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Analysis Optimization of Switchyard Earthing System Using MATLAB

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ABSTRACT

One of the main factors in securing an electric power system is the earthing system. The earthing system in the generating unit is closely related to the switchyard. Switchyard earthing system analysis is done by adjusting the grid distance and ground rod length to get the most optimal quality and cost combination. The definition of optimal conditions in this case is limited to circumstances where there is a combination of quality that does not exceed the technical tolerance threshold and has cost efficiency. The analysis of the switchyard earthing system was taken as a case study. Calculation results and analysis concluded that the grid distance of 23 m and the length of the 6 m ground rod is the best choice in the optimization of this earthing system by meeting the safety quality criteria for earth resistance is Rg = 0.13806 Ω less than 0.5 Ω with a minimum cost of Rp. 1,220,104,730.Technical standards are carried out based on IEEE Std 80-2000. Calculations for obtaining technical parameters and costs are carried out one-by-one in the range of grid spacing and length of certain ground rods to determine the optimum point using MATLAB-GUI as a programming tool and MATLAB R2011a as a tool mathematical computing.

INTRODUCTION

Earthing system or commonly referred to as a grounding system is a security system for devices relating to soil type resistance, earthing resistance also has a large effect on the size of the soil type resistance, the higher the grounding resistance value the higher the soil type resistance. Measurement of soil type resistance is usually done by measuring soil resistance and the level of security in the earthing system [1-10].

Table 1. Soil Characteristics [2]

Type of Soil	Average Soil Resistance (Ω ·m)
Wet Organic Soil	**10^1**
Moist Land	**10^2**
Dry soil	**10^3**
Hard Soil Layer	**10^4**

Specifically, the safety function of the earthing system can be related to three interrelated aspects, namely (1) limiting voltage due to lightning, wave lines, or short circuit with high voltage lines, (2) stabilizing voltage, (3) providing a way to facilitate operation over current device [11-16]. The total length of conductor planting is the sum of the horizontal (grid) and vertical (rod) conductors with the following equation (1):

$$\mathbf{L_T = L_C + L_R} \tag{1}$$

Wherein:
L_C : total length of the grid conductor (m)
L_R : total length of conductor rod (m)

Knowing the number of grid conductors and the length of the grid conductors in the direction of the grid planting, according to the following equation (2):

$$L_C = (N_y + 1).L_x + (N_x + 1).L_y \tag{2}$$

From equation (2) above, to get the length of the conductor which is affected by the grid distance, the number of conductors Nx and Ny becomes Nx =

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Lx/D and Ny = Ly/D, so the above equation becomes the following equation:

$$L_C = \left(\left(\frac{L_y}{D} + 1\right) L_x\right) + \left(\left(\frac{L_x}{D} + 1\right) L_y\right) \quad (3)$$

Where:

Ny	: total grid conductor in Y direction
Nx	: total grid conductor in X direction
Ly	: length of conductor Y direction (m)
Lx	: length of conductor X direction (m)
D	: grid conductor distance (m)

Initial Parameter Data

The optimization of the earthing system is based on the influence of the grid spacing and the length of the ground rod in finding the optimal earthing system value in terms of safety and the total cost to be incurred [17]. The data that need to be included in determining the optimization of the earthing system design are obtained from IEEE Std 80-2000 [17] and the Cilacap Adipala Power Plant Data with a Tolerance Touch Voltage of 240 V as contained in the contract documents. In this case study the data used are 777.8 MVA X" generator d = 21.4%, 800 MVA transformer voltage 22/500 kV, Xt = 16.19%, then the If value of the 500 kV voltage side fault is as follows Fig. 1.

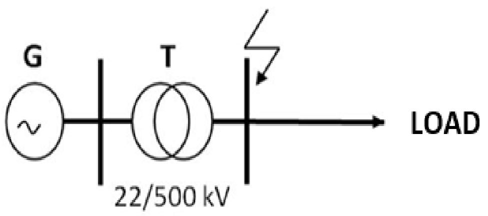

Fig. 1. Single Line Switchyard Diagram 500 kV

To run the program, the initial parameter data will be used as input in the analysis of earthing system optimization in the Matlab program. Before the program reads the input data, the program first reads the length of the ground rod, which was first included in the Matlab program.

