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Optimal hybrid renewable energy generation planning based on BSG-starcraft radius particle swarm optimization

***Abstract.**This paper develops a new methodology to find the optimal size of hybrid renewable energy plants in a microgrid. The power plants planned in the microgrid for this study are photovoltaic (PV) and wind turbines (WT). In this paper, a new method is proposed, the BSG-Starcraft Radius Particle Swarm Optimization (PSO) algorithm, to determine two design variables: the number of PV panels and the number of wind turbines (WT) for the microgrid system in Maginti Island, Indonesia as a case study. The BSG-Starcraft Radius PSO algorithm is an improved method of the BSG-Starcraft PSO algorithm. The results obtained indicate that the proposed method gives the best results because it provides a more optimal configuration than the BSG-Starcraft PSO algorithm. The simulation results show that by using the proposed method, the BSG-Starcraft Radius PSO method, the number of PV panels is 335 andthe number ofWT is 186 turbines units with a total load power of 80 kW, and the investment value must be spent using the proposed BSG-Starcraft Radius PSO is$352,761.1. In contrast, the investment for the microgrid planning using the BSG-Starcraft Radius PSO is$355,265.1*

***Streszczenie.** W niniejszym artykule opracowano nową metodologię znajdowania optymalnej wielkości hybrydowych elektrowni odnawialnych w mikrosieci. Elektrownie planowane w mikrosieci do tego badania to elektrownie fotowoltaiczne (PV) i turbiny wiatrowe (WT). W artykule zaproponowano nową metodę, algorytm BSG-Starcraft Radius Particle Swarm Optimization (PSO), do określenia dwóch zmiennych projektowych: liczby paneli fotowoltaicznych i liczby turbin wiatrowych (WT) dla systemu mikrosieci na wyspie Maginti , Indonezja jako studium przypadku. Algorytm BSG-Starcraft Radius PSO jest udoskonaloną metodą algorytmu BSG-Starcraft PSO. Uzyskane wyniki wskazują, że proponowana metoda daje najlepsze rezultaty, ponieważ zapewnia bardziej optymalną konfigurację niż algorytm BSG-Starcraft PSO. Wyniki symulacji pokazują, że przy zastosowaniu proponowanej metody BSG-Starcraft Radius PSO liczba paneli PV wynosi 335, a liczba WT to 186 jednostek turbin o łącznej mocy obciążenia 80 kW, a wartość inwestycji musi być wydatkowana przy użyciu proponowany BSG-Starcraft Radius PSO wynosi 352 761,1 USD. Natomiast inwestycja w planowanie mikrosieci z wykorzystaniem BSG-Starcraft Radius PSO wynosi 355 265,1 USD (**Optymalne planowanie wytwarzania hybrydowej energii odnawialnej w oparciu o optymalizację roju cząstek promienia BSG-starcraft**)*

Keywords:optimal hybrid renewble energy generation, microgrid, BSG-Starcraft Radius PSO
Słowa kluczowe: optymalizacja hybrydowego źróła energii, mikrosieć, algorytm PSO.

Introduction

The development of renewable energy generation is progressing rapidly throughout the world. However, a faster and more accurate optimization is needed to obtain the optimal generator configuration. Many researchers have researched the optimal size of renewable energy generation in microgrid systems [1,2]. Several optimization methods were used to improve performance of a microgrid system mainly to find size for optimal generations [3]. Sasidhar and Kumar designed the optimal size for photovoltaic (PV) and wind turbines (WT) energy systems using Genetic Algorithms (GA) and Particle Swarm Optimization(PSO) [4]. However, the weakness of GA is that there is uncertainty to produce a global optimum solution, and PSO reaches a local optimal too fast, which is not an optimal global result. Karrich and Kamel developed the Equilibrium Optimizer for the optimal design of Microgrid in Dakhla Marocco [5]. Fathy and Kanniche proposed a method based on the Social Spider Optimizer for the optimal design of a hybrid power plant in Aljouf, Saudi Arabia [6]. Alawani and Kimball studied the optimal size for designing a hybrid microgrid system using the Forever Power Method (FPM) [7]. Furthermore, Samy *et al.* applied Flower Pollination Algorithm (FPA) algorithm to optimize a renewable hybrid system off-grid PV fuel cells [8].

