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Renewable energy systems based on micro-hydro and solar photovoltaic for rural areas: A case study in Yogyakarta, Indonesia

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ABSTRACT

This paper presents renewable energy systems based on micro-hydro and solar photovoltaic for rural areas, with a case study in Yogyakarta, Indonesia. The Special Region of Yogyakarta, located on the island of Java, Indonesia, has a high potential for the development of renewable energy resources, especially hydropower and solar power. Many rural areas in Yogyakarta lack a supply of electricity. In this study, data on the potential for hydropower and solar power in rural regions of Yogyakarta are processed to determine the best capacity of hydroelectric and solar power plants. The extended particle swarm optimization (PSO) technique has been used to ensure optimal capacity optimization of this hybrid systems. The final result of this study is the most optimal of hydropower and solar power generation capacity based on the calculation of cost of capital, grid sales, cost of energy, and net present value.

1. Introduction

Electrical energy for the province of the Yogyakarta Special Region is part of the interconnection system of the Java–Madura–Bali system that covers seven areas on the island of Java, the island of Madura, and the province of Bali (Al Hasibi et al., 2018). This system is an interconnection system with an extra-high voltage network (500 kV) that stretches along the island of Java to the province of Bali (Syahputra et al., 2015). It is the most extensive electric power system in Indonesia and consumes almost 80% of Indonesia's total electricity production. State-owned electricity companies in Yogyakarta are in charge of serving the electricity needs of people in the Yogyakarta region. Eight substations satisfy this need, with a total capacity that reaches 616 MW. This increase in capacity must be balanced with the addition of new energy sources. Most of the energy now used comes from fossil fuels, which cannot be renewed and will run out if they are used continuously. Humans are thus required to look for other energy sources that are renewable sources to the extent possible (Tang et al., 2017; Kumar and Sudhakar, 2015; Sher et al., 2018; Ahmed and Salam, 2018).

Indonesia's attention to renewable energy began in the past few decades, especially in the general policy in the energy sector called the General Energy Sector in 1989 (Syahputra and Soesanti, 2019), and has been revisited in the National Energy Policy 2003–2020, which focused on energy efficiency, conservation energy, energy, and environmental diversification (Syahputra et al., 2014). Regarding energy diversification, the government, via the Ministry of Energy and Mineral Resources, is encouraging people to empower environmentally friendly renewable energy. The government's renewable energy target is 23% of total supply by 2025 (Syahputra et al., 2016).

The Indonesian government has prioritized the development and use of local energy potential, especially renewable energy, to increase supply and guarantee the availability of electricity, especially in rural, remote, and border areas. The government has also issued a regulation concerning the provision of small-scale energy sources in rural or remote areas called the Decree of the Minister of Energy and Mineral Resources concerning Scattered Small Scale Generators. The focus of this regulation is to empower local communities and encourage the development of local energy resources, namely, renewable energy (Syahputra and Soesanti, 2020).

Renewable energy sources are expected to play an active role in the energy diversification scenarios of the future because they are environmentally friendly. For example, solar energy, which

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is an alternative energy source with very adequate availability (Wang et al., 2013). Additionally, water energy is an alternative energy source with potential for development. However, the development of these two alternative energy sources is strongly influenced by geographical conditions. Renewable energy sources have the potential to produce electricity for an individual community (Ghasemi et al., 2018; Hauck et al., 2018). The process of developing technology to use renewable energy sources at a small scale that is cheap and can meet the needs of people is still being developed (Peng et al., 2018). Moreover, the development of renewable energy can be used to reduce dependence on electricity generated from fossil fuels such as oil and coal. To overcome the above problems, many hybrid techniques are used to combine several types of power plants (Patel and Chowdhury, 2018).

