TELKOMNIKA, Vol.10, No.4, December 2012, pp. 695~702
ISSN: 1693-6930
accredited by DGHE (DIKTI), Decree No: 51/Dikti/Kep/2010

Optimal Design of Fuel-cell, Wind and Micro-hydro Hybrid System using Genetic Algorithm

Soedibyo, Heri Suryoatmojo, Imam Robandi, Mochamad Ashari
Department of Electrical Engineering, Sepuluh Nopember Institute of Technology (ITS)
Sukolilo, Surabaya, (60111), Indonesia, Telp: 031 5947302
e-mail: dibyo_55@yahoo.com

Abstrak

Target dari sistem hibrida yang beroperasi mandiri adalah untuk mensuplai beban dengan reliability yang tinggi dan ekonomis. Sebuah teknik optimasi menggunakan kecerdasan buatan diperlukan untuk mendisain sistem ini. Penelitian ini menggunakan Algorithma Genetika untuk menentukan kapasitas optimum dari hidrogen, turbin angin dan mikro-hidro dengan biaya yang minimum. Biaya minimum berhubungan dengan biaya operasi dan perawatan tahunan,biaya penggantiantahunan dan biaya kerusakan tahunan. Metode yang diusulkan akan digunakan untukmengoptimasi sistem di Desa Leuwijawa, Jawa Tengah, Indonesia.Hasil simulasi menunjukkan bahwa konfigurasi optimum dapat diperolehkapasitas tanki hydrogen sebesar 19,85 ton, turbin angin 21 unit x 100 kW dan 1 unit micro-hydro 610 kW.

***Kata kunci:** algoritma genetika,angin, hidrogen, mikro-hidro, optimisasi*

Abstract

The target of stand-alone hybrid power generation system was to supply the load demand with high reliability and economically as possible. An intelligent optimization technique using Genetic Algorithm is required to design the system.This study utilized Genetic Algorithm method to determine the optimal capacities of hydrogen, wind turbines and micro-hydro unit according to the minimum cost objective functions.The minimum cost valutes to these two factors. In this study, the cost objective function included the annual capital cost, annual operation maintenance cost, annual replacement cost and annual customer damage cost. The proposed method will be used to optimize the hybrid power generation system located in Leuwijawa village in Central Java of Indonesia. Simulation results showed that the optimum configuration can be achieved using 19.85 ton of hydrogen tanks, 21x100 kW wind turbines and 610 kW of micro-hydro unit respectively

***Keywords:** genetic Algorithm, hydrogen, micro-hydro, optimization,wind*

1. Introduction

Nowadays, renewable energy has been explored to meet the load demand. Utilization of renewable energy is able to secure long-term sustainable energy supply, and reduce local and global atmospheric emissions [1], [2]. Micro-hydro (Hyd) and Wind Turbine (WT) units are become the promising technologies for supplying the load demand in remote and isolated area. However, there are several weakness faced by such resources. One of the weaknesses is the power generated by wind and micro-hydro energy is influenced by the weather conditions.The variations of power generated by these sources may not match with the time distribution of demand. In addition, the intermittent power from wind and micro-hydro power may result in serious reliability concerns in both design and operation of micro-hydro and wind turbines system. For simplicity, to overcome the reliability problem, over sizing maybe can be applied. However, installing the components improperly will increase overall cost system.

Actually, there are several alternative ways to prevent the shortage power from these powers.A back-up unit can be considered as a power supply whenever the insufficiency power is occurred.For instance, diesel generator is one of the alternative back-uppower. However, the operational cost of diesel generator is considerably high also utilization of diesel generator is not the good option due to the environmental concern. Meanwhile, battery storage also can be considered for the back-up unit. However, the operational and maintenance procedures of

Received August 29, 2012; Revised September 15, 2012; Accepted October 4, 2012

battery are complicated. The last back-up unit goes to utilization of fuel cell equipped with electrolyzer and hydrogen tank.

