Hybrid renewable energy generation planning for isolated microgrid in Indonesia with metaheuristic approach

by Ys Akil

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Abstract. *This paper presents an optimal planning for the configuration of a hybrid microgrid generating system based on the results of renewable energy potentials, which are photovoltaic (PV), wind turbine (WT), micro-hydro (MH) and batteries. Battle Star Galactica Starcraft Particle Swarm Optimization (BSG-Starcraft PSO) algorithm is used to determine the optimal generation size based on the local energy potential. The case study is located in an isolated area, namely Tangkeno area of Kabaena Island, Bombana Regency, Southeast Sulawesi, Indonesia which is used to verify the proposed method. The optimization results for this study are number of wind turbine (WT) required is 27 units with capacity of 180 Watt each and total capacity of 4.86 kW the number of solar panel (PV) needed is 231 units with capacity of 195 Watt each and total capacity of 44.85 kW. Hence the total capacity for renewable energy generation is 49.73 kW. The results of the comparison between the BSG-Starcraft PSO algorithm and PSO showed that by using the BSG-Starcraft PSO provided optimal and faster solution compare to PSO.*

Streszczenie. *W artykule przedstawiono optymalne planowanie konfiguracji hybrydowego systemu wytwarzania mikrosieci w oparciu o wyniki potencjałów energii odnawialnej, którymi są fotowoltaika (PV), turbina wiatrowa (WT), mikrohydro (MH) i akumulatory. Algorytm Battle Star Galactica Starcraft Particle Swarm Optimization (BSG-Starcraft PSO) służy do określenia optymalnej wielkości generacji w oparciu o lokalny potencjał energetyczny. Studium przypadku znajduje się na odosobnionym obszarze, a mianowicie obszarze Tangkeno na wyspie Kabaena, Bombana Regency, południowo-wschodnie Sulawesi, Indonezja, który służy do weryfikacji proponowanej metody. Wyniki optymalizacji dla tego badania to liczba wymaganych turbin wiatrowych (WT) to 27 jednostek o mocy 180 W każda i łącznej mocy 4,86 kW liczba potrzebnych paneli słonecznych (PV) to 231 jednostek o mocy 195 W każda i całkowita moc 44,85 kW. Stąd łączna moc wytwarzania energii odnawialnej wynosi 49,73 kW. Wyniki porównania algorytmu BSG-Starcraft PSO i PSO wykazały, że zastosowanie BSG-Starcraft PSO zapewniło optymalne i szybsze rozwiązanie w porównaniu do PSO.* (***Hybrydowe planowanie wytwarzania energii odnawialnej dla izolowanej mikrosieci w Indonezji z podejściem metaheurystycznym***)

Keywords: Microgrid, renewable energy, BSG-Starcraft PSO algorithm
Słowa kluczowe: mikrosieć, energia odnawialna, hybrydowe wytwarzanie energii.

Introduction

A microgrid is a power generation technology system that uses several renewable energies [1] such as wind turbines, solar energy, and batteries as energy storage [2, 3]. Basically microgrid system can be seen as future electricity generation system because a microgrid system combines several types of generation from renewable energy that does not cause air pollutions [4-6]. Therefore, development of microgrid technology is expected to be a solution to handle development of electrical energy in remote areas and island areas by using local renewable energy sources to meet electrical energy needs in related area [7-9].

Previous researchers have carried out many different studies on microgrid using diesel generation. However diesel generation which used fuel is generally known inefficient due ton some factors such as operating cost is expensive and also not environmentally friendly [10-12]. The goal of this research is about optimal sizing to select the size that is the best for hybrid energy generation isolated microgrid by using BSG-Starcraft PSO. The method is tested for an island in Indonesia, that is Tangkeno area in Kabaena Island.

There are many optimization methods have been developed to improve quality of microgrid system such as searching optimal sizing for hybrid generation. For example, Sasidhar and Kumar studied concerning optimal sizing for PV-wind energy system by using Genetic Algorithm (GA) and PSO [13]. Alawani and Kimball studied optimal sizing for designing a microgrid system which consist of wind/solar/battery by using forever power method [14]. Next Samy et al. conducted study by using Flower Pollination Optimization (FPO) algorithm for an off-grid PV-fuel cell hybrid renewable system [15].

