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Optimization of Technical and Economical Objective Functions of Hybrid Renewable Energy Generation Based Genetic Algorithm

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ABSTRACT

This study is aimed to optimize the technical and economic objective functions of a renewable energy hybrid generator system by using genetic algorithms (GA) in order to create a balanced and optimal power generation system configuration. The technical and economic aspects used were the Loss of Power Supply Probability (LPSP) and Annualized Cost of System (ACS), respectively. The objective functions of GA method were LPSP and ACS. The types of power plants used in this hybrid system were photovoltaic (PV), Wind Turbine (WT), battery, and Micro Hydro Power Plant (MHPP). Validation on the GA method was done by simulation in Matlab. Results of the simulation show that the use of the GA offers the most balanced system configuration with less expensive costs and a very good level of system reliability against hybrid systems. The use of the objective function with penalty factor scenario in GA is not as effective as the conventional GA, following the weakness of its evaluation results.

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1. INTRODUCTION

Fossil-based energy sources are increasingly depleting. Therefore, alternative energy sources such as renewable energy can be more optimally developed to meet energy needs in the future. Renewable energy sources are energy sources obtained from natural resources whose formation time is sustainable, such as solar power, wind power, hydro-power, geothermal power, and so on [1]. However, the main drawback of renewable energy generation systems is the instability of energy sources. This occurs because the energy source generated is highly dependent on natural conditions which tend to fluctuate and vary in each region [2].

One of the effective ways to overcome the instability of renewable energy generation systems is to combine two or more generation systems with different types of energy sources in a hybrid generating system. [3]. The combination of generating systems from renewable energy sources is expected to provide a continuous and more stable power supply with optimal efficiency [4]. Another advantage of a hybrid generation system is a lower life-cycle cost than an individually installed renewable energy generation system [3]. However, the balance of technical and economic aspects of a hybrid generating system needs to be achieved properly in order to produce a balanced and optimal hybrid generating system. Balanced in the sense that it has good reliability from a technical point of view. While optimal in terms of having good efficiency from an economic aspect.

An important step that must be taken to achieve a balance in the technical aspects of a renewable energy hybrid generator system is system reliability analysis [6]. The general parameter used to measure reliability is the Loss of Power Supply Probability (LPSP) [4]. LPSP is used to design and evaluate hybrid generator system combinations with various system configurations, until it finds the best LPSP value [5]. Complementing the balance of technical aspects, a hybrid generating system also requires a balance of economic aspects. Economic aspects are measured using the Annualized Cost of System (ACS) parameter [9]. In its mathematical function, ACS includes parameters for system component costs, maintenance costs and component replacement within certain time intervals. To get the best value from the ACS and LPSP, various methods of finding the optimal value can be used.

There are many optimization methods that have been developed previously for various cases. In[6] and [7] developed the Particle Swarm Optimization (PSO) to solving the robotics and control system problem. The development of hybrid algorithm using Differential Evolution (DE) and Jaya Algorithm have been applied to improve the power point tracking of solar system generation [8]. A study conducted by B. Tudu and Majumder [9] conducted an optimization of a renewable energy hybrid system using the Bees Algorithm (BE). The study states that BE is quite efficient, but has a small surplus power. Mahdi Shaneh in 2018 used Bat Algorithm (BA) [10] in a hybrid system to meet road lighting loads. The study results show that the resulting level of technical reliability does not make sense because the resulting level of reliability is not great enough.

Meanwhile, the research conducted by Imam Ahmad Ashari [11], tried to compare the optimal value search results using the GA algorithm, PSO, and Ant Colony Optimization (ACO). The results showed that GA's performance was better than ACO and PSO. According to Ashari, GA is the best solution in the search for the optimum global value, because GA works at a population point, not at one point. GA uses a relatively large number of iterations to evaluate the value of the best global optimization desired. Annas Alif Putra in 2018 implemented an optimization of the power capacity of solar panels and wind turbine hybrid systems using the DE algorithm [3]. The study yielded an optimal system and a lower number of power outages per year. However, the effectiveness of GA method in optimizing also needs to be proven for the optimization of the hybrid generator system configuration with a more diverse generator composition.