The most important challenge in design of such systems is reliable supply of demand under varying weather conditions, considering operation and investment costs of the components. Hence, the goal is to find the optimal design of a hybrid power generation system for reliable and economical supply of the load [3]. Several methods have been done by another researcher; many papers offer a variety of methods to find the optimal design of hybrid wind turbine and photo-voltaic generating systems [3-5]. In [3-4] and [6] Genetic Algorithm (GA) finds optimal sizes of the hybrid system components and power flow. In some letterresearch, PSO is successfully implemented for optimal sizing of hybrid stand-alone power system, assuming continuous and reliable supply of the load [5].However, none of them working with the micro-hydro system.

This paper proposes the method to find the optimal design of hybrid power generation system consists of micro-hydro, wind turbine and fuel-cell in the system.The target is to find the optimal size of components respect with minimum total annual cost system (ACS). In this way, genetic algorithm is utilized to minimize cost of the system over its 20 years of operation, subject to reliability constrain. Wind speed and stream flow data are available for Leuwijawa village in Central Java, Indonesia and system costs include Annualized Capital Cost (ACC), as well as costumers dissatisfaction cost. Next section briefly describes the hybrid system model.

2. System Configuration

Block diagram of a hybrid Micro-hydro, Fuel-cell and Wind turbines system is depicted in Figure 1. The hybrid system consists of 3 types of power generator; Wind turbines unit, Micro-hydro and Fuel-cellunit connected to the load system through the inverter.The storage system consists of electrolyzer, hydrogen storage tank and fuel-cell required to store all excess power. Detailed component model and their specification, used in this study will be explained in the following sections.

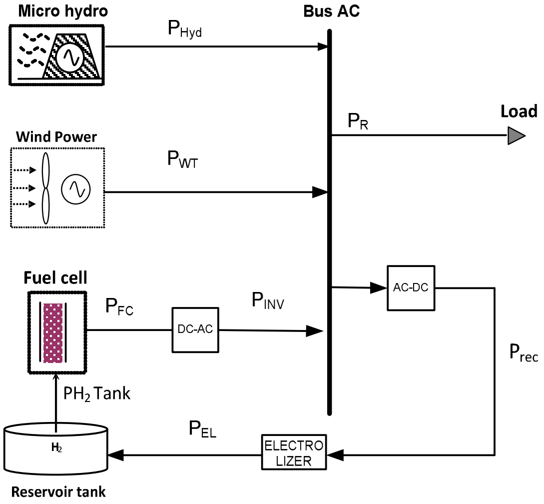

Figure1.Configuration of proposed system

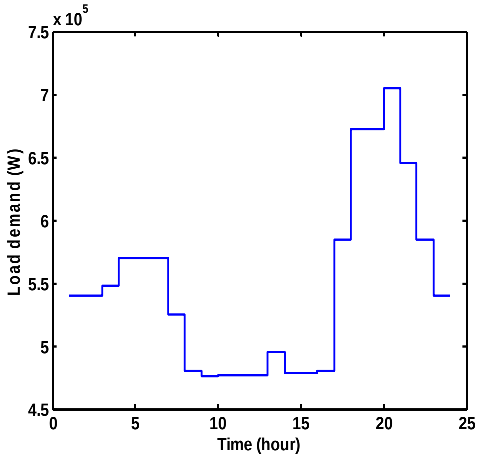

Figure 2. Daily load profile

3. Modeling of Renewable Energy Components

3.1. Wind Turbine Generator

The output power of each wind turbine unit is based on the rated capacity and the specification given by the manufacture. In this study, 100kW wind turbine is considered as a power generator. It has a rated capacity of 100 kW and provides alternating current (AC) at the output side.The output power from wind turbines can be described by equation (1).

$$P_W(t) = \begin{cases} 0 & if\ V_t(t) < V_c \\ \frac{1}{2}.\rho.A.V^3(t).\eta_{wt} & if\ V_c \le V_t \le V_r \\ P_{rated} & f\ V_r \le V_t \le V_f \\ 0 & if\ V_t > V_f \end{cases} \quad (1)$$

where ρ is air density kg/m^3, A is swept area of rotor m^2, t is wind speed (m/s), $\eta_{wt}$is efficiency of WTs, V_c is cut-in speed, $v_r$is rated speed, $v_f$is furling speed and P_{rated} is rated power of WTs.

