Application Analysis of Monte Carlo to Estimate the Capacity of Geothermal Resources in Lawu Mount

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Abstract. Monte Carlo analysis has been applied in calculation of geothermal resource capacity based on volumetric method issued by Standar Nasional Indonesia (SNI). A deterministic formula is converted into a stochastic formula to take into account the nature of uncertainties in input parameters. The method yields a range of potential power probability stored beneath Lawu Mount geothermal area. For 10,000 iterations, the capacity of geothermal resources is in the range of 139.30- 218.24 MWe with the most likely value is 177.77 MWe. The risk of resource capacity above 196.19 MWe is less than 10%. The power density of the prospect area covering 17 km^2 is 9.41 MWe/km^2 with probability 80%.

Keywords: Monte Carlo analysis, geothermal resources capacity, volumetric method, Lawu Mount, the most likely value
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INTRODUCTION

The parameters used to estimate the capacity of geothermal resources are firstly obtained from the integrated exploration involving geophysical, geochemical and geological measurements. To accommodate the uncertainty of the measurement results, the parameter values are presented as a range of values that are statistically random with a certain probability. Monte Carlo Analysis is a stochastic simulation that involves repetitive random sampling on the inputs model to produce a collection of random outputs, which are then analyzed statistically. It can simulate random and probabilistic behavior of the values of these parameters. In this study we propose the application of Monte Carlo analysis to estimate the geothermal resources capacity in term of power sored beneath Lawu Mount geothermal area.

MONTE CARLO SIMULATION

Monte Carlo analysis is a statistic method-based computer that uses statistical sampling techniques in determining probabilistic approximation to the solution of mathematical equations or models [6]. In this case, the model is a mathematical equation that describes the interactions in a system. Generally, the input parameters depend on various external factors. Systematic variations of input parameters result in realistic models that have risks. Monte Carlo simulation can used to investigate the range of risks associated with each of the input parameters.

In Monte Carlo simulation, random numbers have a central role. Random numbers with a given distribution are used to represent the uncertainty circumstance in a real system and expressed as input parameters of model. Random numbers are divided into two types based on the way of generation i.e original and artificial random. Original random numbers are generated by physical processes whereas artificial random numbers are generated with human intervention. Artificial random numbers are used because they can be modified as needed. Most software computers already have specific routines to generate random numbers with a given distribution quickly and practically. Therefore, the analysis Monte Carlo method is rapidly growing and popular in physics and operations research field.

Generally, Monte Carlo simulation consists of several stages. It begins with determining the statistical distribution of each input parameter, then generates random numbers for each distribution describing the variables input values. From each set of random input parameters we obtain output which is one of the outcomes of a series of simulations were run repeatedly (hundreds and even thousands of times). Then, outputs are collected and analyzed

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statistically. Distribution of the output from these iterative processes is illustrated in graph depicting a distribution frequency and cumulative frequency distribution. Distribution frequency graph will provide information on the relative probability value, most likely value, and the form of distribution. While the cummulative frequency graph can provide the probability of a certain value. Results of the analysis provide communicative and varied of feedback and recommendations as a consideration in decision making of geothermal development plan.

VOLUMETRIC METHODS

Basically, a geothermal field utilized as power plant by extracting heat stored within rocks in the subsurface. The heat is transferred from the rocks to the water and moves to the surface with the water well. Estimation of geothermal power potential is based on geological, geochemical and geophysical characteristics of the associated reservoir, and the estimated elictrical power equality[1]. There are two estimation methods of the geothermal resources capacity, i.e the comparison and volumetric methods. Comparison method is used to estimate speculative resources capacity using simple statistics. While the volumetric method is used to estimate resources capacity from the hypothetical to proven categories. The volumetric method is commonly used in exploration by using lumped parameter model in homogeneous-assumed reservoir parameters. In this method, geothermal reservoir is assumed to have box-shaped with a certain area and thickness. The electrical resources capacity of the reservoir is equivalent to the heat energy stored within rocks and fluids (liquid and vapor).