The purpose of this study is to optimize the technical and economic objective functions of a renewable energy hybrid generator system using the GA method in order to create a balanced and optimal power generation system configuration. The optimized hybrid generating system consists of four different types of generators, include solar panels (PV), wind turbine (WT), batteries, and micro-hydro power plants (MHPP). Determination of the best combination configuration of the renewable energy hybrid system refers to capacity optimization using a genetic algorithm in an effort to find the optimal LPSP and ACS values. With a more balanced and optimal configuration of the hybrid generation system, it is hoped that the renewable energy generation system will be able to produce higher quality electrical energy. The main contribution of this study is the technical function optimization scheme and the economic function of the hybrid generator system based on GA method for four different types of power plants.

2. RESEARCH METHOD

In general, the method in this study was developed on the question of how power management is carried out; how the optimization criteria are defined; how the technical and economic aspects are calculated, and how the multi-objective GA is designed. The complete description of the method developed in this study is éxplained in the following sections.

2.1. Power Generation Management

Hybrid system applied in this study consists of four different types of generators, including solar panels (PV), wind turbine (WT), batteries, and micro-hydro power plants (MHPP). The power management used for the hybrid system is described in the following steps:

1. If the renewable energy sources from PV and WT are not able to meet the needs of the electric load, the energy stored in the battery will be used to help meet the needs of the electric load.
2. If the energy source produced by renewable energy is PV and WT in excess, then that energy will be used to charge the battery.
3. If the energy sources from PV and WT fail to meet the electricity load and the energy in the battery is used up, the electricity will go out.

From the three steps above, the power operation management algorithm can be described using the flowchart in Figure 1.

From the flowchart in Figure 1, it is explained that T is the current time t, P_{PV} is the PV power output, P_{WT} is the WT power output, P_{Load} is the load power, P_{MH} is the MHPP power output, η_{inv} is the efficiency of the inverter, E_B is the battery energy, E_{CH} is the charging energy. E_{CH} is discharging energy. The data used at this stage is the generator data found at the University of Muhammadiyah Malang (UMM), with the load centered on the UMM Rusunawa.

