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Optimal Design Of Stand Alone Hybrid PV / WTGS / Battery for Health Center Electricity System in Timor Leste

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Abstract—**The use of renewable energy sources as a power plant has become an alternative option to provide electrical energy sources in a health center in Timor Leste. In this study a standalone hybrid generator system design consisting of Photovoltaic (PV), Wind turbine generation system (WTGS) and battery as energy storage will be made. The PSO algorithm is used to design the optimal number of PV, WTGS and battery capacity to obtain economic value. The result are 16 PV units, 5 WTGS units and 22 battery units. The Optimal results are obtained by taking into account the potential of wind and solar energy and loads on the area. The application of hybrid generating systems with renewable energy sources has several problems that must be resolved. The energy generated by renewable energy power plants is intermittent. Then this system requires energy storage to achieve power balance. The simulation results in this study show how to get the optimal value by using PSO algoritm, to reach power balance with the optimal and economical design of generator and battery capacity.**

Keywords—Hybrid; PV; WTGS; Battery; Control, Optimal Sizing, PSO

I. Introduction

Increasing electricity demand in every year is the reason for the addition of generating units. Most generating units use fossil energy. So the limitation of fossil energy reserves is an important problem that must be resolved. Efforts to replace fossil energy have been carried out in stages with the use of existing and renewable energy potential. The availability of a variety of new and renewable energy sources is the main idea for hybrid power system technology to be developed.

The development of hybrid generator system technology has been carried out on various aspects of life [1]–[3]. In this study, the hybrid power plant system technology will be used to provide a source of electricity in the health center. The health center is an important place in the service of public health needs. The provision of electrical energy in the operational activities of health center and to support facilities and infrastructure is also the main reason for this hybrid system. The main energy source used comes from solar energy and wind energy. Both of these energies have considerable potential to be used in the Timor Leste region.

There are several problems found in this hybrid system. Some of these problems include intermittent and fluctuating energy sources. So we need a tool to be able to store the excess electrical energy produced and be able to supply electricity when there is a lack of energy [4], [5], so that power balance can be achieved. In addition, a good control system is needed to maintain system quality power conditions [6]–[8]. On the other hand, the cost of procurement of generating equipment is still expensive. Then it is necessary to estimate the number of generating units and their combinations to obtain economical prices and optimal, effective and efficient use.

In determining the estimated number of generating units and their combinations, conventional methods are usually used by calculating all possibilities. Then one of the best value is chosen. In this era, revolutionary methods have emerged that are able to shorten calculations with intelligent algorithms. One that is popular in determining the optimal value of a mathematical problem is the PSO algorithm. The PSO algorithm is able to overcome the problem of trapping the process of finding optimal value at optimal locality in order to be able to achieve optimal global values.

There are several references related to this research. several studies have discussed about the sizing optimization such as the optimization of capacity of PV, WTGS and hydrogen generating units [9]. Eco design optimization of an autonomous hybrid photovoltaic-wind turbine with battery storage [10]. Sizing and analysis of renewable power generation and battery sistem in residential microgrid [11]. Modelling and sizing optimization of hybrid PV/wind power generation [12]. Modified particle swarm optimisation technique for optimal design of small renewable energy system supplying a specific load at Mansoura University [13].

In this study the PSO algorithm will be applied to find the optimal value in determining the number of PV generating units, wind turbines and batteries. The case study of this study was conducted at the health center in the Timor Leste region. To get an accurate value, the fitness evaluation also takes into account the potential data of wind energy and sunlight and data on load fluctuations every hour in 1 day.