One of the most popular optimization methods is the PSO algorithm. This method is included in the bird-flock intelligence optimization techniques category. In addition, the optimization problem is considered a search space particle, which adjusts its position to search space based on the own and other perticles flying experiences. According to [9], the PSO algorithm has several parameters to be adjusted to facilitate its application. However, it has a weakness, such as it needed iterations to get the minimum global potential value, and it is straightforward to get trapped in the local optimal. In this regard, many researchers have developed PSO methods, one of which is BSG-Starcraft PSO. Salmon [10] has developed the BSG-Starcraft PSO algorithm based on the Inertial Weight Model. Subsequently, it was further developed into the BSG-Starcraft Radius PSO algorithm [11]. It introduces a minimum radius and stops or resets the iteration process if the swarm radius is less than the minimum radius.

This paper aims to find optimal size for photovoltaic (PV) and wind turbine (WT) for an isolated microgrid hybrid system using BSG-Starcraft Radius PSO algorithm. The method was tested for a microgrid on an island in Indonesia, namely Maginti Island, Southeast Sulawesi province. Here, we focus to determinethe number and size of PV and WT and comparing its results with the BSG-Starcraft PSO. The proposed method, the BSG-Starcraft Radius PSO, has proven its effectiveness. It is more optimal in providing a combination generation in terms of the number of PV and WT units with the cheapest investment costs for the same amount of load. Micrograds reduce green house gas emissions because it uses renewable resources[12].

The structure of this paper is organized as follows. Section 2 describes the planned microgrid system for the case study, Section 3 explains the proposed method, Section 4 provides results and discussions, and then conclusions are given in Section 5.

Planned Microgrid System for Maginti Island

The proposed scheme for a microgrid on the island of Maginti, Southeast Sulawesi, Indonesia, consists of PV, WT, and batteries connected to the DC bus and AC bus [13,14]. In the microgrid system, a converts DC electrical energy sources from the PV power [15,16] to apply AC electrical power. The excess energy produced by renewable energy is stored in batteries. For optimal power distribution, batteries will be used to reduce the intermittent effects of renewable energy as the primary energy resource.

Fig. 1. Proposed Maginti microgrid system

Photovoltaics

Photovoltaic system is a source of electrical energy that converts solar energy into DC electricity through solar panels [17,18]. The power output of photovoltaics is highly dependent on the area of the module, temperature and condition of solar radiation. Factor that apply to the PV panel will be check under normal conditions (STC) when the 1000 W/m^{2}is condition radiation PV panel, and the cell temperature is 25°C [19]. The equation for calculating the module's output power as follows [20],

(1) $$P_{pv} = \eta_{PV} AI(t)(1 - 0{,}005(T_o(t) - 25)\ \forall\ t > 0$$

where: P_{pv} is power production from panel based on radiation (W), η_{PV} is the effectiveness of the panel (%), A is the facepart of the solar module (m^2), I is the real radiation (W/m^2), T_o is the cell temperature in ^{o}C. The total amount of power generated by the installed PV can be calculated by knowing the output power of each PV unit multiplied by the number of PV as [21],

(2) $$P_{pvtot}(t) = P_{pv}(t) x N_{pv}(t)$$

where:$P_{pvtot}(t)$ is the total PV panel (W), $P_{pv}(t)$ is output power of one PV panel (W). $N_{pv}(t)$ is the quantity of PV panels to be installed. The electrical power released by PV panels can be calculated by taking into account solar radiation. Fig. 2 shows variation PV radiation value and Fig. 3 shows variation temperature values in Maginti.

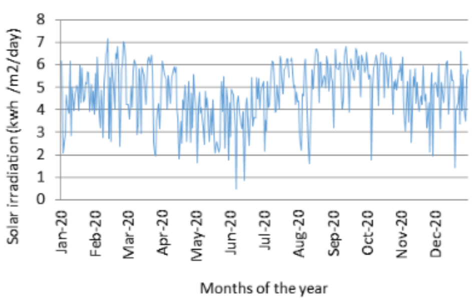

Fig.2. Variation of solar radiation value

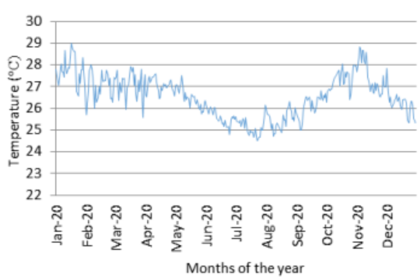

Fig. 3. Variation oftemperature value

Wind Turbine

In the last decade wind power has been integrated into the electric power system [22]. Output power for WT depend on the speed of wind, pressure, humadity and temperature as independent variables [23,24] that rotates the wind turbine as in Eq. (3) [25],

(3) $$P_{wt}(t) = \begin{cases} 0 & V(t) < V_{ci} \\ \frac{1}{2}.\rho.A.V^3.\eta_w & V_{ci} \le v(t) < V_r \\ P_{rated} & V_r \le v(t) \le V_{co} \\ V_{co} & v(t) > V_{co} \end{cases}$$

where:P_{rated} is the output power of the WT (W),V_{ci} is the cut-in (m/s), V_{co} is the cut-out speed (m/s), V_r is the wind speed rating (m/s), η_w is the wind efficiency turbine,ρ is air density (kg/m^3), A is swept area (m^2).

