.09
UDRGND CB BANTL-WBJAN2	0.09	0.09
OVERHEAD BANTL-KLATN	6.11	6.01
OVERHEAD BANTL-KLATN2	6.11	6.01
OVERHEAD BANTL-WATES	1.26	1.26
OVERHEAD GDEAN-BANTL	0.16	0.08
OVERHEAD KNTUG-BANTL	0.10	0.11
OVERHEAD PWRJO-BANTL	1.74	1.74
OVERHEAD SMANU-BANTL	1.13	1.13
OVERHEAD SMANU-BANTL2	1.13	1.13
UDRGND CB GJYAN-KNTUG2	0.20	0.20
UDRGND CB GJYAN-KNTUG	0.20	0.20
OVERHEAD KNTUG-GDEAN	0.26	0.19
OVERHEAD MDARI-KNTUG	1.21	0.87
OVERHEAD SGRAH-KNTUG	6.01	5.90
OVERHEAD SGRAH-MDARI	4.79	5.03
OVERHEAD WATES-PWRJO	0.48	0.48
Average	**1.83%**	**1.79%**

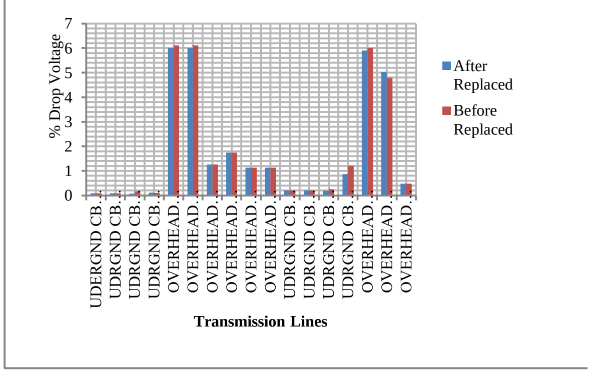


Figure 6. Comparison of voltage drop in the system

The result output of the bus voltage profile before the turn of overhead lines shows the voltage of Medari bus at the marginal level (intermediate voltage level) where voltage drop at 5% from the nominal voltage of the bus, the operating voltage of Medari bus is 95.2% while the other buses at critical level or voltage drop at 5% of nominal voltage. Requirements standart for maginal and critical voltage level is output setting ETAP 7.0.0 power station while PLN's standart for bus voltage must not exceed 5% and less than 10% so that condition of buses under normal state all.

Table 4. Bus operation of bus

Bus	Before Replaced	After Replaced
	% Operating	% Operating
BANTUL	93.9	94
GEJAYAN	93.8	93.9
GODEAN	93.7	93.9
KENTUNGAN	94.0	94.1
PURWOREJO	92.2	95.2
SMANU	92.8	92.9
WATES	92.6	92.7
WIROBRAJAN	93.8	93.9
MEDARI	95.2	95

The output result of the bus voltage profile after the turn of overhead lines where all the buses in critical voltage condition, the percent operating of the bus loading is below 95% from voltage nominal bus. According PLN's standart, the bus voltage must not exceed 5% and less than 10% so that the condition of the bus under normal state all

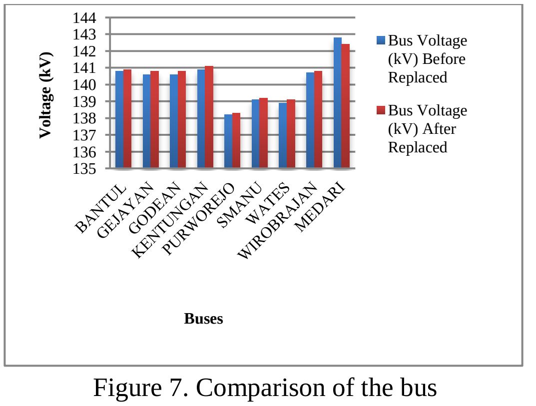


Figure 7. Comparison of the bus voltage profile

The generating of reactive power on overhead lines and underground cable

In this simulation, branches of transmission line system consist of 14 high voltage overhead power transmission line branches and 4 high voltage underground cable power transmission line branches.

The case study, the turn of the branches as much as 4 buses i.e overhead lines Godean-Bantul, overhead lines Kentungan-Bantul, overhead lines Kentungan-Godean and overheadlines Medari-Kentungan so analysis of reactive power generation is only done on these branches.

Both of simulation experiments can be made in the table of value important on the system before and after the turn of overhead lines as in Table 5 and Table 6 while the capacitance value and charging current shown in Table 7 and Table 8.