Optimization

Optimization is the results achieved in accordance with the wishes, so optimization is the achievement of the results according to expectations effectively and efficiently. Much optimization is also defined as a measure by which all needs can be met from the activities carried out [18].

To get the optimal design, it can be done by fulfilling the following minimum cost functions:

$$B(N_x, N_y, N_r, L_r) = (N_r.L_r.C_{ri}) + (N_r.C_r) + (C_{ci} + C_c).((N_x + 1).L_y + L_x.(N_y + 1)) \quad (4)$$

From the cost function above, to get the minimal cost function influenced by grid distance, equation (1).

$$B(D, L_r) = \left(2\left(\frac{L_y + L_x}{D}\right).L_r.C_{ri}\right) + \left(2\left(\frac{L_y + L_x}{D}\right).C_r\right) + (C_{ci} + C_c).\left(\left(\frac{L_x.L_y}{D} + L_y\right) + \left(\frac{L_y.L_x}{D} + L_x\right)\right) \quad (5)$$

Wherein:

N_r	: total ground rod
N_x	: total grid conductor in X direction
N_y	: total grid conductor in Y direction
L_r	: length of each ground rod (m)
C_{ri}	: ground rod installation fee (rupiah/m)
C_r	: cost of rod conductor material (rupiah/rod)
L_c	: length of the grid conductor
C_{ci}	: grid conductor installation costs (rupiah/m)
C_c	: grid conductor material costs (rupiah/m)
L_x	: length of conductor X direction (m)
L_y	: length of conductor Y direction (m)
D	: grid conductor distance (m)

EXPERIMENTAL METHOD

In analyzing Earthing performance analysis by taking conductor length data, general system data parameters and soil characteristics. In the case of a simple performance analysis, the program requests data related to the length of the grid conductor, number of ground rods, data about switchyard, general data related to the power system for safety criteria, conductor size and materials and others.

RESULTS AND DISCUSSION

The conductor used in the design of this earthing system is Copper, annealed soft-drawn, obtained from the calculation of the grid conductor size 177,4066 mm^2, then conductors with a cross-sectional area of 240 mm^2. The reduction factor (Cs) value equals 0.71264 is used to calculate the touch voltage and tolerance step voltage. The touch tolerance value is 240,0002 V and the tolerance step voltage is 612,0009 V. As for the maximum grid current with a disturbance current rms value of 5.7 kA, the maximum grid current value is 7506.33 A.