Several researchers have conducted studies on renewable energy power plants and their applications in various regions of the world (Kalla et al., 2018; Li et al., 2019; Kusakana et al., 2009; Mosobi and Gao, 2018; Rajadurai et al., 2017; Tudu et al., 2014; Khan et al., 2014). Kalla et al. (2018) conducted a study of a single phase standalone microgrid power system. In their study, they used adaptive sliding mode control to improve the power quality of the microgrid system. Microgrid system, which is the objective of research is a renewable energy power generation system. This system integrates wind, micro-hydro and solar power plants, which are integrated into a single-phase standalone grid system through a suitable voltage converter. The study conducted by Kalla and his colleagues is worthy of being used as a reference in research on independent power plants that utilize the potential of renewable energy in an area. In the study, shear mode control is applied to maintain the balance of energy produced by power plants, namely micro-hydro, wind, and solar power plants. Besides, the sliding mode control is also useful for estimating the real power that is output from the system, making it easier to control the frequency.

Li et al. (2019) performed a multi-objective optimization of hybrid power generation systems derived from micro-hydro, photovoltaic solar and pumped hydro storage. The optimization method used is a modified multi-objective particle swarm optimization (MOPSO). Optimization is carried out for hybrid system operation so that there is a similarity between the generation and the electrical load it serves. The operating strategy applied in optimization is based on hour-load data of seven days of pumped hydro storage. This strategy aims to maximize the value of similarity between the power generation curve and economic income from the storage of pumped hydro. The study was carried out in Xiaojin county, Sichuan province, China. It resulted in a similarity between electricity generation and load, which could be increased by 7.89% under participation of pumped hydro storage.

Research on independent power generation systems which are a combination of solar photovoltaic and micro-hydropower plants has been carried out by Kusakana et al. (2009). In their study, they named the power plant a hybrid power plant. The effort made by Kusaka et al. is noble because it is trying to build a self-generating plant in a rural area that does not yet have electricity energy facilities. Research conducted by Kusaka et al. is also worthy of being used as one of the references because it is closely related to research conducted by the author. In this study (Kusakana et al., 2009), solar and micro hydro-based hybrid power plants are designed for low-cost electricity generation, so that the selling price of electricity also becomes affordable. This effort is very realistic because the power plant is designed to meet the needs of electrical energy in remote and isolated areas. In this study optimization of the hybrid power plant system has been carried out, which includes technical and economic considerations. Another factor that supports the research is that micro-hydro and solar energy are sustainable sources of energy in the area of research. Optimization related to technical and economic issues in the study was carried out with the help of Homer software. The focus of the problem is the availability of solar and hydro energy. However, studies are also carried out with the possibility of on-grid electricity distribution networks supplied by diesel power plants.

Mosobi and Gao (2018) conducted a study on the integration of photovoltaic solar power plants, wind power plants, and micro-hydro plants. Hybrid generator performance analysis is performed on changes in temperature, solar radiation and wind speed. In their study, they also considered battery storage systems and micro-hydro systems which function to help reduce the effects of sporadic variations on hybrid systems due to extreme weather conditions. Their study also discussed the use of power converters, namely power inverters and power rectifiers, to integrate the system into the DC bus. Furthermore, Rajadurai et al. (2017) have conducted a study of a new methodology to replace conventional energy storage mechanisms in photovoltaic solar power generation systems. The photovoltaic directly serves the load of a DC motor to lift water. The water is then stored in a water storage tank. In this direct system, the fluctuating intensity of solar light can affect water discharge. In the water storage tank, a drainage pipe will be installed, then used to drive the micro-hydro turbine. In this system practically does not require maintenance costs.

Tudu et al. (2014) conducted a study on optimizing the design and size of micro-hydro, the solar, wind, and fuel cell-based hybrid power generation systems. Optimization has been done using the bees algorithm (BA) and compared with the particle swarm optimization (PSO) algorithm. The optimal size of the system design is obtained based on its net present value (NPV). The results of their study have concluded that the system is quite feasible in meeting the burden with suitable energy costs. The results of the analysis of the method show that although both algorithms can provide a global solution, the PSO method is faster in achieving the optimal solution and less time consuming than the BA method. In research in the same field, Khan et al. (2014) have conducted studies on the optimization of hybrid renewable energy systems for resort islands. Optimization is carried out on an optimal combination of hybrid systems based on side-generation energy audits, techno-economic analysis, and assessment of the availability of seasonal renewable energy resources versus the electricity load profile. Their research has been carried out on the island of Tioman, the South China Sea, which has been highly dependent on diesel generators. Their study has produced an optimal hybrid system configuration, which includes investment costs, fuel savings, and improvements in CO_2 emissions.