In the volumetric method, the capacity of geothermal resources is the amount of electrical energy generated for *t* year period (in MWe):

$$H_{el} = \frac{Ah\{(1-\Phi)\rho_r c_r + \Phi \rho_L c_L\}(T_i - T_f) R_{f\eta}}{t\,x\,365\,x\,24\,x\,3600\,x\,1000} \qquad (1)$$

where :

H_{el} = Resource capacity (MWe)
A = Reservoir area (m^2)
h = Reservoir thickness (m)
Φ = Porosity
ρ_r = Rock density (kg/m^3)
ρ_L = Fluid density (kg/m^3)
c_r = Rock specific heat (kJ/kg^oC)
c_L = Fluid specific heat (kJ/kg^oC)
T_i = Reservoir average temperature,(^oC)
T_f = Reservoir abandon temperature (^oC)
R_f = Recovery factor
η = Conversion efficiecy
t = Plant life (year)

Assumed Parameter

Reservoir Volume

Reservoirs are usually characterized by 20 – 80 Ωm resistivity anomaly and lie under clay cap having a lower resistivity. Based on magnetotelluric survey results conducted by PSDG [5], the geothermal prospect area is assumed to be 17 km^2 (Figure 1). This area is located beneath the southwest part tending to be open to the north. The integrated investigation results of Lawu geothermal field conducted by PSDG [3] yields that the reservoir thickness is 2 km.

Reservoir Temperatur and Cut off Temperatur

The gas geothermometries analysis results using CO_2/Ar-H_2/Ar grid indicates that the reservoir temperature is 250 °C[3]. While cut-off temperature used is 180 ^oC (for high temperatur reservoir)[1].

Rock density

Rock density are assumed to be in range 2350 kg/m^3 to 2640 kg/m^3.

Porosity

The minimum and maximum rock density are assumed to be 3% and 15%, respectively.

Fluid density and specific head

Fluid density and specific head are assumed to be 748.67 kg/m^3 and 5.34 kJ/kg-^oC, respectively.

Recovery factor

Recovery factor is defined as ratio between wellhead thermal energy to reservoir thermal energy. by a geometrical concept of the reservoir, recovery factor is defined as ability to extract hot fluid at a certain volume. Generally, the recovery factor is assumed to be 0.25 [2].

Conversion efficiency

Conversion efficiency is assumed to be 10%[1].

Plant Life and Load factor

The plant life is plant availability throughout the year consider the period when the plant is operated as a base-load [4]. Plant life is assumed to be 30 years [1], whereas load factor is assumed to be 80% to 90%.

RESULT AND DISCUSSION

Resources capacity of a geothermal field can be determined by considering all input parameters obtained through a series of exploration. Based on the results of exploration and identification of input parameters that have been done before, estimation resources capacity in Lawu geothermal area can be conducted using volumetric method combined with Monte Carlo analysis. Deterministic formula in volumetric method was changed into stochastic formula by applying Monte Carlo analysis. Propability of each input parameter is evaluated statistically as well as the output.