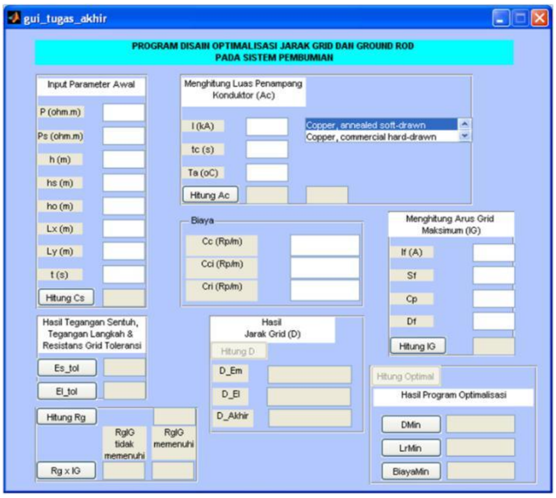

Fig. 2. Display of the Earthing System Optimization Calculation Program

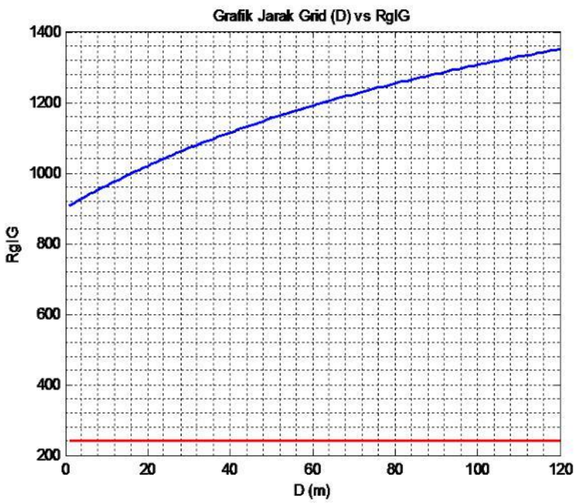

Fig. 3. Grid Distance Graph (D) against RgIG

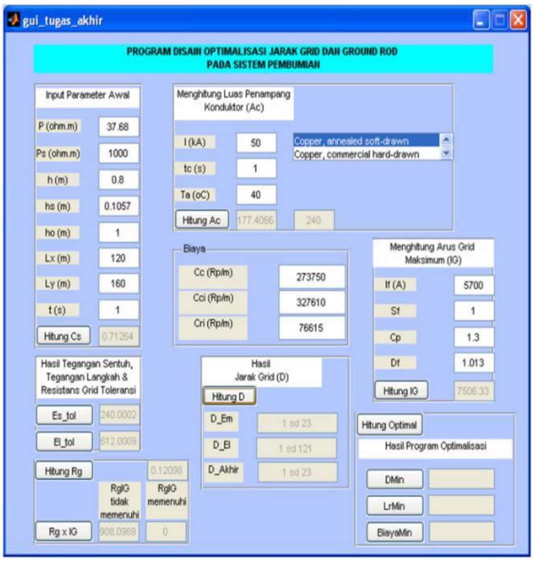

Fig. 4. Display Program Distance Range Grid Results

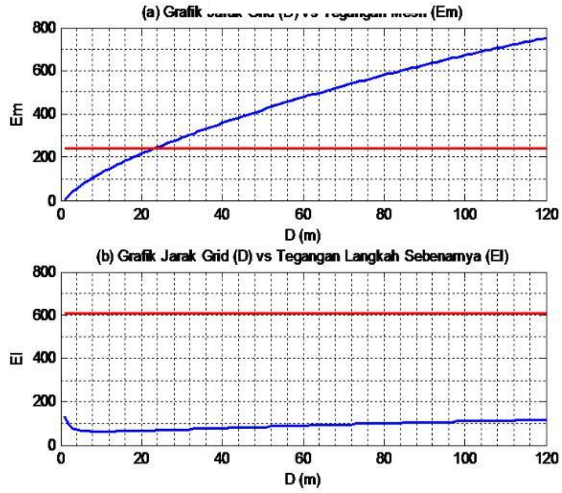

Fig. 5. (a) Effect of Grid Distance on Em, (b) Effect of Grid Distance on El

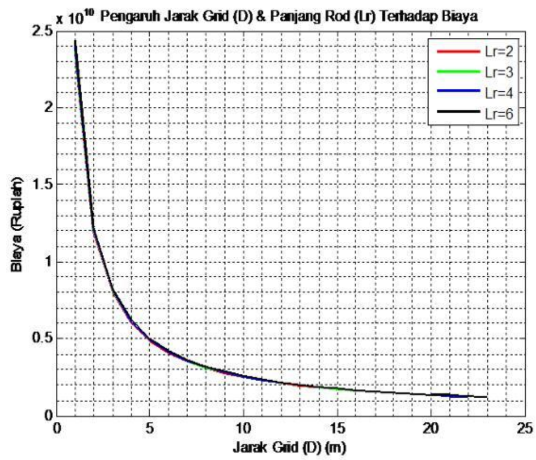

Fig. 6. Graphic Effect of Ground Rod Length on grid distance and cost

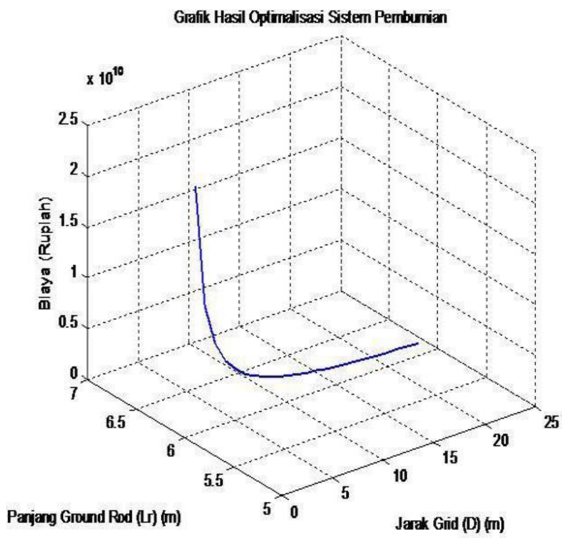

Fig. 7. Graph of Results of Earthing System Optimization Program

Table 2. Analysis Optimization of Switchyard Earthing System Using MATLAB

Distance Grid (D)	Ground Rod Lenght (Lr)	Es_tol	El_tol	Rg	IGRg	IGRg<Es_tol	Em	Em<=Es_tol	El	El<=El_tol	cost
1	6	240,0002	612,0009	0,120977483	908,0969116	Not Fulfill	5,1809709	Fulfill	130,6405349	Fulfill	Rp. 24.358.031.200
2	6	240,0002	612,0009	0,121861912	914,7357282	Not Fulfill	23,06284564	Fulfill	91,51578579	Fulfill	Rp. 12.263.206.000
3	6	240,0002	612,0009	0,122734715	921,287274	Not Fulfill	40,73408417	Fulfill	77,63277869	Fulfill	Rp. 8.231.597.600
4	6	240,0002	612,0009	0,123596119	927,7532585	Not Fulfill	56,58882949	Fulfill	70,78770146	Fulfill	Rp. 6.215.793.400
5	6	240,0002	612,0009	0,124446347	934,1353471	Not Fulfill	70,82931347	Fulfill	66,93275165	Fulfill	Rp. 5.006.310.880
6	6	240,0002	612,0009	0,125285614	940,4351619	Not Fulfill	83,82182278	Fulfill	64,62899965	Fulfill	Rp. 4.199.989.200
7	6	240,0002	612,0009	0,126114131	946,6542838	Not Fulfill	95,86027326	Fulfill	63,23225125	Fulfill	Rp. 3.624.045.143
8	6	240,0002	612,0009	0,126932103	952,7942532	Not Fulfill	107,1580718	Fulfill	62,41004321	Fulfill	Rp. 3.192.087.100
9	6	240,0002	612,0009	0,127739731	958,8565717	Not Fulfill	117,8687506	Fulfill	61,97314512	Fulfill	Rp. 2.856.119.733
10	6	240,0002	612,0009	0,128537208	964,8427031	Not Fulfill	128,1042032	Fulfill	61,80579437	Fulfill	Rp. 2.587.345.840