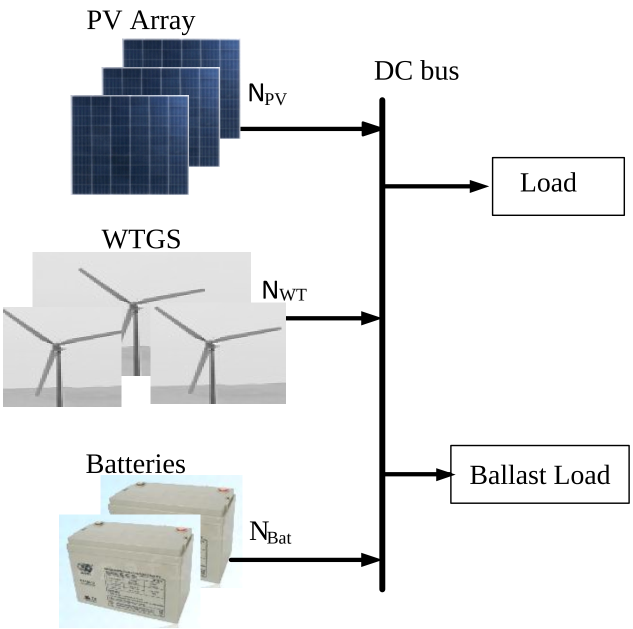


Fig 1. Hybrid PV/Wind/Battery sistem

II. CONFIGURATION SYSTEM DESIGN

The design of the hybrid generator system in this study consisted of photovoltaic (PV), wind power generation systems (WTGS), batteries and loads. Wiring diagram of the system is shown in figure 2.1. The discussion of the system's power flow control was discussed earlier [6]. PV, WTGS, battery and load connected to DC bus. PV and WTGS, each connected to a DC - DC boost converter that is controlled to always produce maximum power. The battery is connected to a bidirectional converter that is controlled to set the DC bus voltage to a constant of 311 Volts.

A. Photovoltaic system (PV)

The source of electricity from this photovoltaic system is obtained from sunlight captured by solar panels. Photovoltaic is intermittent power generation. The PV power equation is shown in eq 1. Based on its power characteristics, each level of solar irradiation has a maximum point of different power. So that it takes MPPT control techniques to regulate and maximize the power produced to obtain good system power efficiency. In this study PV is connected to DC bus using boost converter [14]. Incremental Conductance completed by various step has been choosed for MPPT technique algorithm [15] applied to the boost converter. The number of PV units is determined by using the PSO algorithm to obtain an optimal and economical combination of PV quantities.

$$P_{PV} = P_{rated} x F_{loss} x \left(\frac{G_h}{G_s} \right) x \left(1 + \alpha_T * \left(T_c - T_s \right) \right) \tag{1}$$

where, P_{rated} is the rated power WTGS. G_h is the irradiation of the sun each hour (W/m2), G_h is standart irradiation level of the sun, F_{loss} is derating factor, α_T is temperature coefficient, T_c is current temperature, T_s is standart temperature.

B. Wind Turbine Generation System (WTGS)

Electric energy sources are obtained from generators with rotors coupled with wind turbines that rotate due to wind energy. WTGS is an intermittent renewable power generation. Wind turbines have power characteristics that change with changes in wind speed. The wind turbine power equation is shown in eq. 2.

$$P_{WTGS} = 0.5 * \rho x A x (v_{wind})^3 x \eta \tag{2}$$

ρ is air density (1.225 kg/m^3), A is cross section area in m^2, v_{wind} is wind speed in m/s, η is efficiency of WTGS. The maximum operating power generated by wind turbines also varies depending on wind speed. So it takes MPPT control techniques to regulate and maximize the power generated by the WTGS to obtain good power efficiency. Sensing voltages and currents are carried out on the output side of the rectifier that has been filtered with an LC passive filter to reduce voltage and current ripple. Voltage and current will be processed by the controller to give a trigger signal to the boost converter. The MPPT algorithm used is the Incremental Conductance with various step algorithm. This algorithm has good performance with high MPPT control efficiency that is already discussed on reference [15].

C. Battery Energy Storage System

The excess energy in the system will be stored in the battery and if there is a lack of energy the battery will supply power to the system. In this case, bidirectional converters are needed to support the charging and discharging energy of the battery. Bidirectional converters are controlled with constant voltage control to regulate DC bus voltage. DC bus voltage is used as feedback on the control diagram with a reference voltage of 311 Volts. A detailed description of the voltage control on DC buses with batteries has been discussed in reference [6].

III. OPTIMIZATION SIZING CAPACITY DESIGN

In this section discusses the problems in generating capacity design optimization and the PSO method optimization algorithm. The problems that will be solved in this optimization contain a single objective function (in the form of a price function) taking into account the system conditions (system operating patterns and load fluctuations) and the existing energy potential, which is difficult to solve with conventional optimization methods. In addition, the model used also has constraints that must be met.