In our study, the renewable energy systems planning based on micro hydro and solar photovoltaic for rural areas has been carried out. A case study is in the Yogyakarta area, Indonesia. The Special Region of Yogyakarta, located in Java island, Indonesia, has a large geographic potential for the development of solar and hydro energy (Suyono et al., 2018; Raza et al., 2018). Because of the location of Yogyakarta near the equator, solar energy can be obtained most of the year with sufficient radiation levels to be used as an alternative energy source. In terms of geography, villages in the Special Region of Yogyakarta have significant energy potential. In irrigation canals, the resulting hydro discharge can reach 7000 l/s. Generally, the hydro potential here is only used to meet household needs and agricultural irrigation, even though this energy potential has great potential to be used as a renewable energy source, especially for the supply of electrical energy. Because of the background of these problems, it is necessary to plan to develop the potential of existing renewable energy sources as providers of electrical energy. The purpose of this study is to design a grid-connected power generation system model to support solar radiation and hydro energy use. Another goal is to determine the estimated benefits obtained from the construction of renewable energy power plants. This research is expected to be the best reference for renewable energy power generation systems in the Special Region of Yogyakarta, Indonesia, based on the potential data about solar radiation and hydro energy production and electrical loads at the same time intervals.

The novelty of this study is that the calculated hydro energy potential comes from irrigation channels that have a low head but with stable water flow. So far, irrigation canals are only used for their primary purpose, which is to flow through paddy fields in the province of the Yogyakarta Special Region. This study also considered the potential of solar energy, which is very abundant. Indonesian territory is crossed by the equator, and the entire region thus receives sunshine throughout the year. The potential of hydro and solar energy is combined into hybrid power plants. The next step is an analysis of hybrid systems planning that includes the power production capacity of the plant, capital cost, grid sales, cost of energy (COE), and net present value (NPV) in the analysis of optimal hybrid systems. The use of extended particle swarm optimization (PSO) techniques in COE and NPV optimization also strengthens the novelty of this study. A literature review has also been carried out in tabular form to know this research's contribution, as shown in Table 1. Based on the literature study summarized in Table 1, it can clearly show this research's position towards previous studies.

This research is beneficial for the people of Indonesia, especially in the province of the Special Region of Yogyakarta. The hydro and solar potential of this province are still not optimally used. Irrigation channels that have been built since the pre-independence era of the Republic of Indonesia in the 1940s have historical values that are very important to the communities, and the existence of the irrigation channels will undoubtedly continue to be maintained. The potential of solar energy is also not yet optimally used. Therefore, this research is expected to be a source of awareness for all components of the nation, including the government, academics, companies, and the public, about how hydro and solar energy sources can be economically beneficial and beneficial for supplying electrical energy to regions that do not yet have electricity.

2. Renewable energy systems based on micro-hydro and solar photovoltaic

Renewable energy sources are expected to have an active role in the energy diversification scenario in the future because these energy sources are environmentally friendly. For example, solar energy, can be used as a very available alternative energy source (Roncallo et al., 2020). Additionally, hydro energy is an alternative energy source with the potential to be developed (Hui et al., 2015). However, the development of these two alternative energy sources is strongly influenced by geographical conditions. Renewable energy sources have the potential to produce electricity for communities (Younas et al., 2018). The process of developing technology to utilize small-scale renewable energy sources that are cheap and able to meet the needs of people is still being developed (Ronad and Jangamshetti, 2015; Murni et al., 2012; Metry et al., 2017).

Hydro energy is a cheap and relatively plentiful source of energy because kinetic energy is stored in the flowing water. Hydropower is the energy obtained from flowing water; it can be used in the form of mechanical strength and electrical energy. The use of water energy is mostly achieved by waterwheels or water turbines that use the presence of a waterfall or the water flow in a river or ditch (Younas et al., 2018).