In this paper, BSG-Starcraft PSO method is proposed to get best solution for Tangkeno area of Kabaena Island, South East Sulawesi, Indonesia to calculate amount generation renewable energy sources optimally based on existing potential. Development of the application of algorithms for calculating optimal sizing in using renewable energy plants for microgrid especially in isolated areas very suitable for many places including in Indonesia [16].

Microgrid system

A microgrid system connects several generations from different renewable energies to generate electrical energy. Microgrid generation system in this study is designed without diesel generators as shown in Fig. 1. The microgrid system contains an inverter that convert DC electrical energy sources from photovoltaic, wind and micro-hydro energy to use AC electrical energy, then the excess energy generated is stored in the battery to be used during peak load hours.

Microgrid configuration system

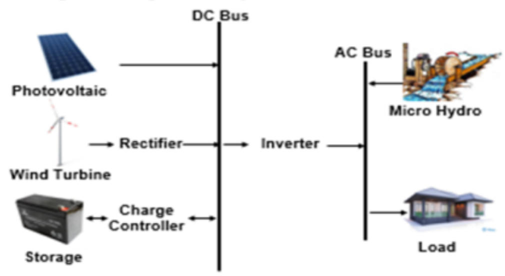

Fig. 1. Proposed microgrid system.

As can be seen from Fig.1, developed microgrid system consists of PV, wind turbine, and micro-hydro as main energy source for system, and batteries to store energy with intention to ensure uninterrupted power supply when production of energy electricity from main sources is deficit.

Renewable energy generation such as wind turbine, micro-hydro, and PV panels are installed for hybrid power generation. The charger controller functions to control the generator capacity installed on the microgrid system. The PV panels and wind turbines are connected to DC bus then the bus inverter is connected to AC bus. Micro-hydro power plants connected the AC bus supply electricity into the system [17,18].

Electrical load profile

The main daily load in the Tangkeno area for electricity consumption needed by the community consists of housing, schools, health office, mosque, and village office. In general, loads are used for lighting loads and other electrical equipment. The load profile for Tangkeno area can be seen in Table 1. It shows distribution of hourly electrical load according to existing consumers. Next, Table 2 provides information concerning electricity energy consumption according to the unit and type of used equipments. As can be seen from Table 2, total energy consumption per day is 537,070 Wh therefore total energy consumption in one month is 16,112,100 Wh, and one year amounted is 193,345,200 Wh

Fig. 2 shows the profile consumption daily according to load demand. The daily consumption profile varies according to the load. The profile consumption informs a 24 hours the day with the highest consumed day between hour 18 to 22.

Table1. Electricityneeds for Tangkeno area

Facility	Number of Unit	Power Needs (W)	Total Power (W)
Houses	170	450	76,500
Elementary school	1	450	450
Junior high school	1	450	450
Health center for community	1	900	900
Mosque	1	900	900
Village office	1	900	900
		Total	80,100 W
			80 kW

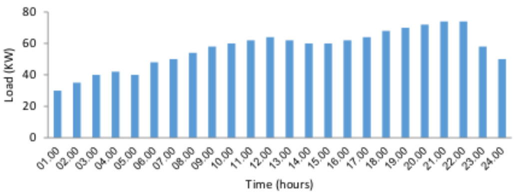

Fig. 2. Load profile.

Table 2. Power of day for Tangkeno area

No	Unit	Type of Equipment	Quantity	Multiplier	Power (W)	Average Usage (hour)	Energy Comsumption (Wh)
1	Residental houses	General room lights	4	170	20	12	163,200
		Special room lights	3	170	10	12	61,200
		Television	1	150	100	12	180,000
		Fan	1	170	80	4	54.400
		Iron	1	170	150	2	51,000
		Radio	1	170	30	4	20,400
2	Elementary school	Lamp	7	1	20	8	1,120
		Fan	1	1	80	4	320
		Speaker Set	1	1	100	1	100
3	Junior high school	Lamp	7	1	20	8	1,120
		Fan	1	1	80	4	320
		Speaker set	1	1	100	1	100
4	Public health center	Lamp	4	1	20	8	640
		Iron	1	1	80	4	320
		Medical tools	1	1	350	1	350
5	Village office	Lamp	4	1	20	8	640
		Iron	1	1	80	4	320
		Equipment electrical	1	1	350	1	350
6	Mosque	Lamp	3	1	20	10	600
		Iron	1	1	80	4	320
		Radio	1	1	30	5	150
		Speaker set	1	1	100	5	500
						Total	537,070