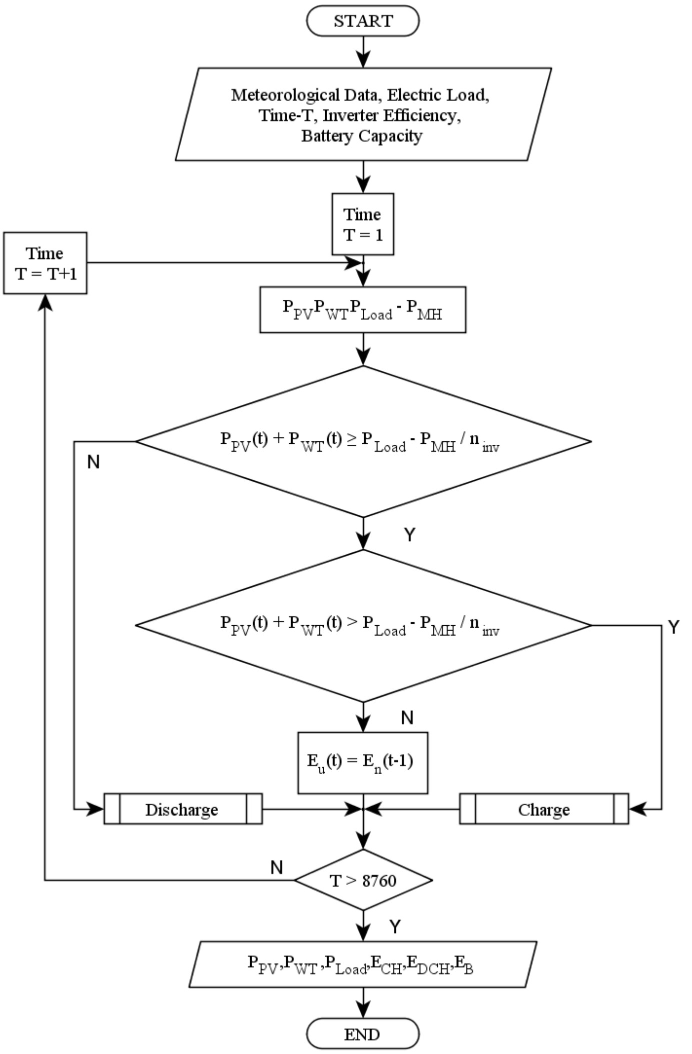

Figure 1. Flowchart of Power Control Operation

2.2. Optimization Criteria

In a renewable energy hybrid generator system, there are several optimization aspects in its modeling, including size, operation, technical, and cost. The technical and cost (economical) aspects are the main aspects in designing a renewable energy hybrid system. The technical aspect is generally a way to find the efficiency and reliability of the generating system. Meanwhile, the economic aspect includes energy costs and system costs, which includes operating, maintenance and component replacement costs.

2.2.1 Technical Aspects Calculation Using the LPSP Concept

LPSP (Loss of Power Supply Probability) is a statistical parameter for measuring system performance for an assumed or known load distribution. It is the probability when the load requirements cannot be met within a certain period of time by the energy generated by the renewable energy generating system. When the energy generated or the energy used is known, it is possible to analyze the LPSP value of the system. LPSP will have a value in the range of 0 to 1, which is if the value of the LPSP is close to 0 or less than 0.1, then the modeling of the renewable energy hybrid system can be said to be very good. If the LPSP value obtained is 1, it means that the electricity load needs cannot be met. Meanwhile, if the LPSP value is 0, it means that the electricity load needs are fully met. The LPSP calculation is shown by Equation (1):

$$LPSP = \frac{\sum_{t=1}^{T} LPS_t}{\sum_{t=1}^{T} E_{Lt}} \tag{1}$$

with E_{Lt} is the energy required by the load at time t,

$$LPS_t = E_{Lt} - \left(E_{gt} + E_{Bt-1} - E_{Bmin}\right).\eta_{inv} \quad (2)$$

In equation (2), E_{gt} is the energy that can be generated by renewable energy at time t, E_{Bt-1} s the energy stored in the battery at time t-1, mean while E_{Bmin} s the minimum capacity of the battery, and η_{inv} is the efficiency of the inverter.

$$E_{gt}(t) = P_{PV}(t) + P_{MH}(t) + P_{WT}(t) + (E_B(t) - E_{Bmin}) \quad (3)$$

where P_{PV} is the power generated by PV, P_{MH} is the power generated by MHPP, dan P_{WT} is the power generated by WT.

2.2.2 Economical Aspects Calculation Using the ACS Concept

Calculating the annual cost with regard to capital costs, component replacement, operating costs, and maintenance is an important factor in how much costs need to be spent on the proposed generating system. The total annual cost of the system is defined as ACS with a formula as in Equation (4) - (10) below.

$$Cost = \sum_t C_{arepi} + C_{acapi} + C_{aomi} \quad (4)$$

$$C_{acap} = C_{cap} * CRF(i, Y_{pro\ j}) \quad (5)$$

$$CRF\left(i, Y_{pro\ j}\right) = \frac{(i*(1+i)^{Y_{pro\ j}})}{(1+i)^{Y_{pro\ j}-1}} \quad (6)$$

$$i = \frac{i'-f}{1+f} \quad (7)$$

$$C_{arep} = C_{rep} * SFF(\mathrm{i}, Y_{rep}) \quad (8)$$

$$SFF\left(\mathrm{i}, Y_{pro\ j}\right) = \frac{\mathrm{i}}{(1+\mathrm{i})^{Y_{rep}-1}} \quad (9)$$

$$C_{amain}(n) = C_{amain}(1) * (1+f)^n \quad (10)$$

From Equation (4) to (10) can be defined C_{aomi} is the operating and service cost, C_{arepi} is the component replacement cost, C_{cap} is the component's capital cost, C_{acapi} is the component's annual capital cost, CRF is the capital recovery factor, i is interest rate, $Y_{pro\ j}$ is component lifetime, i' nominal interest rate, f is annual inflation rate, C_{rep} is component replacement cost, SFF is future financing, Y_{rep} is lifetime component, and $C_{amain}(n)$ is system maintenance cost for the n^{th} year [10].