Table1. Specification of wind turbine

Rated power (kW)	100
Cut-in (m/s)	3.5
Cut-out (m/s)	25
Rated (m/s)	12
Swept area of rotor(m^2)	314.16
Efficiency (%)	30

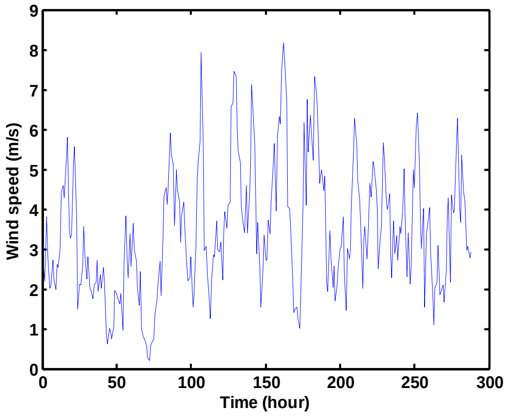

Figure 3. Wind speed data

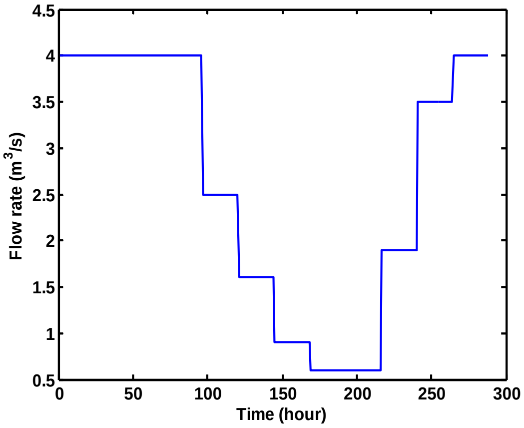

Figure 4. Flow rate data

3.2. Micro-hydro Power

The electrical power generated by the hydro turbine can be determined using the following equation [5].

$$P_{hvd} = \eta_{hvd} \cdot \rho_{hvd} \cdot g \cdot H_{net} \cdot Q_t \quad (2)$$

whereH_{net} is the effective head, the actual vertical drop minus this head loss. It can be calculated using the following equation [7].

$$H_{net} = H\ (1 - f_h) \quad (3)$$

Meanwhile, Q_t is the hydro turbine flow rate, theamount of water flowing through the hydro turbine. It can be calculated using the following equation [7].

$$Q_t(t) = \begin{cases} 0 & if\ Q_{Av}(t) < Q_{min} \\ Q_{Av}(t) & if\ Q_{min} < Q_{Av}(t) < Q_{max} \\ Q_{max} & if\ Q_{Av}(t) > Q_{max} \end{cases} \quad (4)$$

where$Q_{Av}$is the flow rate available to the hydro turbine (m^3/s),$Q_{min}$is the minimum flow rate of the hydro turbine (m^3/s),$Q_{max}$is the maximum flow rate of the turbine (m^3/s) [7]. Q_{min} is the minimum flow rate, the minimum allowable flow rate through the hydroturbine; it is assumed that the hydro turbine can operated only if the available stream flow is equal to or exceeds this minimum value. It can be calculated using the following equation [7]:

$$Q_{\min}(t) = W_{\min} \cdot Q_D \tag{5}$$

$Q_{max}$is the maximum acceptable flow rate through the hydro turbine, expressed as a percentage of the turbine's design flow rate [7]. This simulation uses this input to calculate the maximum flow rate trough the hydro turbine, and hence the actual flow rate through the hydro turbine.

$$Q_{\max}(t) = W_{\max} \cdot Q_D \tag{6}$$

3.3. Electrolyzer

Basically, electrolyzer work based on the water electrolysis. A direct current is passed between two electrodes then submerged in water and decomposes into hydrogen and oxygen. Then, the amount of hydrogen can be collected from the anode side. Usually, the hydrogen produces by the electrolyzers at a pressure around 30 bars. Also, the reactant pressures within a Proton Exchange Membrane Fuel Cell (PEMFC) are around 1.2bar. For assumption, the electrolyzer is directly connected to the hydrogen tank. Transferred power from electrolyzer to hydrogen tank can be defined as follows [5]:

$$P_{EL-\tan k} = P_{EL} \cdot \eta_{el} \tag{7}$$

Where η_{el} is the efficiency of electrolyzer.