Solar photovoltaic panel

Photovoltaic is a source of renewable energy power generation that converts energy from sunlight into electrical energy without producing gas emissions. The power of PV is highly dependent on solar radiation conditions and temperature [19-22]. The parameters to the PV module, PV will be tested on a standard test condition (STC) which occurs when the PV radiation conditions are 1000 W/m^2 and the conditions are at a cell temperature of 25 °C. The output power for PV panel is based on Eq. (1) [23].

$$P_{PV} = \eta_{PV} A I_r(t)[1 - 0.005(T_o(t) - 25] \; \forall t > 0 \quad (1)$$

where Ppv is the output power of the module when radiation (W), ηPV is panel efficiency (%), A is surface area of the solar panel (m^2), I_r is actual radiation (W/m^2). The cell temperature is in °C.

Wind turbine

A wind power plant is a power plant that converts wind power into electricity. The wind that blows towards the wind turbine will move the fan and will rotate the generator producing electrical energy. The power generated in the generator depends on existing wind speed to rotate wind turbine. The calculation of wind speed output power is given in Eq. (2) [24].

$$P_{Wind} = \frac{1}{2}\rho A C_P V_{Wind}^3 \quad (2)$$

where P_{Wind} is output power for wind turbine (W), ρ is air density (kg/m^3). Meanwhile A is the swept area for wind turbine blades, C_p is wind efficiency turbine, and V_{wind} is wind speed (m/s).

Microhydro

Microhydro power plants convert the potential of energy of hydropower into electrical energy by utilizing a stream of water in the form of a river that has a water discharge and a high head which can produce electrical energy. Determination of potential power generated is as follows [25,26].

$$P_{MH} = g.\eta.h.Q\ \text{design} \quad (3)$$

where P_{MH} is output nominal power (kW), g is acceleration of gravity (m/s^2), η is efficiency, h is the gross head (m), and Q_{design} is water flow (m^3/s).

Battery

The battery converts chemical energy into electrical energy. The battery serves to store electrical energy. When energy produces from renewable energy is more than the energy supplied to the load, then energy will be stored in battery. Next if energy produced from renewable energy is not enough, the battery will supply the load. Determination of battery capacity is as in Eq. (4) [27].

$$Batteray\ Capacity\ (Ah) = \frac{ELoad\ xDays\ of\ outonom}{DODx\ \eta bat\ x\ Vbat-nom} \quad (4)$$

Where $\text{Days of outonom} = 4$, $\text{DOD}_{\max} = 0{,}75$, efficiency battery = 0,85 , $V_{bat-nom} = 12$.
The number of batteries required iscomputed by using Eq. (5) [28].

$$Nba = \frac{Batteraycapacity}{nominalbatteraycapacity} \quad (5)$$

The inverter is a power electronic circuit used to convert or change direct voltage (DC). The inverter capacity can be calculated by considering the addition of 15% of the power capacity served by assuming an inverter efficiency value of 0.95. The inverter capacity can be determined by using Eq. (6)[28].

$$Pinv = \frac{Ppeak - Loadx1{,}15}{\eta nv} \quad (6)$$

If electrictity production of microgrid is higher than load, power can be stored in the battery. However, characteristic of battery is affected by State Of Charge (SOC) condition. For SOC battery, if SOC = 0 then the battery is empty, and if SOC = 100% then the battery is full.The process of charging and discharging the battery must consider the constraints of the battery $SOC_{min} \leq SOC \leq SOC_{max}$. Usually values are limited to a value of 20%≤ SOC≤80% to protect battery from damage and battery life.

Optimal sizing method

The study obtains the optimal size of a generation consisting of solar panels, wind turbines and micro-hydro power plants by using BSG-Starcraft PSO [29,30].