2.3. Optimation Method with Genetic Algorithm (GA)

In determining the optimal configuration, this study uses the GA method with a flowchart as shown in Figure 2.

The steps for working on capacity optimization in a hybrid system with technical and economic aspects using GA in Figure 2 above are as follows:

1. Determine the GA parameters.

Table 1. GA Parameters

Data	Frequency
Population	20
Dimention	4
CrossOver Ratio	0,85
Iteration	Maximum

   The population in this case is a vector combination of the amount of PV, WT, battery, and MHPP. Meanwhile, dimension is the range of the program to be executed.
2. The capacities of PV, WT, and MHPP used are 500 Wp, 200 Wp, and 100 kWp. While the battery used has a capacity of 100 Ah 12 Volt (2 pieces).

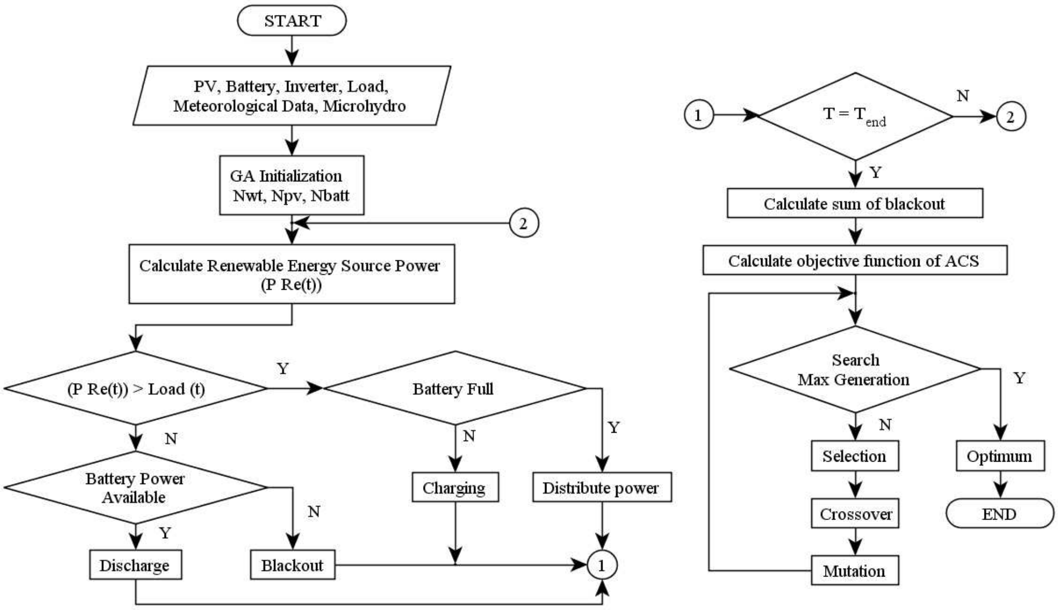

Figure 2. Flowchart of the Overall Operating System

3. Determine meteorological data from renewable energy sources (solar radiation, air temperature, wind speed, and water discharge)
4. Determine the load profile
5. Determine the characteristics of the equipment or tools used in the generator.
6. Initialization process by generating a new vector as much as the population with random dimensions. The first dimension is the amount of PV with an upper and lower limit, [1,100]. The second dimension is the amount of WT, which is the same as the first dimension the amount of WT has an upper limit and a lower limit, [1,10]. In the third dimension there are batteries with an upper and lower limit, [1,20] and MHPP 1. The selection of the upper limit is assumed based on the comparison of previous studies to the load used.
7. Generate a random population of PV, WT, battery, and MHPP amounts.
8. Selection of population vectors. The vector with the best (smallest) fitness value will be the parent vector.
9. Recombination or crossover, is a vector marriage with the previous vector (new vector) to create derivative vectors.
10. Mutation of the parent vector into the newest vector.
11. Regeneration, is the re-generation of a new vector or population.
12. Evaluation of new vectors with technical objective functions (LPSP) and economical (ACS) in an effort to obtain the best (lowest) fitness function value.
13. Repeat steps 7 through 12 for the specified number of iterations.