A. Sistem Operation Pattern

In this determination, the operating pattern of the system consisting of PV, WTGS, Battery and load is described as follows:

1. If all electrical power produced by PV and WTGS is supplied to the load, while the energy shortage will be squirted by the battery as long as the battery energy is still available (SOC >= 30%).

$$P_{PV}(t) + P_{WTGS}(t) + P_{discharge}(t) = P_L(t), \quad (3)$$

2. If the amount of PV power and WTGS exceeds the load demand, the battery energy is not fully charged (SOC <100%). then the excess power is stored in the battery.

$$P_{PV}(t) + P_{WTGS}(t) = P_L(t) + P_{charge}(t), \quad (4)$$

3. If the battery is fully charged (SOC = 100%), the excess power will be discharged through ballast load.

$$P_{PV}(t) + P_{WTGS}(t) = P_L(t) + P_{ballast}(t), \quad (5)$$

If the load demand exceeds the PV and WTGS capacity or the energy stored in the battery reaches the minimum level, then some parts of the load must be turned off. Then, there will be a loss of load.

B. Optimization Problem and Constrain

To solve the problem of PV, WTGS and battery capacity optimization, it is necessary to consider the potential of wind and solar energy in the area used as the research location. In this study the hybrid generating system wanted to be applied to health centers in the east. Measurement data of wind speed, solar irradiation and loads have been carried out at the health center. The measurement data is taken 24 hours in 1 day with data collection every 1 hour. The wind speed data are shown in figure 2. Solar irradiation data is shown in figure 3. Load data is shown in figure 4. Data will be entered and considered in optimization, so that accurate results are expected and in accordance with the conditions of the region.

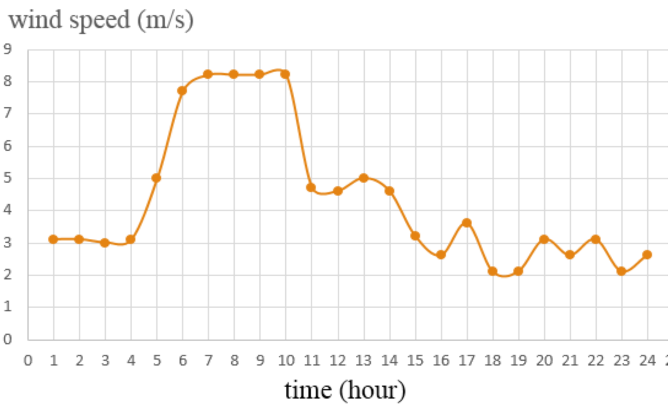


Fig. 2 wind speed variation on 24 hours in a day

Optimization of the capacity of generating units and batteries aims to get a minimum price in the procurement of the number of each generating unit and battery. There are several conditions that must be met in the operation of this hybrid system. Some of these conditions are the most important, there is no loss of load, besides that it must have good system power quality and achieve system power balance. Then in battery operation, the battery level (SOC) cannot be empty without energy. Therefore, in this study the battery level (SOC) was limited to a minimum of 30%.