Objective functions

This study aims to optimize developed microgrid system for Tangkeno area which consist of PV and wind turbine. Therefore it is needed to determine the amount of hybrid power generated from PV unit and wind turbine to fulfill load demand namely 50 kW (as 30 kW is supplied by micro-hydro system) by using Eq. (7) [31].

$$P_{CG} = N_{WT}P_{WT} + N_{PV}P_{PV} \quad (7)$$

where P_{CG} is the total power wind turbine and PV. N_{WT} is number of wind turbine, meanwhile P_{WT} is the amount of power generated by the wind turbine. N_{PV} is the number of solar panels, P_{PV} is the amount of power generated by solar panels.

Constraint

The constraint to be considered in optimization is the power balance. By referring to objective function main constraint is minimum and maximum scale from combined power generation. The study is to design a minimum limits variable to guarantee the complete system hybrid renewable supply to load, and the maximum limits are calculated for each power resource to fulfill load demand as formulated in Eqs. (8) and (9) [31].

$$N_{PV}^{min} \leq P_{PV} \leq N_{PV}^{max} \quad (8)$$

$$N_{wt}^{min} \leq P_{wt} \leq N_{wt}^{max} \quad (9)$$

Where N_{PV} and N_{wt} represent number of photovoltaic and wind turbine units respectively.

BSG-Starcraft PSO

BSG-Starcraft PSO method is a meta-heuristic algorithm which is used to optimize the size of renewable energy plants in this paper. The development of this algorithm is the based on PSO.To obtain the best value solution, application of BSG-Starcraft PSO algorithm is done through several steps [32].The first step is the position, velocity, and weight of inertia on all particles in the set that are initialized. The position and velocity of particle *i*in iteration *j* in the *n*-dimensional search space are as follows.

$x_i^j = (x_{i,1}^j, x_{i,2}^j \ldots, x_{i,n}^j) = (p_1, p_2, \ldots, p_n)$ and $v_i^j = (v_{i,1}^j, v \ldots, v_{i,n}^j)$.

The initial position x_i^0 and velocity v_i^0 are randomly generated particles within the range defined below:

$$x_i^0 = x_{min} + \text{rand}(x_{max} - x_{\min}) \quad (10)$$

$$v_i^0 = v_{min} + \text{rand}(v_{max} - v_{\min}) \quad (11)$$

where $x_{\min}$ and x_{max}values are maximun and minimum of random positions x respectively. The value at v_{max} is the maximum velocity v and $v_{\min}$ is the minimum velocity v randomly of values of v. Weight inertia (w) is calculated as in Eq. (12)

$$w^j = w_{max} - j\left(\frac{w_{max} - w_{min}}{j_{max}}\right) \quad (12)$$

where w_{max} and w_{min} are the maximum and minimum values, respectively.

The second step is to find the best position of particle *i* from P_{best} and the best position G_{best} and to find the smallest value of P_{best} for the best value determined by G_{best}. The smallest value of the P_{best},*i* is the best solution of G_{best}.

The third step is to determine the value of G_{best}as the operator X carrier. The X carrier iteration to send some articles called raptors with a probability of 0.9. At position *k* in iteration *j* in the search space with the equation below.

(13) $$\Delta p^{j}_{raptor,k} = \Sigma^{n}_{i=1}\sqrt{(P_{CG,k} - P_{l,j})^2}$$

where *n* the number of raptors. When the raptor is at a better position than the X carrier, this condition become with a vector jump. The best position the raptor will be the solution for optimization.

Next, the fourth and fifth steps are finding the best solution of the position and velocity of particle *i* according to the procedure as below.

(14) $$x_i^{j+1} = x_i^j + v_i^{j+1}$$

(15) $$v_i^{j+1} = w^j v_1^j + c_1 r_1 (P_{Best,j} - x_i^j) + c_2 r_2 (G_{Best} - x_i^j)$$

where c_1 and c_2 are vectors of self-confidence and swarm factors, r_1 and r_2 are random of numbers between 0 and 1. Parameters according to the BSG-Starcraft PSO are used to get the optimal solution. The number of particles and raptors in the iteration setting of 30 the maximum and minimum inertia weight between 0.4 and 0.9. The c_1 is 1.5 and c_2 is 2. The iterations running on the program are 20 for optimal sizing of wind turbines and solar panels using BSG-Starcraft PSO.