The amount of hydropower available from a hydro source depends on the size of the head and the water flow. The mathematical model of a micro-hydropower plant begins with calculating the water discharge from a water source. The water discharge can be calculated based on the catchment area. The catchment area is an area where rain falls towards the intended water source. Thus, the hydro potential of an area can be stated as follows,

$$Q_{area} = K_s \left(\frac{A_{area}}{A_{gauge}} \right) Q_{gauge} \quad (1)$$

where Q_{area} is the water discharge available at the micro-hydro power plant site (m^3/s), K_s is the scaling constant, A_{area} is the water catchment area of the micro-hydro power plant (m^2), A_{gauge} is the catchment area of the gauge at the power plant site micro-hydro power plant (m^2), Q_{gauge} is the water discharge in the gauge (m^3/s).

Concerning a water reservoir, the head is the height difference between the water level at the reservoir and the water level coming out of the water wheel or water turbine. The total available energy from a hydroelectric reservoir is hydro-potential energy expressed as follows:

$$E = m\,g\,h \quad (2)$$

where m is the mass of water (kg), h is the head (m), and g is the gravitational acceleration constant (m/s^2).

In addition to using falling water, hydropower can be obtained from low water flows. In this case, the available energy is kinetic energy given by the following:

$$E = \frac{1}{2} m \upsilon^2 \quad (3)$$

where m is the mass of water (kg) and v is the velocity of water flow (m/s).

The potential hydro power can be expressed by the following:

$$P = \frac{1}{2} \rho A \upsilon^3 \quad (4)$$

where ρ is the water density (kg/m^3), A is the cross-sectional area of water flow (m^2), and v is the velocity of water flow (m/s).

2.1. Micro-hydro systems

Micro-hydro systems is the term used for electrical power plant installations that use hydro energy and are small in size (micro); the term micro-hydro is not a standard term in practice. The water conditions that define micro-hydro's potential use as a power source are a specific flow capacity, height and installation (Tudu et al., 2014). The potential power capacity of micro-hydropower plants can be seen from the characteristics of the available hydropower. Two important factors determine the water discharge and high head of water flow. The higher the water discharge and the head high of a water source, such as a river or irrigation canal, the higher the micro-hydropower capacity generated. Three main components must be met to build a micro-hydropower plant, namely flowing water that is used as an energy source, turbines used as a generator of mechanical energy driving generators, and generators as a producer of electrical energy.

As described above that the capacity of micro-hydro plants depends on water discharge and head height, so to build a micro-hydro plant requires a comprehensive study of water discharge and head height. Data about water discharge and head height are essential to get the potential electrical power to be generated. This fact is since the construction of micro-hydropower plants also pays attention to economic aspects. The financial issue, in

Table 1
Literature review related to this research.

Authors	Power plant		Research parameters			Real object	Methods and tools		
	Micro-hydro	Solar PV	Objectives	Technical aspect	Economical aspect		HOMER	PSO	Other method
Kalla et al. (2018)	✓	✓	Estimating the real power by controlling the output systems, such as frequency and output voltage	✓					Adaptive sliding mode control
Li et al. (2019)	✓	✓	Multi-objective optimization of hybrid system for a similarity between the generation and the electrical load	✓				✓	
Kusakana et al. (2009)	✓	✓	Optimization of the hybrid power plant system	✓	✓	✓	✓		
Mosobi and Gao (2018)	✓	✓	Hybrid performance analysis in change of temperature and solar radiation	✓					Conventional
Rajadurai et al. (2017)	✓	✓	Replace conventional energy storage mechanisms	✓					Conventional
Tudu et al. (2014)	✓	✓	Optimizing the design and size of hybrid system	✓	✓			✓	Bees algorithm
Khan et al. (2014)	✓	✓	Optimization of hybrid renewable energy systems for resort islands	✓	✓	✓	✓		
Suyono et al. (2018)	✓		Dynamic stability impact of the hybrid wind and micro-hydro system	✓		✓			Stability analysis
Raza et al. (2018)			Enhance the control performance of VSC stations	✓				✓	
Roncallo et al. (2020)	✓	✓	Analyze the impact of grid-scale energy storage in a hydro dominated power system	✓	✓	✓			EnergyPLAN tool
Younas et al. (2018)	✓	✓	Economic planning of hybrid energy system		✓	✓	✓		
Ronad and Jangamshetti (2015)		✓	Optimal cost analysis of wind–solar hybrid systems		✓	✓	✓		
Murni et al. (2012)	✓		Impacts of a micro hydro system on rural communities	✓		✓			Conventional
This research	✓	✓	Optimization of hybrid power systems based on micro-hydro and solar PV	✓	✓	✓	✓	✓	