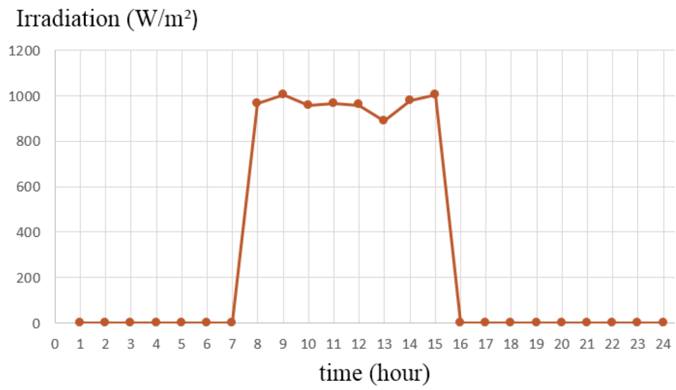


Fig. 3 irradiation variation on 24 hours in a day

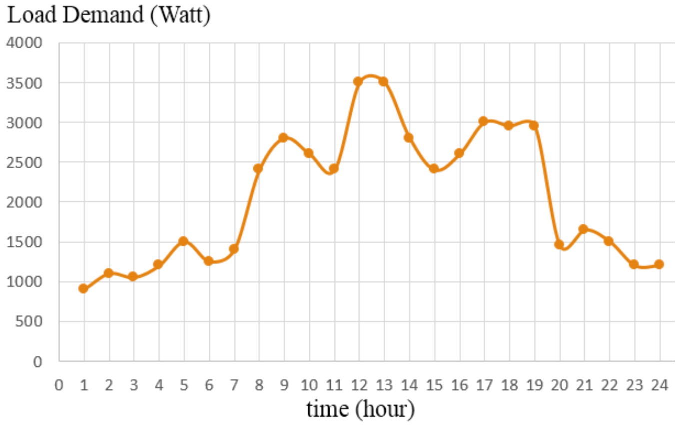


Fig. 4 load demand on 24 hours in a day

C. Particle Swarm Optimization (PSO)

PSO algorithm is one of the popular algorithms in obtaining optimal value from a problem. In Particle Swarm Optimization (PSO), a population is assumed to have a certain size with each individual located in a random location in a multidimensional space. Each individual is assumed to have two characteristics, namely position and speed. Each individual moves in a certain space and remembers the best position that has been passed or found for food sources or objective function values. Each individual conveys the best information or position to other individuals and adjusts the position and speed of each based on the information received regarding the good position. Each individual will do a fitness evaluation to determine the price. The fitness evaluation flowchart is shown in Figure 5. The sizing optimization algorithm used is shown in Figure 6. Each change in position and speed in each individual is obtained from the formula in equation 4.

$$V_{id}^{k+1} = w \times V_{id}^{k} + c_1 \times rand_1 \times (P_{id} - X_{id}) + c_2 \times rand_2 \times (G_{id} - X_{id}) \quad (6)$$