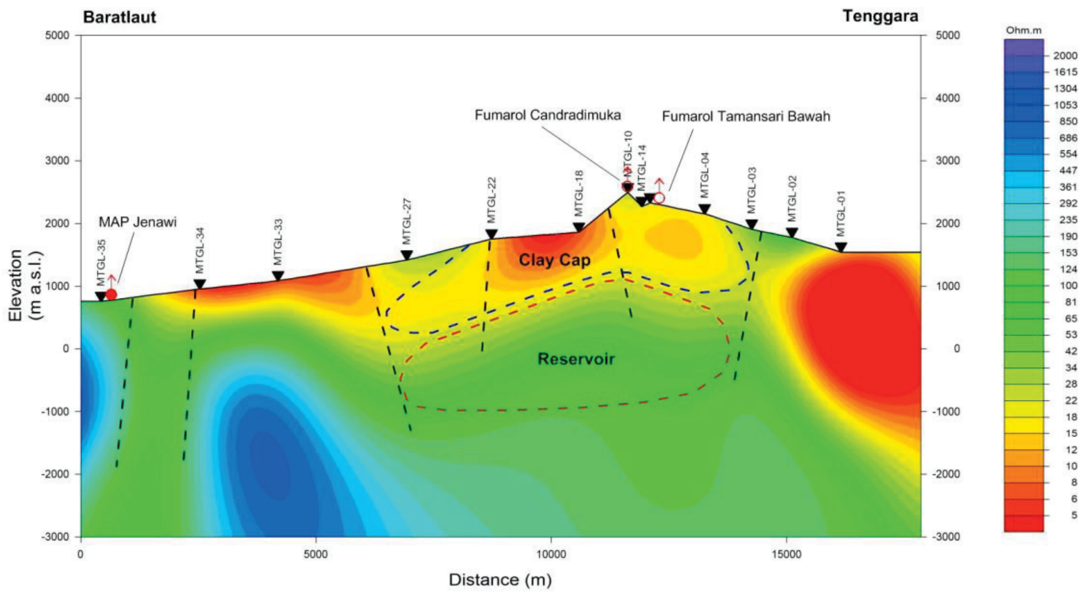


FIGURE 1. 2D resistivity data magnetotelluric survey in Lawu Geothermal Field [5]

In this study, Monte Carlo simulation is run 10,000 times. For one cycle, each input parameter is randomly selected between minimum and maximum values. The selected random numbers have a normal distribution to describe the nature of the data input parameters. Different combinations of input parameters for each cycle also generate 10.000 different outputs which are then analyzed statistically. Monte Carlo analysis results (Table 1) are presented in graphical form of frequency distribution and cumulative frequency distribution as shown in Figure 2. The frequency distribution of the resource capacity is calculated as a fraction of the total number of data points. On the other hand, the cumulative frequency distribution is plotted by accumulating the frequency distribution from minimum value of the random variable to the maximum, whereas possibility is opposite to cumulative frequency.

TABLE 1. Result of 10,000 Time Iteration Monte Carlo Simulation

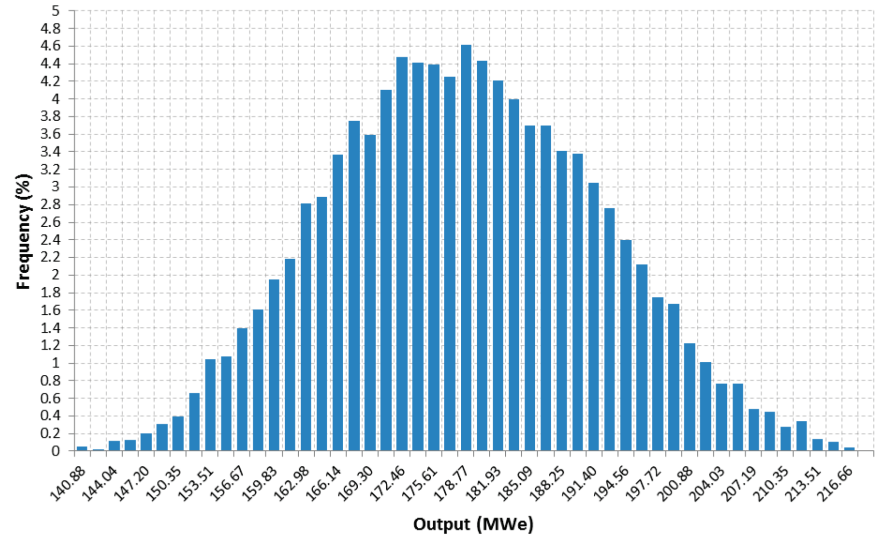
Parameter Input (Units)	Most Likely	Min	Max
Area (km^2)	17	17	17
Thickness (m)	2000	2000	2000
Rock Density (kg/m^3)	2494.3	2350	2640
Porosity	0.09	0.03	0.15
Recovery Factor	0.25	0.25	0.25
Rock Specific Heat (kJ/kg-^{o}C)	0.9	0.8	1
Temperatur Reservoir (^{o}C)	250	250	250
Fluid Density (kg/m^3)	748.67	748.67	748.67
Conversion Efficiency	0.1	0.1	0.1
Fluid Specific Heat (kJ/kg-^{o}C)	5.34	5.34	5.34
Plant Life (years)	30	30	30
Load Factor	0.85	0.8	0.9
Rejection Temperatur (^{o}C)	180	180	180
Power Capacity (MWe)	177.77	139.30	218.24