3.4. Hydrogen Tank

The basic principle of energy stored in the hydrogen tanks is the same as in the battery banks. Everyhour energy stored in the hydrogen tanks can be described by using the following equation [5]:

$$E_{\tan k}(t) = E_{\tan k}(t-1) + \left(P_{EL-\tan k} - \frac{P_{HT}(t)}{\eta_{storage}} \right) \tag{8}$$

where P_{HT} is the power transfered to the fuel cell. Here, it is assumed the hydrogen tanks efficiency is 98%. Meanwhile, the mass of stored hydrogen, at any time step t, is calculated as follows [5]:

$$m_{\tan k}(t) = \left(\frac{E_{\tan k}(t)}{HHV_{H_2}} \right) \tag{9}$$

Where, the Higher Heating Value (HHV) of hydrogen is equal to 39.7kWh/kg. The energy stored in the hydrogen tanks cannot exceed the constraint as follows [5]:

$$E_{\text{tank},\min} \le E_{\tan k}(t) \le E_{\text{tank},\max} \tag{10}$$

3.5. Fuel-Cell

Fuel-cells are electrochemical devices to convert the chemical energy of a reaction directly in to electrical energy. The output power produced by fuel-cell can be determined by multiplying its input power and efficiency (η_{FC}). In this case the efficiency of fuel-cell is assumed to be 50% [5].

$$P_{FC-inv} = P_{\tan k-FC}\ x\ \eta_{FC} \tag{11}$$

3.6. Inverter

Inverter is an electrical device to convert electrical power from DC into AC form at the desired frequency of the load [5].

$$P_{INV-L} = (P_{FC} + P_{INV}) \cdot \eta_{inv} \tag{12}$$

where η_{inv} is inverter efficiency.

4. Reliability and Objective Function

In this study, the objective function is the annual cost of system (ACS). Meanwhile, all economical components can be seen at Table 2. The ACS model is suitable to find the best benchmark of cost analysis. Annual cost of system convert the annual capital cost (ACC), annual operation maintenance (AOM), annual replacement cost (ARC) and annual customer damage cost (ADC). The components to be considered are windturbine, micro-hydro, electrolyzer, hydrogen tank, fuel-cell and inverter. ACS is calculated in the following equation [1]:

$$ACS = ACC + AOM + ARC + ADC \tag{13}$$

Annual capital cost of each unit that does not need replacement during project lifetime is calculated as follows:

$$ACS = C_{cap}\ CRF(i, y) \tag{14}$$

where C_{cap} is the capital cost of each component in US\$, y is the project lifetime in year. CRF is capital recovery factor, a ratio to calculate the present value of a series of equal annual cash flows. This factor is calculated as follows:

$$CRF = \frac{i(i+1)^y}{(1+i)^y - 1} \tag{15}$$

where i is the annual real interest rate. The annual real interest rate includes the nominal interest and annual inflation rates. This rate is calculated as follows:

$$i = \frac{(i' - f)}{(1+f)} \tag{16}$$

where i' is the loan interest and f is the annual inflation rate. The annual operation and maintenance cost of the system (AOM) as a function of capital cost, reliability of components λ and their lifetime can be determined using the following equation:

$$AOM = C_{cap}(1-\lambda)/y \tag{17}$$

ARC is the annual cost value for replacing units during the project lifetime. Economically, annual replacement cost is calculated using the following equation:

$$ARC = C_{rep} SFF(i, y_{rep}) \tag{18}$$

where C_{rep} is the replacement cost of fuel cell and electrolyzer in US$, y_{rep} is the lifetime of electrolyzer and fuel cell in year. In this case the replacement cost of battery banks is similar to its capital cost. SFF is the sinking fund factor, a ratio to calculate the future value of a series of equal annual cash flows. This factor is calculated as follows:

$$SFF = \frac{i}{(i+1)^{y} - 1} \tag{19}$$

Table 2.Technical and economical specification

Variables	value
Nominal interest rate *i'* (%)	8.25
Inflation rate *f* (%)	8.17
Project Lifetime (years)	20
Wind turbines lifetime (years)	20
Hydrogen tanks lifetime (years)	20
Electrolyzer lifetime (years)	10
Fuel cell lifetime (years)	10
Inverter lifetime (years)	20
Cost of Hydrogen (US$/kW)	1,500
Cost of electrolyzer (US$)	2,000
Cost of fuel-cell (US$)	3,000
Cost of micro-hydro (US$/kW)	4,000
Cost of wind turbine of 100 kW (US$)	1,000,000
Cost of inverter (US$/kW)	800

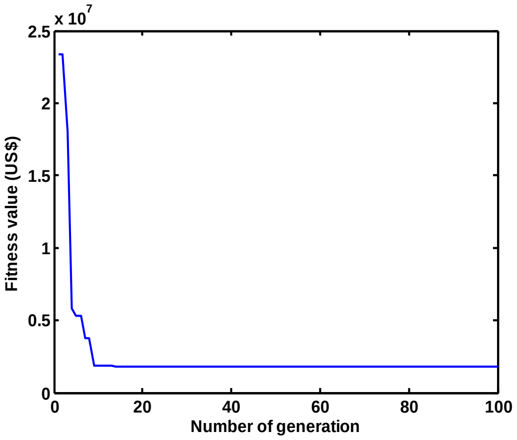

Figure 6: Optimization process using GA

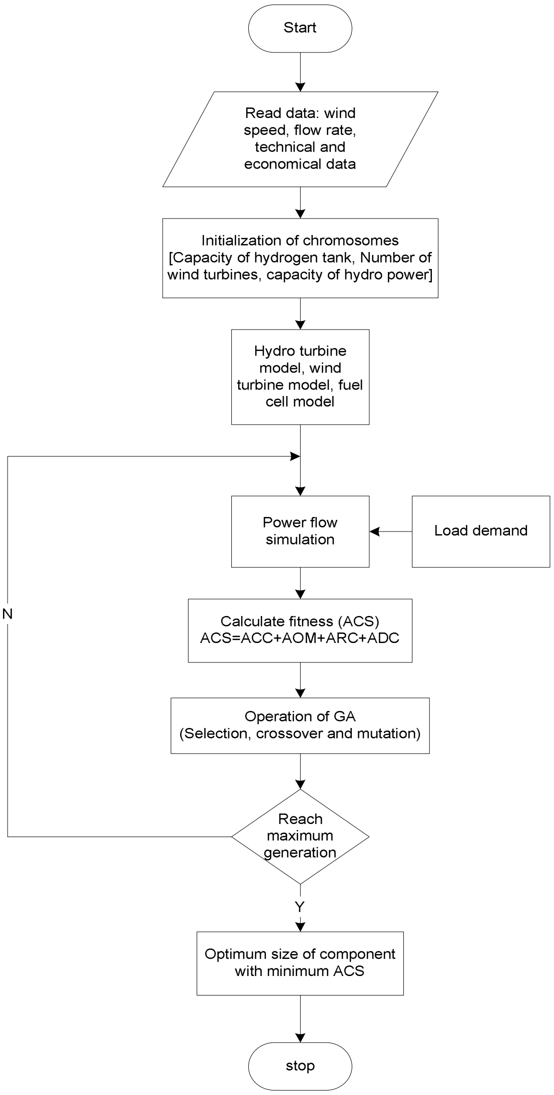

Figure 5.Optimization process using Genetic Algorithm

5. Optimization Procedure using Genetic Algorithm

Simulation method utilizes genetic algorithm (GA) to determine the optimal sizing of the hybrid system. The concept of GA is different from traditional search and optimization method used to solve the engineering problems. The basic idea of GA is taken from genetic process in biology that used artificially to build search algorithms. This technique is introduced to find the optimal solution based on natural selection. The main objective of the proposed method is to find the optimum size of hydrogen tanks, number of wind turbines and number of micro-hydro.