$$V_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \quad (7)$$

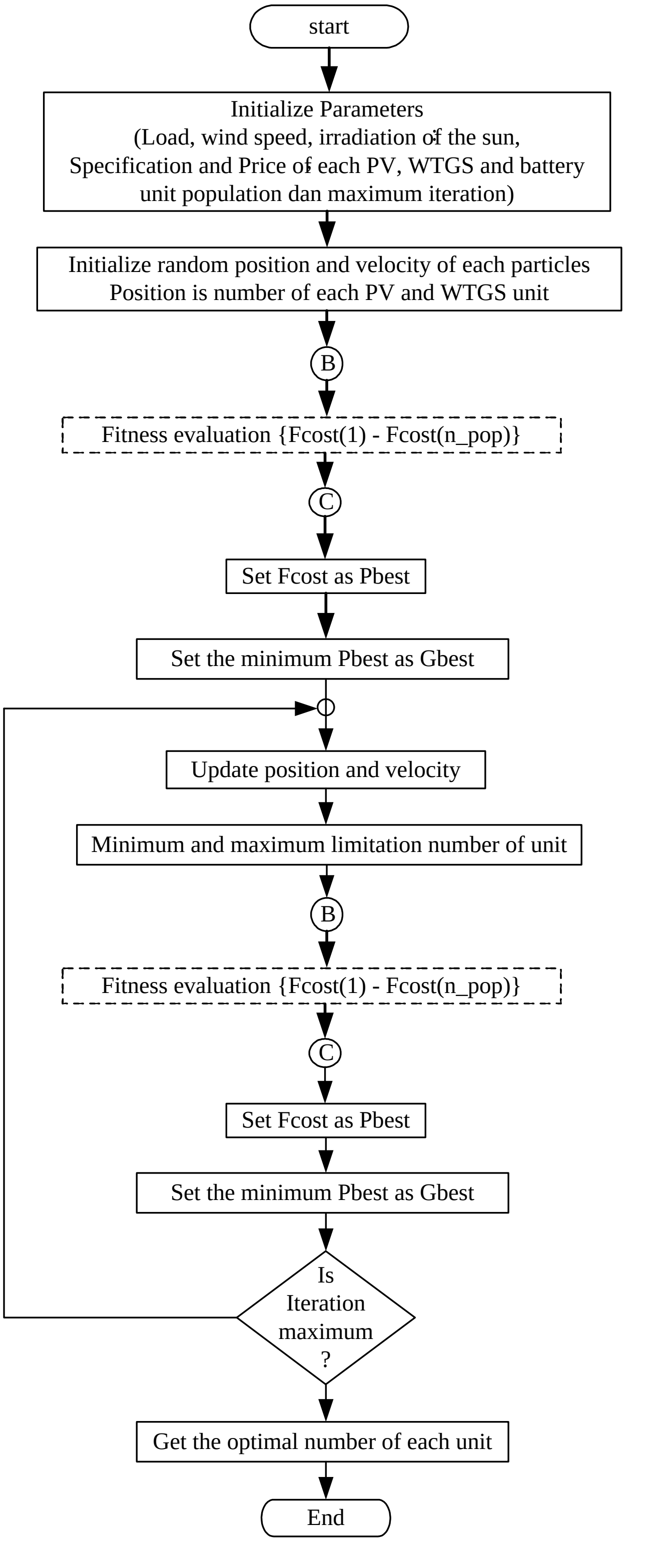


Fig 5. Optimization Sizing Capacity design algorithms using PSO

V_{id} is the component of the individual velocity at d dimensions, X_{id} is the individual position i on d dimensions, ω is the weighting parameter, c_1 and c_2 are learning rate constants the value is between 0 to 1, rand1, rand2 is a random parameter between 0 to 1, P_{id} is pBest (local best) individual i in d dimension, G_{id} is gBest (global best) in d dimension. (2.2

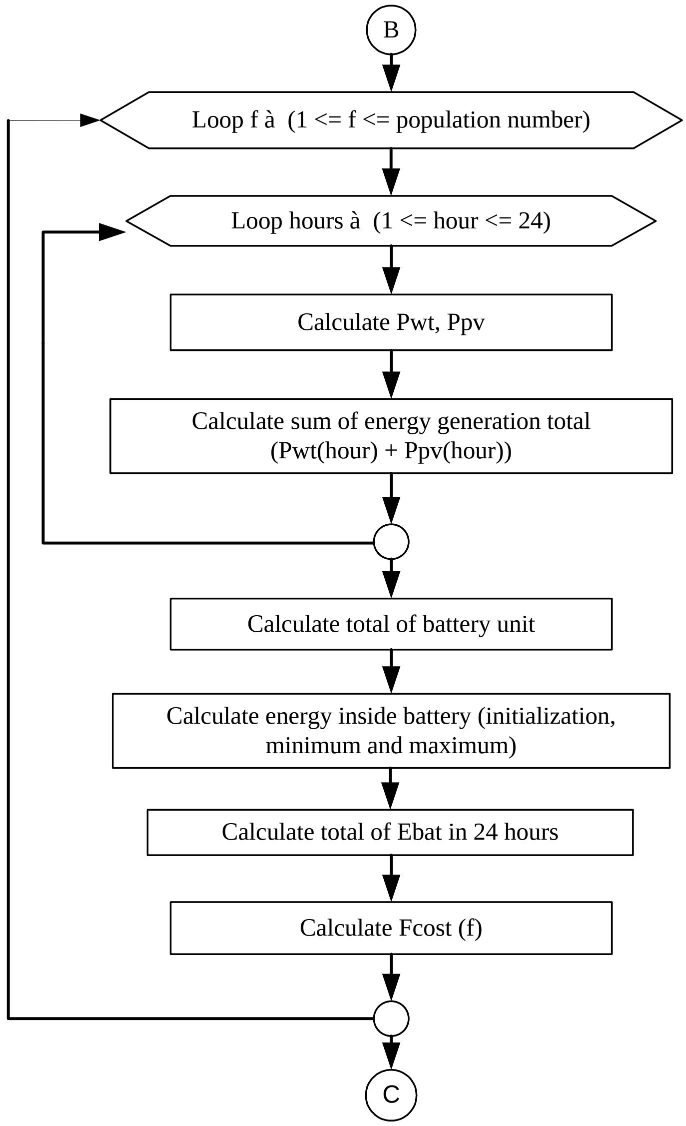


Fig 6. Flowchart of Fcost calculation as fitness evaluation

IV. RESULT AND DISCUSSION

This section presents optimization sizing capacity results with parameter as shown in table 1.