2.3.1 Multi-objective Optimization Using Genetic Algorithm Methods

There are 2 scenarios in finding the multi-objective optimal value in equation (11) and equation (12) on the basis of GA. The first fitness function in value in equation (11) is a departure from the ACS on the LPSP, and equation (12) uses a penalty factor [9].

$$F = \text{ACS\^{}LPSP} \quad (11)$$

$$F = ACS + M \cdot [\max(0, LPSP - 0.5\%)]2 \ fitness. \quad (12)$$

where M is value of *penalty factor.*

3. RESULT AND ANALYSIS

The following is a description of the results and discussion of the studies that have been carried out. The results and discussion are divided into two parts: the results of the configuration testing and the results of the whole system testing.

3.1. Simulation Results of Systems Configuration

The following are the results of the overall research simulation:

Table 2. Overall Configuration Simulation Results

Configuration	Number			
	PV	WT	MHPP	Batteray
Technical Objective Function Calculation	66	10	1	17
Economical Objective Function Calculation	8	3	1	7
Using Genetic Algorithm	1	1	1	15
Using Genetic Algorithm - *Penalty Factor*	1	1	1	14

Table 3. Results of Optimation Evaluation for Overall Configuration

Configuration	Blackout Period (Hour)	Total Cost (Annual)
Technical Objective Function Calculation	516	Rp. 369.120.000,-
Economical Objective Function Calculation	2.766	Rp. 154.340.000,-
Using Genetic Algorithm	45	Rp. 194.080.000,-
Using Genetic Algorithm - *Penalty Factor*	393	Rp. 186.420.000,-

From Table 2 and Table 3, it can be seen that GA is superior in terms of less power outage, and less annual costs. The configuration is a balanced system from a technical and economic aspect compared to the other three configurations. In terms of the use of penalty factor in GA, the resulting configuration is not much different from GA optimization. However, the resulting technical aspects are greater than the use of GA alone. The results that are influenced by penalty factor even have a greater downtime of 873.3% compared to GA, although with a 4% lower annual cost. So, it can be seen that the best balance is obtained by the system configuration based on GA.

The optimal system composition of this study is a PV, a WT, an MHPP, and 15 batteries. Balanced results of technical and economic multi-objective functions with a breakdown of 45 hours of downtime for a year, and an annual fee of Rp. 194,080,000 is a very reliable and cost-balanced system. Figure 3 and Figure 4 below are graphs of the convergence of GA during the simulation.

As seen in Figure 4 and Figure 5, the process of finding the optimal value is the smallest fitness value, which is 1.0513 in GA. While the use of penalty factor in Figure 5, the fitness value is greater at the value of 1.3174.9.

3.2. Simulation Results of Overall System Testing

After obtaining various types of configurations as described in Table 2 and Table 3, determining the configuration of research simulation results from various scenarios can be described as in Table 4.

Table 4. Simulation Results of Overall Scenario

Optimation Criteria		WT	PV	MHPP	Battery	Total Cost (Annual)	LPSP
Using LPSP	Average	7,4	51,3	1	8,9	Rp. 268.627.000,-	0,26982
	Min.	10	66	1	17	Rp. 369.120.000,-	0,0590
	Max.	8	94	1	2	Rp. 298.550.000,-	0,5393
Using ACS	Average	7,4	51,3	1	8,9	Rp. 268.627.000,-	0,26982
	Min.	3	8	1	7	Rp. 154.340.000,-	0,3238
	Max.	10	66	1	17	Rp. 369.120.000,-	0,0590
GA	Average	2.5	2.7	1	15	Rp. 203.535.000,-	0,00601
	Min.	1	1	1	15	Rp. 194.080.000,-	0,0053
	Max.	7	2	1	15	Rp. 221.010.000,-	0,0071
GA - *penalty factor*	Average	1,4	2,4	1	1,4	Rp. 190.450.000,-	0,0452
	Min.	1	1	1	14	Rp. 186.420.000,-	0,0449
	Max.	1	4	1	13	Rp. 184.400.000,-	0,0850