To process this study, the annual data of flow rate of river, wind speed and load demand are initially set as the inputs. Then, the size of hydrogen tanks, wind turbines and micro-hydro are randomly chosen to become the GA chromosomes. Each chromosome consists of three genes in form of [N_{HyT}, N_{WT}, N_{Hyd}]; where N_{HyT} is the number of hydrogen tanks, N_{WT} is the number of wind turbines and N_{Hyd} is number of micro-hydro. After setting the initial population, the annual power supply simulations are performed. The simulations of annual power supply are repeated for each chromosome until it reaches the final generation as defined in the beginning of the simulation process. Each generation of the best chromosome is preserved and compared with the best chromosome obtained from the next generation. The best chromosome in the final generation is considered as the optimum parameter value of the hybrid system. In order to select the chromosomes subjected to the crossover and mutation for processing the next generation population, the roulette wheel method is considered as the selection process. In this simulation, the crossover and mutation probability are assumed as 0.75 and 0.015, respectively

The convergence curves of the GA for the system under study is shown in Figure 6. It can be seen that the optimal values can be obtained closed to 70 generations. Hence, 100 iterations can be considered as a fair termination criterion.

6. Results and Analysis

Table 3 depicts the capacity of each component that was optimized using GA (method 1) and trial and error (method 2). The optimum system size will be implemented in Leuwijawa hybrid power system, located in Central Java, Indonesia. The cost element of the optimum system using Genetic Algorithm is presented in Figure 7.

Table 3.The main component of the generating capacity of hybrid

No	Component Type	Capacity	
		Method 1 (GA)	Method 2
1	Hydrogen Tank	19.85 tones	19.85 tones
2	Wind Power	21 unit x100 kW	23 unit x100 kW
3	Hydro Power	610 kW	400 kW

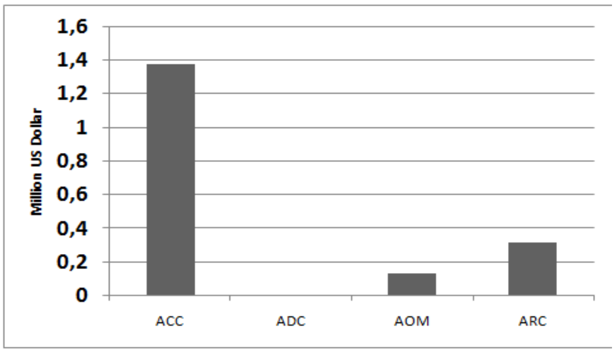

Figure 7.Cost element of proposed configuration

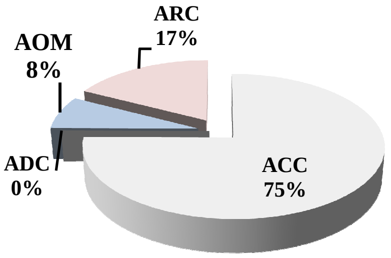

Figure 8. Percentages of each element cost

The optimum capacity of the components are, hydrogen tank of 19.85 tones, 21 wind turbine generator units each100k Wand micro-hydro power of 610kW. In this case overall cost to design such system is US$1.83 million. This cost composed of ACC ofUS$ 1.35 million, AOM of US$ 0.14 million and ARC isUS$0.3 million and requires no annual cost for ADC.These results can be seen in the Figure 8. This figure, depicting the percentage of the cost of each part of the cost is; annual capital cost=75%, annual peration and maintenance= 8 %, annual replacement cost=17% and annual customer damage cost=0% interruption the value is zero. It means that the proposed configuration has 100% reliability.