Table 1. Initialization Parameters

WTGS Parameters	Value	PV Parameters	Value

P-rated	0.5 kW	P	250 W
D	1.67 m	Prat	125 W
A	2.189 m2	floss	0.5
ρ	1.225	Gh	Irradiance
η	30%	Gs	1000
blade	3	ap	0.43
Start-up wind speed	2.5 m/s	Ts	27
		Tc	40
Nominal wind speed	10 m/s		

Parameters Battery	Value	PSO Parameters	Value
Capacity	100 AH	Population	30
Terminal voltage	48 Volt	Maximum iteration	20

There are several parameters as initialization of generator unit capacity and battery optimization algorithms. By reviewing the potential of hourly wind and solar energy in one day in the area around the health center, and reviewing hourly load data in 1 day for the health center operational activities, the optimal search for PV units, WTGS and batteries with 40% SOC initialization is obtained as shown in table 2 .

Table 2. The result of optimal sizing value on 10 times running program

Run program	PV unit	WTGS unit	Battery unit	Last SOC value	Minimum Cost
1	12	9	22	31%	$70571
2	14	8	23	33%	$72929
3	16	5	22	31%	$67857
4	13	8	22	31%	$69893
5	14	10	25	37%	$80357
6	11	10	22	31%	$71250
7	12	9	22	31%	$70571
8	16	5	22	31%	$67857
9	16	5	22	31%	$71250
10	16	5	22	31%	$67857

The optimal searching process (the cheapest price) is carried out as much as 10x running programs. From the results of running the program, the cheapest price is $67857. With a combination of 16 PV unit with a capacity of 250 W, 5 unit of WTGS 0.5 kW with 22 units of battery with a capacity of 100 AH, 48 Volts. Searching for optimal values with the PSO algorithm in this case is done in a 2-dimensional area occupied by a population consist of several individuals. The number of individuals included in this case were 30 individuals scattered randomly in the 2-dimensional area. 1 individual represents the value (x, y) with x is the number of PV units and y is the number of WTGS units. From each individual, an individual evaluation is carried out which has the most optimal value or the lowest price. In the evaluation process, the number of battery units is predicted by taking into account the potential of wind and solar energy in that location. In addition, by paying attention to data on load fluctuations that are calculated in 1 x 24 hours.

Figure 7 shows the initial population initialization. With the PSO algorithm, the flock of the population will look for the optimal point based on the objective function that has been determined (the price function). By updating the position and speed of each individual to its optimal point as many as 20 iterations, it was found that a flock of these populations gathered at a point in the 2-dimensional space as shown in Figure 7. The point is the optimal value of the problem of generating unit capacity and battery in this case.