From Table 4 it can be seen that GA is able to produce the most balanced and optimal system configuration compromise. This can be seen from the level of system reliability that is very good (seen from the LPSP value) with a relatively low annual cost. Meanwhile, although GA with a penalty factor is able to produce annual costs that are slightly smaller than GA, the reliability is far below GA. As it is known, the reliability factor takes precedence over the cost factor. So that in the case of conventional GA offers better balance and efficiency than GA with penalty factor.

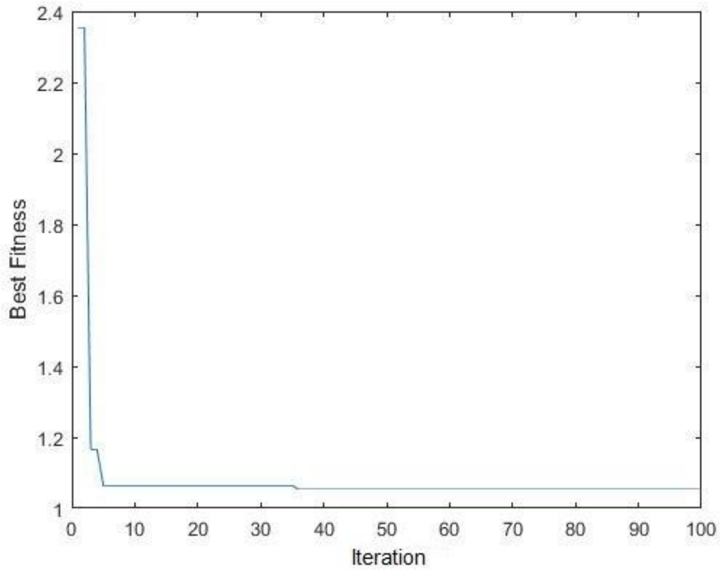

Figure 3. GA Convergence Graph

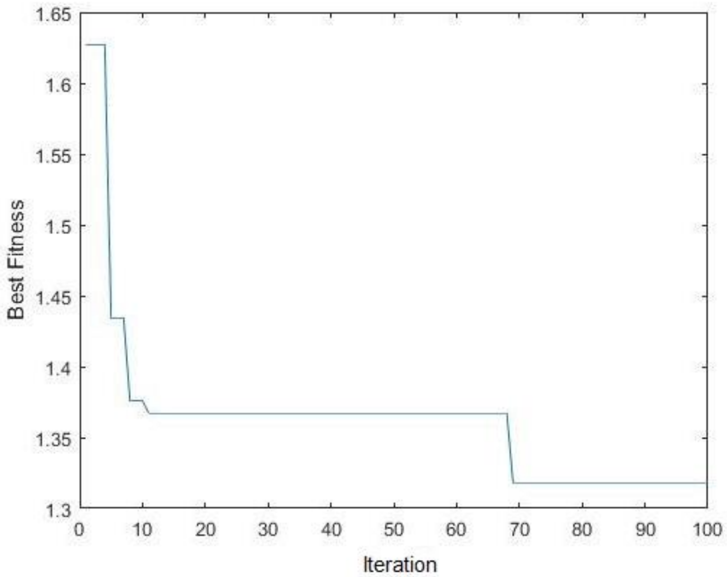

Figure 4. GA Convergence Graph with Penalty Factor

4. CONCLUSION

Optimization of the technical and economic objective functions of the renewable energy hybrid generator system based on genetic algorithms in order to create a balanced and optimal configuration of the generating system has been successfully carried out. From the results of the study conducted, the multi-objective function optimization using the GA method is able to produce a more balanced and optimal hybrid generator system, respectively in terms of reliability and cost efficiency. The system configuration using GA optimization is able to produce an LPSP value of 0.6% or a blackout period of about 52 hours for a year and an average annual cost of Rp. 203,535,000, -. The use of the objective function with the penalty factor scenario in GA does not make it more effective than conventional GA.

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