Considering minimum and maximum values for each parameter, the computed potential resources ranges from 139.30 to 218.24 MWe due to the inherent uncertainties of the input parameters (Figure 2a). Within the range, the highest frequency appears at 178.77 MWe. The probability of resources capacity refers to cumulative frequency is calculated to be 80% for 166.44 MWe and 50% for 177.54 MW (Figure 2b). Power density for the area of 17 km^2 is equal to 9.41 MWe/km^2 for probability of 80% and 10.44 MWe/km^2 for probability of 50%. Generally, the estimation of resources capacity using volumetric method is rather conservative because the method does not calculate continuous heat flow from depth through conduction or convection. Therefore, the result of simulation indicate that the resource capacity of Lawu geothermal field much larger than 160.6 Mwe (90%). However, the possibility for the resources capacity above 196.19 MWe calculated in this study less than 10%.

Using the most likely values for each parameter as input parameter in deterministic equation of volumetric method, the amount of electric potential in Lawu geothermal field is found to be 177.57 MWe. Whereas the capacity of geothermal resources calculation by geothermal investigation group of PSDG is amounted to 193 MWe[3].

CONCLUSION

Monte Carlo Analysis is powerful to estimate geothermal resources capacity in Lawu geothermal field. The risks related to uncertainty of a geothermal field measurement could be quantified. Based on this analysis, the most likely resources capacity in Lawu



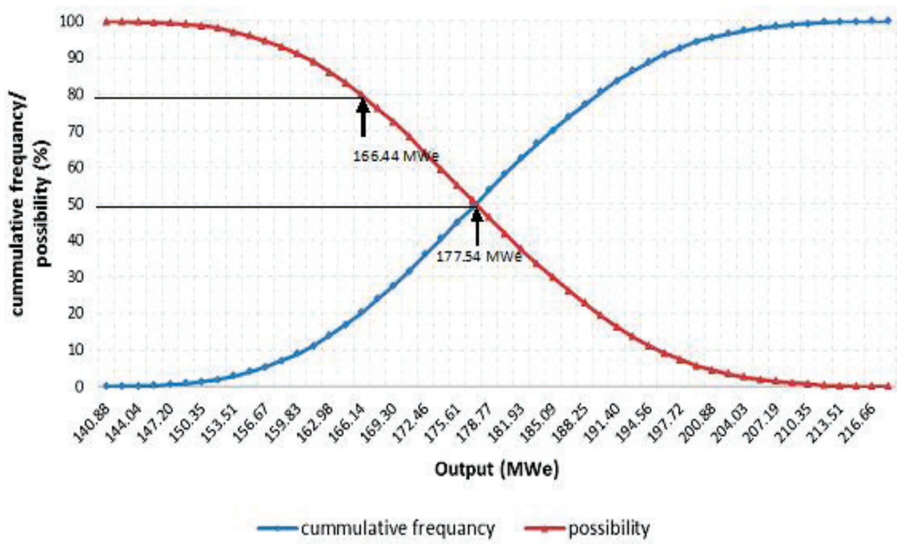


FIGURE 2. Output simulation results 10000 times iteration. a) The frequency distribution b) The cummulative frequency distribution

geothermal field is 177.77 MWe. The resources capacity risks above 196.19 MWe is less than 10%, whereas the calculation conducted by PSDG is 193 MWe.

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