The total amount of power produced by the installed WT can be calculated by knowing the output power of each WT multiplied by the number of WT as in Eq. (4) [21],

(4) $$P_{WT\ tot}(t) = P_{wt}(t).N_{wt}(t)$$

where:$P_{WT\ tot}(t)$ is the total power of WT (W), $P_{wt}(t)$ is the output power of one WT (W), $N_{wt}(t)$ is the number of WT to be installed. Fig. 4 shows the typical wind speed in Maginti Island.

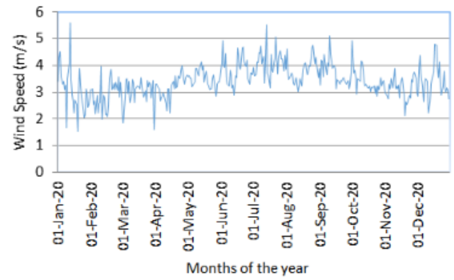

Fig.4. Variation wind speed in Maginti

Battery Energy Storage System (BESS)

In connection with increasing system reliability, it is planned that Battery Energy Storage System (BESS) will be connected to the microgrid system on Maginti Island. Its function is to balance the power input in a power shortage in renewable energy resources such as PV and WT panels. The charging time of the battery is determined by the power generated by the PV and WT. The battery capacity can be calculated by using Eq. (5) [26],

(5) $$C_{bat} = \frac{EL{-}day}{U_{sys}} H_{out}\ \frac{1}{DOD}$$

where: C_{bat} battery capacity (Ah), *EL-day* is load power demand per day (Vah), U_{sys} is DC voltage (V), H_{out} means autonomous day, DOD is Depth of Discharge (%).

Load profile

The use of electrical power on the island of Maginti is intended for the needs of every home. The design of the hybrid power system is used to meet the electricity needs of 178 housing units, with an electrical power capacity of 450 VA per house so that the total system load is 80,000 VA. The electricity consumption of each house is 530.20 watt-hours, and the peak load is 76 kW. Fig. 5 shows the daily load for electricity demand on Maginti Island.

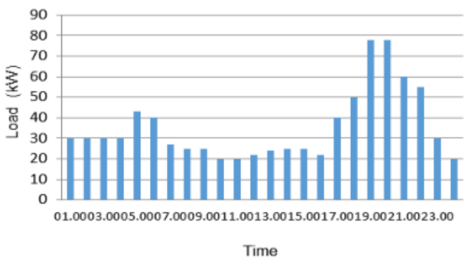

Fig. 5. Load profile in Maginti

Investment Cost Calculations

Because in the planning of a hybrid power plant, this research uses PV and WT, as for the investment costs that must be incurred for PV can be computed by using Eq. (6) as [21],

$$C_{PV} = \mathrm{N_{PV}} \,.\, \mathrm{Cost_{PV/Unit}} \tag{6}$$

where: C_{PV} is the cost of PV ($), N_{PV} is the number of PV installed (units), $Cost_{PV/Unit}$ is the price of PV per unit ($). While the investment costs that must be incurred for the WT is given by Eq. (7) as,

$$C_{WT} = \mathrm{N_{wt}} \,.\, \mathrm{Cost_{wt}/Unit} \tag{7}$$

where: C_{WT} is the WT cost ($), N_{wt} is the number of installed WT (units), $Cost_{wt}/Unit$ is the WT price per unit ($).Hence, the total cost for PV and WT can be calculated as follow,

$$C_{Total} = \mathrm{C_{PV}} + \mathrm{C_{wt}} \tag{8}$$

where: C_{Total} is the total generation cost ($), C_{PV} is the installed PV cost ($), C_{wt} is the installed WT cost ($).

Methodology

Hybrid Microgrid System Optimization

This study aims to obtain the optimal sizing value for new and renewable energy plants PV and WT according to the local energy potential that can be generated. To get the optimal value, we used the computational method of the BSG-Starcraft Radius PSO algorithms according to the objective function and constraints in running the optimization program, then compared its results with the BSG-Starcraft PSO.