Figure 3 shows the flowchart of BSG-Starcraft PSO. The first step of the algorithm determines parameters such as

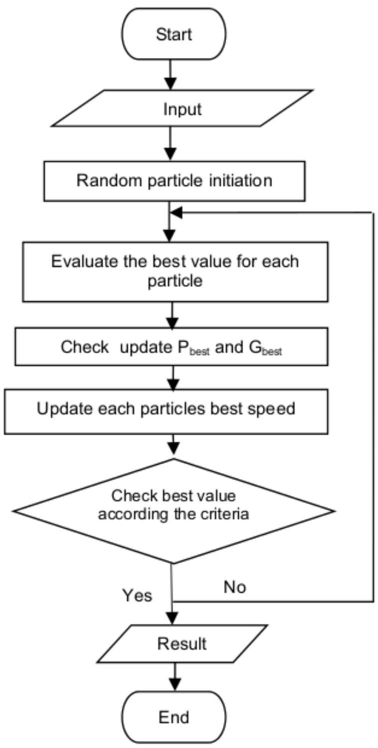

Fig. 3. Flowchart BSG-Starcraft PSO.

population size, particle dimension, and maximum iteration that are initialized. The second step evaluates the fitness value for each particle and the best value to records P_{best} and G_{best}. The third step updates particle using the BSG-Starcraft PSO formula. The algorithm terminates and gives the output optimal if the algorithm reaches the best value of the criteria. Otherwise, the algorithm iterates again to the second step.

Discussion and analysis

The potential data for renewable energy in the Tangkeno area of Kabaena Island, Indonesia was taken from NASA [33]. For Tangkeno the latitude is 5°1557.21°S, whereas longitude is 121° 5711.04° E.The total load is 80 kW. The used PV panel and wind turbine are given in the Table 3 and Table 4.

Table 3. PV panel data

Type power source	PV Panel
Type PV	Polycristaline
Power	300 W
NOTC	45°
Isc	0.27 A
A_{PV}	1.9433 m

Table 4. Wind turbine data

Type power source	Wind generator
Power	500 W
Starting wind speed	1 m/s
Wind speed rating	10 m/s
Working at wind speed	1-25 m/s

Figures 4-6 show typical values for wind speed (m/s), temperature (°C), and solar irradiation (kWh/m^2) in the studied area for year 2016, respectively. Meanwhile Fig. 7 shows electric power generated from wind turbine and Fig. 8 from PV system. Based on the data, simulation is done by using BSG-Starcraft PSO method to find optimal configuration for the developed microgrid system. Next, obtained result is compared with PSO method to examine performance of the proposed algorithm as seen in Table 5. Convergence processes for the two methods are given in Figs. 9 and 10.

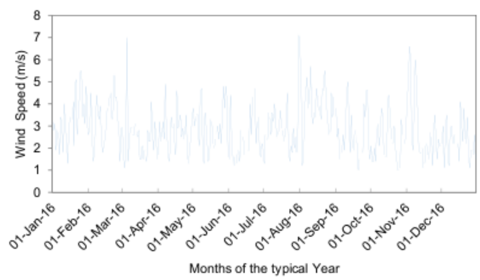

Fig. 4. Typical wind speed in the studied area.

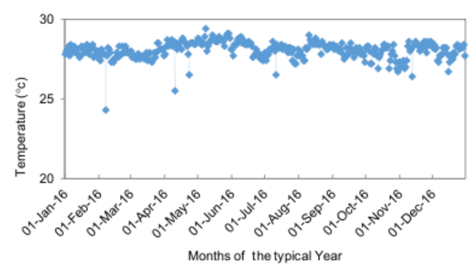

Fig. 5. Typical temperature values in the studied area.