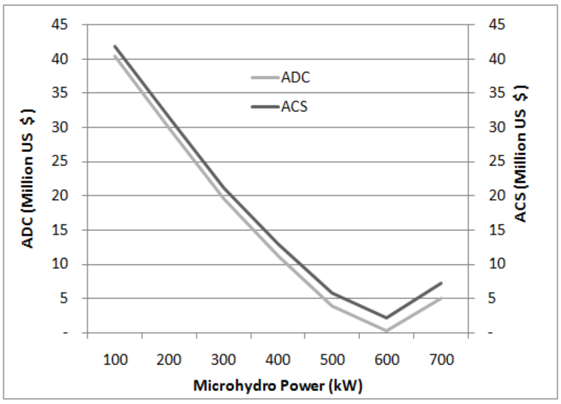

Figure 9. Optimization for Micro-hydro PowerVs ADC and ACS

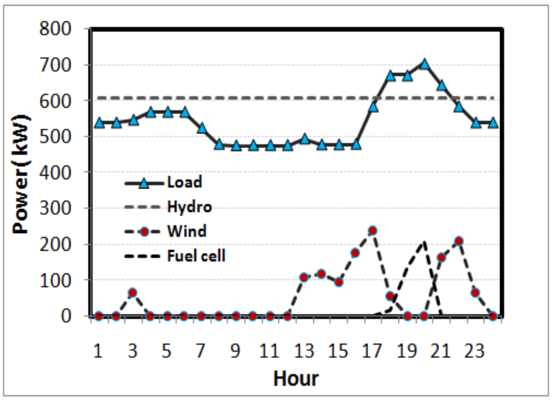

Figure 10. Operation of each power system in 24 hour

Figure 9 illustrates the optimum condition provided by genetic algorithm that the Micro-hydro size is 610 kW. Other components are 21 units of wind turbine with each capacity is 100 kW,the annual cost of systemis US$ 2.08 million.In this condition, the cost for annual customer damage is zero. However, the annual capital cost of method 2 was found as US$ 12.83 million

Figure 10 demonstrates the daily profile of optimum component sizes to meet the load. The micro-hydro supplies constantly at 610 kW for 24 hour. When the load is lower the micro-hydro power, the remaining energy is for producing hydrogen whilethe fuel-cell does not supply any power to the load. Then, during the peak load, the fuel-cell contributes power to the load, sharing with the micro-hydro.

7. Conclusion

Intelligence method by mean of genetic algorithm has been successfully tested to find the optimal size of hydrogen, wind turbines and micro-hydro system for remote island application. The simulation resultsachieving an optimum configuration consist of 19.85 Tons of hydrogen tanks, 610kW of micro-hydro unit and 21 units of wind turbine with each capacity is 100kW. The annual cost of system isUS$ 2.08 million, while the annual capital cost is US$ 1.35 million.This system is planned to be used for electrification in the Leuwijawa village Central Java, Indonesia.

References

[1] H Suryoatmojo, AA Elbaset, T Hiyama. Economic and Reliability Evaluation of Wind-Diesel-Battery System for Isolated Island Considering CO_2 Emission. *IEEJ Trans. PE.* 2009; 129 (8): 1000-1008.
[2] Doaa M Atia, Faten H Fahmy, Ninet M Ahmed, Hassen T Dorrah. Modeling and Control PV-Wind Hybrid System Based On Fuzzy Logic Control Technique.*TELKOMNIKA.* 2012; 10(3): 431-441.
[3] H Suryoatmojo, T Hiyama, AA. Elbaset, M Ashari. Optimal Design of Wind-PV-Diesel-Battery System using Genetic Algorithm. *IEEJ Trans.PE.*2009; 129(3): 413-420.
[4] Mithun M Bhaskar, Sydulu Maheswarapu. A Hybrid Genetic Algorithm Approach for Optimal Power Flow. *TELKOMNIKA.* 2011; 9(2): 211-216.
[5] A Kashefi Kaviani, GH Riahy, SHM Kouhsari. Optimal Design of A Reliable Hydrogen-Based Stand-Alone Wind/PV Generating System Considering Component Outages. *Renewable Energy.* 2009; 34: 2380-2390.
[6] R Dufo Lopez, JL Bernal-Agustin. Design and Control Strategies of PV-Diesel Systems using Genetic Algorithms. *Solar energy.* 2005; 79: 33-46.
[7] New Distribution Process for NREL's HOMER Model, https://analysis.nrel.gov/homer/