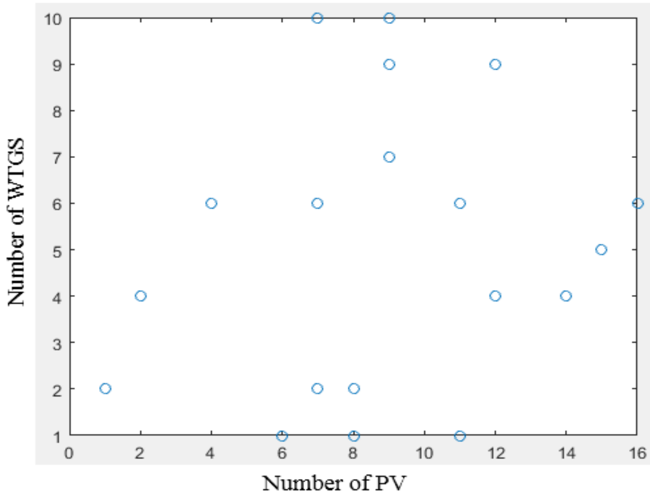


Fig. 7 Inisialization of random particles in 2 dimension space

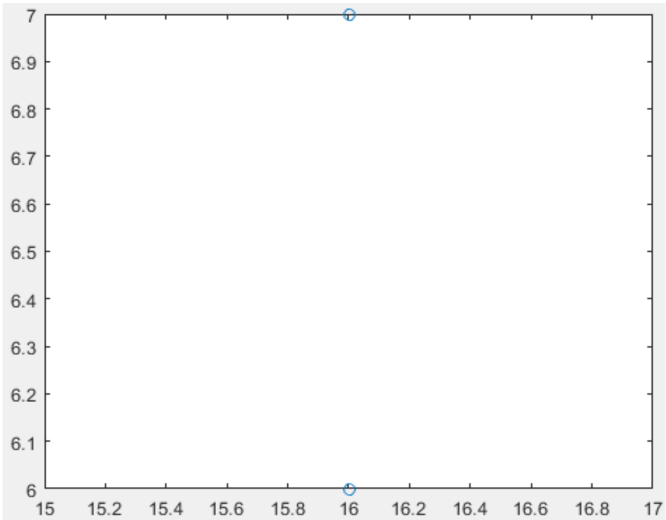
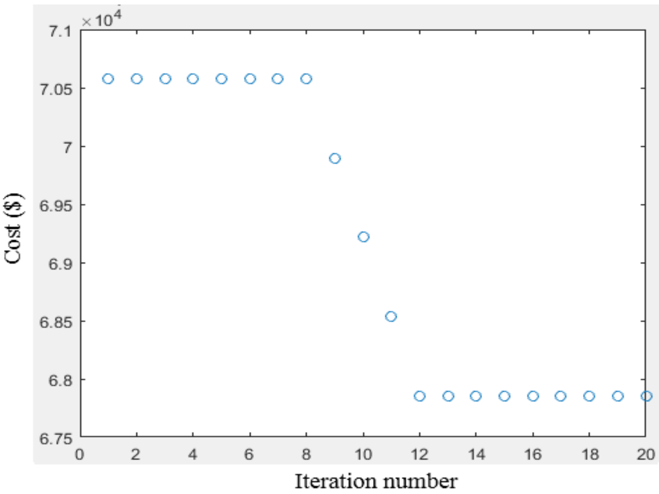
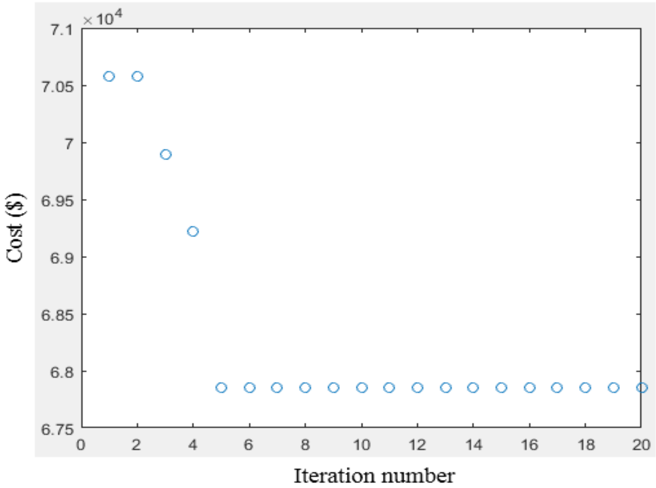


Fig. 8 Selected particle as the optimal number of PV and WTGS in the last iteration

The optimal search results based on objective functions in the form of the lowest price in each iteration are shown through the gBest variable as shown in Figure 8. In the PSO algorithm the optimal value is obtained from the gBest variable selected from the pBest value. The pBest value is obtained from the fitness evaluation process with the formulation of the price function. From figure 9 it can be concluded that the lowest value is reached at the price of $67857. From Figure 9 it can also be seen that when the 4th iteration, the results of fitness evaluation with the price function have reached its optimal point.



(a)



(b)

Fig. 9 gBest (cost in dollars) selection result in 20 times iteration as the optimal value; a) the first run; b) the third run.

CONCLUSION

The search for the number of PV generating units, WTGS and batteries can be done well using the PSO algorithm. The PSO algorithm can show and direct each particle to its optimum point with a short iteration. In the 10x running program, it can be seen that the PSO algorithm has a fairly good search accuracy. From the search for the optimal value obtained a combination of the number of generating units with the results in the form of 16 PV unit with a capacity of 250 W, 5 WTGS unit with a capacity of 0.5 kW and 22 batteries with a capacity of 100 AH, 48 Volts at a price of $67857.

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