Objective Function

The objective function of this research is to get optimal size for generator consisting of PVs and WTs. Several generators' amount of power capacity includes PV and WT as in Eq. (9) [27],

$$P_{CG} = N_{WT}P_{WT} + N_{PV}P_{PV} \tag{9}$$

where: P_{CG} is the power from the combine generation of PV and WT, N_{WT} is the amount of WT, P_{WT} is the amount of power produced by WTs, N_{PV} is the amount of PV moduls, P_{PV} is the amount of power generate by the PV module.

Constraints

Constraints in optimization need to be consider because they affect the controlstability. In this microgrid system, two types of energy sources are used: PV and WT. These generators have the maximum and minimum values shown in Eqs. (10) and (11) as follows [27],

$$N_{PV}^{min} \le N_{PV} \le N_{PV}^{max} \tag{10}$$

$$N_{wt}^{min} \le N_{wt} \le N_{wt}^{max} \tag{11}$$

where the min and max subscripts explain the minimum and maxmum limit values for PV and WT.

Particle Swarm Optimization (PSO)

The Particle Swarm Optimization (PSO) is a global heuristic optimization method that initializes the population randomly and then looks for the best value position which was developed in 1995 by Eberhart and Kennedy. The speed of each iteration and in the swarm will be updated following the position of the the previous best position (best i,j) in the best position with the global best *(best i, j)*. In the PSO algorithm, there are two updates, namely the speed function (v) and position (x), then the weight of inertia (w) as shown in Eqs. (12)-(14) [28],

$$v_{i,j}(t+1) = w.v_{i,j}(t) + c_1 .R_1\left(p_{besti,j} - x_{i,j}(t)\right) + c_2 .R_2\left(g_{besti,j}(t) - x_{i,j}(t)\right) \tag{12}$$

$$x_{i,j}(t+1) = x_{i,j}(t) + v_{i,j}(t+1) \tag{13}$$

$$w(t+1) = wmax - \left(\frac{wmax - wmin}{t_{max}}\right).(t+t) \tag{14}$$

where *i* is the particle index in the swarm (i = 1,....n), *n* is the size in population, *j* is the particle place index (j = 1,...m) *m* is the dimension size, t is the quantity of iterations, *v(i,j)* is velocity of the *i* particle. Meanwhile R_1 and R_2 are number values among 0 and 1, c_1 and c_2 are acceleration coefficients, and w values are positive inertia weights.

BSG-Starcraft PSO

Shi and Eberhart 1998 later developed this PSO method by modifying the velocity equation that can accelerate convergence by including a time-dependent variable called the Inertia Weight Model (IWM) [29],

$$v_{i,} + 1 = w_i.v_{i,} + R_1 .C_1(g - x_{i,}) + R_2 .C_2\,(p - x_i) \tag{15}$$

where $v_{i,}$ is the velocity of the –i particle, is the positive inertial weight (i=1,....n), *n* is the population size, R_1 and R_2 are number values among 0 and 1, c_1 and c_2 are acceleration coefficients.

BSG-Starcraft PSO is a optimization method that develops the PSO method based on the Inertia Weight Model and developed by S. Salmon in 2014. The BSG-Starcraft PSOmethod was developed based on two ideas from the Battle Star Galactica (BSG) film and the Starcraft video game, namely:

1. Particle leaders can randomly send new particles to explore space (raptors).
2. If a raptor gets the best position, the swarm jump will go to a new location.

This increase will be helpful when the initial herd is far from the optimal objective function value and is helpful in the evaluation stage. The flowchart of the BSG-Starcraft PSO algorithm can be seen in Fig. 6.

BSG-Starcraft Radius PSO

Salmon also developed the BSG-Starcraft Radius PSO method based on the IWM, which stops the iteration process if the swarm is too small. There are some limitations when optimizing natural systems, so there is no point in continuing with calculations while comparing particles with actual measuring equipment is impossible. The minimum radius is determined, and if the swarm radius is greater than the minimum, then the optimization calculation process can be continued. If the radius of one particle is less than the minimum radius, then iteration is reset, or calculation process is stopped. The BSG-Starcraft Radius PSO flowchart can be seen in Fig. 7.