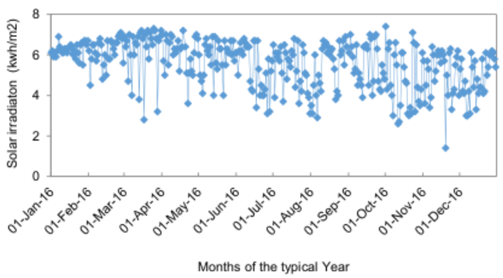

Fig. 6. Variation of solar radiation values.

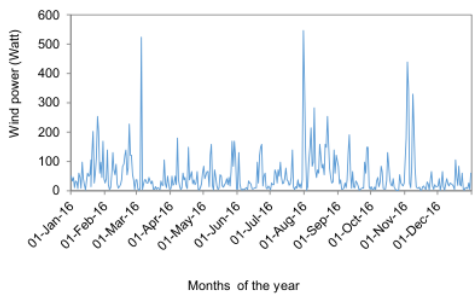

Fig. 7. Wind electrical power output at Tangkeno.

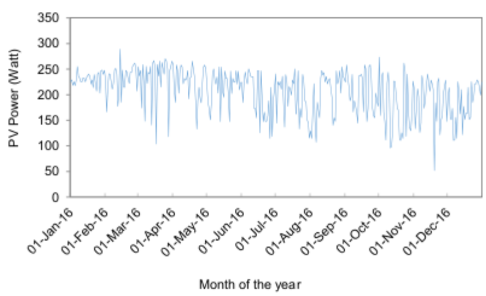

Fig. 8. Solar irradiation electrical power output at Tangkeno.

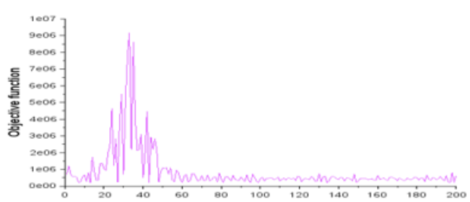

Fig. 9. The convergence process with PSO.

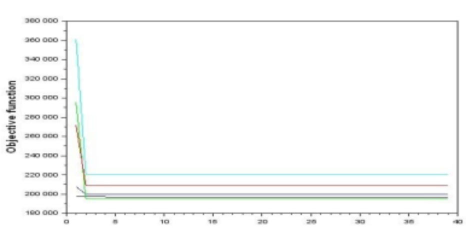

Fig. 10. The convergence process with the BSG-Starcraft PSO.

Table 5. Optimization results for PSO and BSG-Starcraft PSO

Algorithm	Number of WindTurbin (N_{wt})	Number of PV panels (N_{pv})	Power combined generation P_{max} (kW)
PSO	52.92	220.85	52.59
	53	221	
BSG-Starcraft PSO	26.89	230.62	49.73
	27	231	

From Table 5, optimal results for proposed method is 27 for number of wind turbine and 231 for number of PV panels which will produce power around 50 kW. Meanwhile for PSO method is 53 for number of wind turbine and 221 for PV panel with produced power around 53 kW. As the limit for microgrids is 50 kW, the results indicate that BSG-Stratcraf PSO is better than the conventional PSO algorithm. Next for backup, the capacity of used battery can be calculated as follows.

$$Cb = \frac{537{,}070\,x4}{0{,}75\,x\,0{,}85\,x12} = 280{,}828{,}0\;Ah$$

The battery capacity used is 280,828,0 Ah, number of batteries is 1404 units, and the converter capacity is based on the peak load of 89,678 kW or 90 kW.

Conclusion

This paper proposed a metaheuristic approach namely BSG-Starcraft PSO algorithm to find optimal solution in planning an isolated microgrid system to serve load for Tangkeno area of Kabaena Island, Indonesia which consists of photovoltaic (PV), wind turbine (WT), micro-hydro and battery as backup. To examine the performance of the proposed method, the result is compared with PSO algorithm. From simulation, BSG-Starcraft PSO algorithm gives better and faster solution than PSO method. It is found that to get optimal configuration to serve load around 50 kW in Tangkeno area, the number of wind turbine and PV panel needed for microgrid system is 27 and 231, respectively. Meanwhile the rest of the load (30 kW) will be served by micro-hydro generator. Basically, this system has reliability as it uses also a micro-hydro generator and has a battery as a backup in case of a lack of electric power produced by renewable energy sources in the system.

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