11	6	240,0002	612,0009	0,129324727	970,7540745	Not Fulfill	137,9474946	Fulfill	61,83312876	Fulfill	Rp. 2.367.439.927
12	6	240,0002	612,0009	0,130102471	976,5920779	Not Fulfill	147,4614673	Fulfill	62,00456247	Fulfill	Rp. 2.184.185.000
13	6	240,0002	612,0009	0,130870621	982,3580707	Not Fulfill	156,6945203	Fulfill	62,28468603	Fulfill	Rp. 2.029.123.138
14	6	240,0002	612,0009	0,131629355	988,053377	Not Fulfill	165,6845404	Fulfill	62,64799326	Fulfill	Rp. 1.896.212.971
15	6	240,0002	612,0009	0,132378844	993,6792889	Not Fulfill	174,4616259	Fulfill	63,07567582	Fulfill	Rp. 1.781.024.160
16	6	240,0002	612,0009	0,133119256	999,2370668	Not Fulfill	183,0500076	Fulfill	63,55359328	Fulfill	Rp. 1.680.233.950
17	6	240,0002	612,0009	0,133850755	1004,727941	Not Fulfill	191,4694291	Fulfill	64,07094142	Fulfill	Rp. 1.591.301.412
18	6	240,0002	612,0009	0,134573502	1010,153113	Not Fulfill	199,7361546	Fulfill	64,61935141	Fulfill	Rp. 1.512.250.267
19	6	240,0002	612,0009	0,135287651	1015,513754	Not Fulfill	207,8637166	Fulfill	65,19226444	Fulfill	Rp. 1,441.520.295
20	6	240,0002	612,0009	0,135993356	1020,811009	Not Fulfill	215,8634784	Fulfill	65,78448756	Fulfill	Rp. 1.377.863.320
21	6	240,0002	612,0009	0,136690766	1026045996	Not Fulfill	223,7450634	Fulfill	66,39187219	Fulfill	Rp. 1.320.268.914
22	6	240,0002	612,0009	0,137380025	1031,219806	Not Fulfill	231,5166855	Fulfill	67,01107742	Fulfill	Rp. 1.267.910.364
23	**6**	**240,0002**	**612,0009**	**0,138061277**	**1036,333505**	**Not Fulfill**	**239,1854077**	**Fulfill**	**67,63939334**	**Fulfill**	**Rp. 1.220.104.730**
24	6	240,0002	612,0009	0,138734659	1041,388135	Not Fulfill	246,757345	Not Fulfill	68,27460747	Fulfill	Rp. -
25	6	240,0002	612,0009	0,139400308	1046,384714	Not Fulfill	254,2378265	Not Fulfill	68,91490261	Fulfill	Rp. -
26	6	240,0002	612,0009	0,140058355	1051,324235	Not Fulfill	261,6315246	Not Fulfill	69,55877811	Fulfill	Rp. -