Fig. 6. Flowchart of the BSG Starcraft PSO method

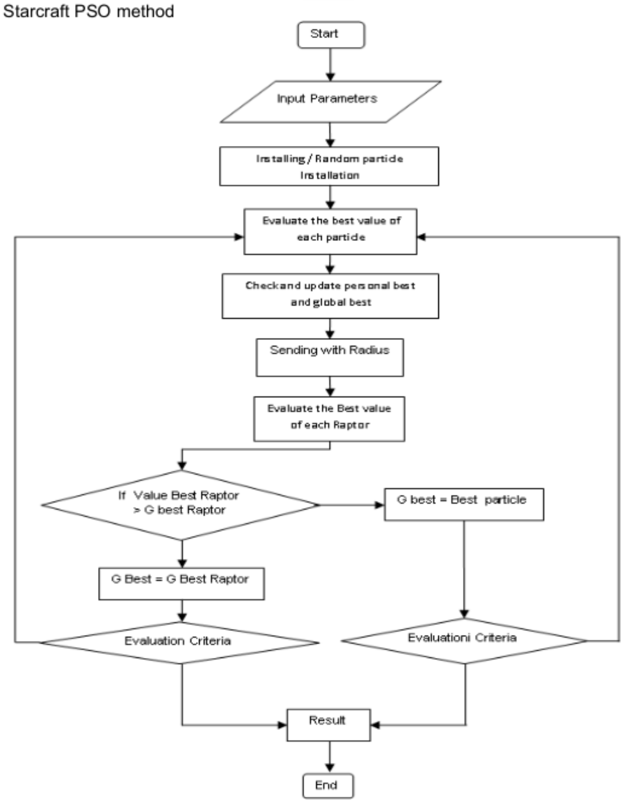

Fig. 7. Flowchart of the BSG-Starcraft Radius PSO method

Results and discussions

This study designs the number and size of PV and WT for a microgrid system on Maginti Island, Indonesia, as shown in Fig.1.The method used is the BSG-Starcraft Radius PSO then the calculation results are compared with the BSG-Starcraft PSO. Maginti Island is located northwest of Muna Island, bounded by the Tiworo Strait, precisely at a position of 122°11'34.09"-122°11'46.00° BT and 4°50'8.46"-4°50'6.73"LB East Longitude, Southeast Sulawesi Indonesia [30].Table 1 shows the component technical data for microgrid design on Maginti Island [31]. Here, only the number and size of PV and WT will be calculated through the optimization process of the BSG-Starcraft Radius PSO method, while the battery capacity can be calculated as,

$$C_{bat} = \frac{530{,}000}{48}\, 1\, \frac{1}{0{,}8} = 13807.29 \text{ Ah}$$

Table 1. Component of data the microgrid system [31]

Quantity	Conversion
Type PV Panel	Polycrystalline
Power PV Panel	300W
NOTC	45°
Isc	0.27A
A_{PV}	1.9433m
Regulator cost	$ 276,26
Source	Generator
Power	500 W
Wind-speed starting	1 m/s
Rating wind speed	10 m/s
Wind-speed working	1-25 m/s
Regulator cost	$ 1.399

The battery power used is 13807.29 Ah, hence the amount of batteries needed is 69 units, and the converter power at peak load is 92 kW.Total output power from PV and WT systems is calculated based on the powerrequirements. Fig. 8 shows solar irradiation, electrical power output at Maginti, and Fig. 9 shows power output of wind electrical at Maginti.