Table. 5 Important values in the transmission line before the turn of overhead lines

Study ID		Numerical Value
Load of System	Active Power	496.597 MW
	Reactive Power	230.942 Mvar
Power Losses	Active Power	16.983 MW
	Reactive Power	49.163 Mvar
Voltage at the sending end	Bantul	140.8 kV
	Bantul	140.8 kV
	Kentungan	141 kV
	Medari	142.8 kV
Voltage at the receiving end	Godean	140.6 kV
	Kentungan	141 kV
	Godean	140.6 kV
	Kentungan	141 kV

Table. 6 Important values in the transmission line after the turn of overhead lines

Study ID		Numerical Values
Load of System	Active Power	497.195 MW
	Reactive Power	230.754 Mvar
Power Losses	Active Power	16.809 MW
	Reactive Power	48.652 Mvar
Voltage at the sending end	Bantul	141 kV
	Kentungan	141.2 kV
	Kentungan	141.2 kV
	Medari	142.9 kV
Voltage at the receiving end	Godean	140.9 kV
	Bantul	141 kV
	Godean	140.9 kV
	Kentungan	141.2 kV

Table 7. The values of charging current and capacitance before the turn of overhead lines

Branches	Suseptans (S/km)	Length (km)	Charging Current (Amper)	Capacitance (F/Phase)
Overhead L. Godean-Bantul	2.88×10^{-6}	12.25	2.269	8.891×10^{-5}
Overhead L. Kentungan-Bantul	2.88×10^{-6}	19.96	3.709	1.449×10^{-4}
Overhead L.Kentungan-Godean	2.88×10^{-6}	7.71	1.429	5.599×10^{-5}
Overhead L. Medari-Kentungan	2.88×10^{-6}	10.64	1.977	7.725×10^{-5}

Table 8. The values of charging current and capacitance after the turn of overhead lines

Branches	Suseptans (S/km)	Length (km)	Charging Current (Amper)	Capacitance (F/Phase)
UDR GND CB Godean-Bantul	73×10^{-6}	12.25	72.84	2.848×10^{-3}
UDR GND CB Kentungan-Bantul	73×10^{-6}	19.96	118.76	4.641×10^{-3}
UDR GND CB Kentungan-Godean	73×10^{-6}	7.71	45.84	1.792×10^{-3}
UDR GND CB Medari-Kentungan	73×10^{-6}	10.64	63.17	2.474×10^{-3}

Results of simulation experiments and analysis that has been done, the turn of four branches of overhead lines with underground cable, generate of reactive power which is great as of underground cable's capacitance value larger than overhead lines. Generation of reactive power in the form of capacitive resulted in correction of power factor increasing so that the voltage drop in the system decreases.

As an example on branch that connects of Godean bus with Kentungan bus and Bantul bus where before the turn of overhead lines, reactive power of the load is 15.631 Mvar while reactive power at overhead line Kentungan-Godean is 12.602 Mvar and overhead line Bantul-Godean is 3.124 Mvar. Total reactive power flowing in the branchs is 15.726 Mvar. After the turn of overhead lines with underground cable, reactive power in the branch increased by 29 Mvar.

Generation of reactive power resulted in value of bus voltage at the sending-end and receiving-end before the turn of overhead lines wirh underground cable different with value of bus voltage at the sending-end and receiving-end after the turn of overhead lines with underground cable.

Comparison of reactive power in the branches and reactive power of the load on overhead line Godean-Kentungan and overhead line Bantul-Godean before and after the turn of overhead line with underground cable shown in Table 9.

Table 9. Comparison of reactive power in transmission line before and after the turn of overhead lines with underground cables

Branches of Transmisson Lines	Before the Turn of Overhead Line with Underground Cable		After the Turn of Overhead Line with Underground Cable	
	Reactive Power in the Branch (Mvar)	Reactive Power of the Load (Mvar)	Reactive Power in the Branch (Mvar)	Reactive Power of the Load (Mvar
Overhead Godean-Bantul	3.124	15.630	2.164	15.690
Overhead Godean-Kentungan	12.602		13.591	
Total	15.726	15.630	15.755	15.690

Conclusion

Based on simulation result and discussion of result research that has been done, it can be concluded : The result of simulation showed average voltage drop at 1.79% for the mounting 4 branches underground cable or after the turn of overhead lines. This value is smaller than the voltage drop on the system without the underground cable is 1.83% so underground cable will contribute to the voltage and improvement the voltage profile of the system.

The presence of underground cable, power losses on the branches will be smaller due to the supply of reactive power to the system.

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