27	6	240,0002	612,0009	0,140708931	1056,207672	Not Fulfill	268,8425604	Not Fulfill	70,20498851	Fulfill	Rp. -
28	6	240,0002	612,0009	0,141352162	1061,035972	Not Fulfill	276,1745888	Not Fulfill	70,85249542	Fulfill	Rp. -
29	6	240,0002	612,0009	0,141988171	1065,810066	Not Fulfill	283,3308683	Not Fulfill	71,50042952	Fulfill	Rp. -
30	6	240,0002	612,0009	0,142617079	1070,53086	Not Fulfill	290,414319	Not Fulfill	72,1480603	Fulfill	Rp. -
31	6	240,0002	612,0009	0,143239005	1075,199242	Not Fulfill	297,4275706	Not Fulfill	72,79477184	Fulfill	Rp. -
32	6	240,0002	612,0009	0,143854065	1079,816081	Not Fulfill	304,373002	Not Fulfill	73,44004331	Fulfill	Rp. -
33	6	240,0002	612,0009	0,14446237	1084,382225	Not Fulfill	311,2527751	Not Fulfill	74,0834332	Fulfill	Rp. -
34	6	240,0002	612,0009	0,145064033	1088,898505	Not Fulfill	318,0688632	Not Fulfill	74,72456646	Fulfill	Rp. -
35	6	240,0002	612,0009	0,145659161	1093,365733	Not Fulfill	324,8230746	Not Fulfill	75,36312399	Fulfill	Rp. -
36	6	240,0002	612,0009	0,146247861	1097,784704	Not Fulfill	331,5170733	Not Fulfill	75,99883401	Fulfill	Rp. -
37	6	240,0002	612,0009	0,146830235	1102,156195	Not Fulfill	338,152396	Not Fulfill	76,63146491	Fulfill	Rp. -
38	6	240,0002	612,0009	0,147406385	1106,480969	Not Fulfill	344,7304675	Not Fulfill	77,26081931	Fulfill	Rp. -

CONCLUSION

Based on the results of the optimization program using Matlab GUI and Matlab R2011a, it can be concluded that the grid distance of 23 m and the length of the 6 m Ground rod provides the most optimal grounding system design results, with a safety quality for Earthing Resistance (Rg) of 0.13806Ω smaller than The maximum limit of Earthing Resistance is 0.5 Ω (IEC 60694) and the value of the mesh voltage is smaller than the touch tolerance voltage (Em = 239.1854 V <Es_tol = 240,0002 V) and the tolerance step voltage is more than Rp. 1,220,104,730.

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