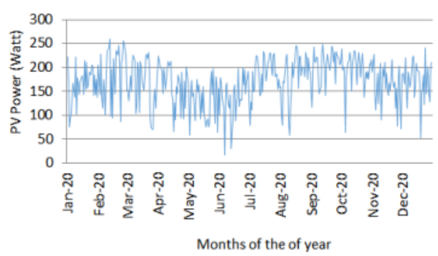

Fig. 8. Solar-irradiation electrical power output at Maginti

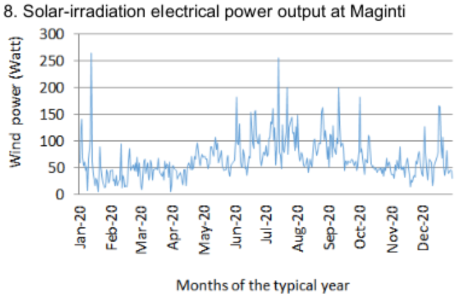

Fig.9. Wind electrical power output at Maginti

Fig.10 shows with the BSG-StarcraftPSO algorithm to the convergence process. The most favourable solution value, the parameters used include the number of particles and raptors in iterations is 20, the weight inertia of minimun is 0.4, the maximum value is 0.9. Then the value of c_1 is 1.5, and c_2 is 2.The number of iterations carried out once running on the program is 200. The total system load is 80 kW. Fig.11 shows the convergence process using the BSG-Starcraft Radius PSO method. The parameters used to obtain the optimal result value are the quantity of raptors and particles in iterations is 30. The minimum value of inertia weight is 0.4, the maximum value is 0.9, and the value of c_1 is 1.5. So that the particle does not go out of its radius, then c_2 is limited to a value of 2. The number of iterations carried out once running the program is 30. The total system load is also 80 kW.Table 2 shows optimizing the amount of PV and WT on the Maginti Island microgrid system using the proposed BSG-Starcraft Radius PSO and BSG-Starcraft PSO methods.

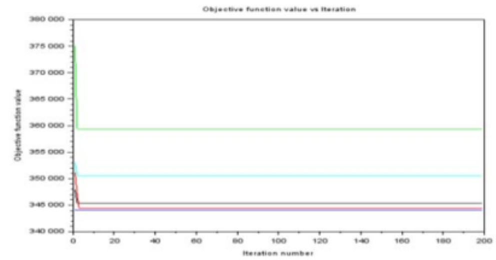

Fig.10. Convergence process with BSG Starcraft PSO

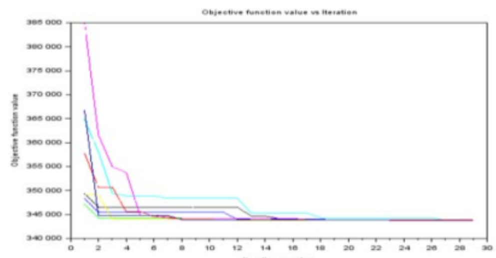

Fig.11. Convergence process with BSG Starcraft Radius PSO

Table 2 shows that in the Maginti area, the results obtained indicate that the proposed approach BSG-StarcraftRadius PSO algorithm provides the best solution because it provides the PV and WT configurations that are more optimal than the BSG-Starcraft PSO algorithm. From the calculation results, it is found that the amount of PV is 335 modules,the amount of WT is 186 turbine units with a total power of 80 kW using BSG-Starcraft Radius PSO. In comparison, the number of PV panels is 339 panels, and the number of WT of 187 turbine units with a total power of 81 kW was obtained using the BSG-Starcraft Radius PSO.

Table 2. Comparison of sizing optimization results between BSG-Starcraft PSO and BSG-Starcraft Radius PSO

Method	Amount of wind turbine units (Nwt)	Amount of photovoltaic panel units(Npv)	Total Nominal Power (kW)
BSG-Starcraft PSO	187	339	81
BSG-Starcraft Radius PSO (Proposed)	186	335	80

Based on Table 1, the price specifications per unit of PV and WT, the required investment costs based on optimal sizing results are obtained and summarized in Table 3.

Table 3. Investment costs for WT and PV plants.

Method	C_{WT} ($)	C_{PV} ($)	Total cost ($)
BSG-Starcraft PSO	26,1163	93,652.1	355,265.1
BSG-Starcraft Radius PSO (Proposed)	26,0214	92,547.1	352,761.1

Table 3 shows that the investment value incurred for the generation cost between PV and WT generators for the BSG-Starcraft PSO algorithm is $355,265.1, while with the BSG-Starcraft Radius PSO is $352,761.1. The investment value spent for optimal microgrid design using the proposed method BSG-Starcraft Radius PSO is lower than BSG-Starcraft PSO. Hence, it is proven that BSG-Starcraft Radius PSO is more optimal and effective in determining the optimal design.

Conclusions

This paper proposes a PV, WT, and battery microgrid design. Only the amount of PV and WT will be calculated through the optimization process in this study. BSG-Starcraft Radius PSO is planned to get optimal choice for the number of PV and WT panels. The simulation results show that the performance of BSG-Starcraft Radius PSO can solve complex problems. The method proposed is more effective and efficient than BSG Starcraft PSO. Optimization results with BSG Starcraft Radius PSO proposed 335 PV and 186 WT for a power configuration of 80 kW. At the same time, the number of PV panels is 339 panels, and the number of WT is 187 turbine units, with a total of 81 kW of power was obtained using the BSG-Starcraft PSO. The investment value that was spent on the cost of generating between PV and WT for the BSG-Starcraft PSO algorithm is $355,265.1,while the BSG-Starcraft Radius PSO is $352,761.1, which is cheaper than the BSG-Starcraft PSO algorithm.

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