this case, is a calculation of whether the micro-hydro generator that will be produced is capable of producing sufficient electrical energy to be sold to consumers. It cannot be denied that the construction of micro-hydro plants requires a high amount of costs related to the physical structure of the plant. The investment costs incurred include civil works to make dams with the water discharge control system and the costs of turbine and generator components.

Micro-hydro power plants are known as renewable and environmentally friendly power plants (Tudu et al., 2014). This power plant utilizes natural resources, namely river water flow or existing irrigation canals, so there is no fuel cost. In addition, there is also no pollution generated, so it is beneficial to help reduce the greenhouse effect. The energy that comes from running water with a difference in height between upstream and downstream can then be converted into electrical energy. Micro-hydro power plants are prevalent in potential areas because they have a simple construction and easy maintenance. The investment costs to be incurred are also quite competitive when compared to other power plants of the same capacity (Younas et al., 2018). A community can build this power plant independently, without having to have high knowledge and expensive costs (Murni et al., 2012). This power plant can be made in remote areas that do not yet have a grid system from electricity supply companies. The waterpower used can be in the form of water flow in irrigation systems, dammed rivers, or waterfalls.

The principle of operation of a micro-hydropower system is a power plant that utilizes the difference in water level and volume of water every second in a flowing water source such as a river, waterfall, or irrigation canal. The kinetic energy flow of water that has an adequate discharge is used to turn turbines in micro-hydro power plants to produce mechanical energy. The turbine shaft that is coupled with the generator will automatically turn the generator, thus producing electrical energy. This electricity is utilized by electricity consumers who are in dire need, especially in remote areas. In the construction of micro-hydropower plants, begins with the construction of dams that function to regulate the volume and flow rate of water. This water flow is utilized by micro-hydro. This dam is usually made of concrete. These dams are usually equipped with sluice gates and a filter for dirt or rubbish.

In this study, the source of water used as an object for micro-hydropower plants is the irrigation canal. This irrigation canal was made with concrete construction that had begun to be built since 1942. To utilize this irrigation canal as a micro-hydropower plant, a fast pipe must be made to flow water before entering the turbine. In this rapid pipeline, the potential energy of water in the sedation pond is converted to kinetic energy which will turn

Fig. 1. Irrigation canal in Semawung, Banjarharjo Village, District of Kalibawang, Kulon Progo Regency, Special Region of Yogyakarta.

the turbine wheel. Rapid pipes are usually made of steel pipes which are rolled and welded. This pipe must be supported by a foundation that can withstand static and dynamic loads during the operation of micro-hydro plants. Foundations and stands are kept as easy as possible because they must be designed according to the soil conditions around the plant site.

The primary device in a micro-hydropower system is water turbines, electricity generators, and control systems. This primary device is placed in a building that is separate from the water source. Usually, the foundation of the turbine and generator must also be separated from the foundation of the building. This building separation is intended to avoid problems due to vibration. Turbine houses must be designed so that operators are easy to carry out maintenance and inspection. After exiting the pipe rapidly, water will enter the water turbine in the inlet section. Inside there is a propeller guide to adjust the opening and closing of the turbine and adjust the amount of water that enters the turbine's main component, the runner or blade. Blades from water turbines are usually made of high tensile strength steel. Water flow with sufficient discharge will rotate the blade and produce kinetic energy which will rotate the turbine shaft. Power arising from the turbine shaft rotation is then transmitted to the generator. The entire turbine and generator system of the micro-hydro system must be balanced. Water turbines need to be equipped with a casing that serves to direct the water to the blade. In the carrying part of the turbine casing, there is a turbine key. Furthermore, there are also bearings mounted on the left and right sides of the shaft that serves to support the beam so that it can rotate smoothly. The shaft power of this turbine must be transmitted to the generator so that it can be converted into electrical energy. Generators that can be used in micro-hydro are synchronous and induction generators. The power transmission system can be in the form of a linear transmission system (shaft power directly connected to the generator shaft with the help of a clutch) or an indirect power transmission system that uses a belt to move energy between two parallel axes.

The advantage of the linear transmission system is that it is more compact, easy to maintain, and has higher efficiency. However, the shaft axis must be completely straight, and the generator shaft rotation must be the same as the turbine shaft rotational speed. The problem of axis non-alignment can be overcome with the help of flexible clutches, and a gearbox can be used to correct the rotation speed ratio. Indirect transmission systems allow variations in generator use more broadly because the rotating speed of the generator shaft does not need to be the same as the turbine shaft rotational speed. The type of belt commonly used for large scale micro-hydro is a flat belt type, whereas v-belts are used at scales below 20 kW. Supporting components needed in this system are pulleys, bearings, and couplings. The electricity produced by the generator can be directly transmitted via a cable to the electricity pole next to the consumer's house.

2.2. Potential micro-hydropower in Yogyakarta Special Region, Indonesia

The initial stage of the development of the micro-hydro power plant began with a field survey to determine the potential of irrigation channels that could be developed into a hydropower source for micro-hydro plants. After obtaining a location for research, data for the physical irrigation canal were collected and calculated, along with the potential for electric power. Tests were conducted on the irrigation canal in Semawung, Banjarharjo Village. The village is administratively included in the District of Kalibawang, Kulon Progo Regency, Special Region of Yogyakarta, Indonesia. Data is collected from April 27, 2018, to May 24, 2018, as seen in Fig. 1.

In this work, the testing procedure was as follows: (a) determine the canal width using a meter, (b) measure water depth using long bamboo poles, and then measure by the meter, (c) measure the speed of water using a small plastic ball washed on a 10-meter long channel, then calculate the travel time using a stopwatch. The measurement was done repeatedly to obtain a more valid water speed. Based on the testing procedures conducted in 2 irrigation canals, the measurement results were obtained and are shown in Table 2. For testing purposes, the width of the irrigation canal was 9.4 m, the water level from the bottom of the irrigation was 1.9 m, and the length of the irrigation canal tested was 10 m.

Based on data obtained from the Ministry of Energy and Mineral Resources, the water resources for the Kalibawang micro-hydro drive originated from the Progo river, which then entered the Kalibawang, Kulon Progo, Yogyakarta irrigation canal. This canal has a capacity of approximately 7000 L/s, which irrigate 6377 hectares of rice fields. The field testing was carried out in April and May 2018 to validate the water discharge data obtained from the Irrigation Department of Kulonprogo, Yogyakarta, Indonesia. For planning, debit data for the Kalibawang irrigation channel for the last eight years (2010–2017) were obtained from the Irrigation Department of Kulon Progo Regency, Yogyakarta. The average flow rate on the Kalibawang irrigation channel is 6,96

Table 2
Results of velocity testing of irrigation canals in Yogyakarta.

Testing numbers	Examination in April 2018		Examination in May 2018	
	Time (s)	Velocity (m/s)	Time (s)	Velocity (m/s)
1	28.86	0.347	24.72	0.405
2	28.38	0.352	26.26	0.381
3	26.02	0.384	24.78	0.404
4	20.62	0.485	24.46	0.409
5	24.28	0.412	24.90	0.402
6	21.40	0.467	25.56	0.391
7	22.26	0.449	25.20	0.397
8	23.72	0.422	24.02	0.416
9	24.72	0.405	23.12	0.433
10	23.26	0.430	22.68	0.441
Average	24.352	0.415	24.57	0.408

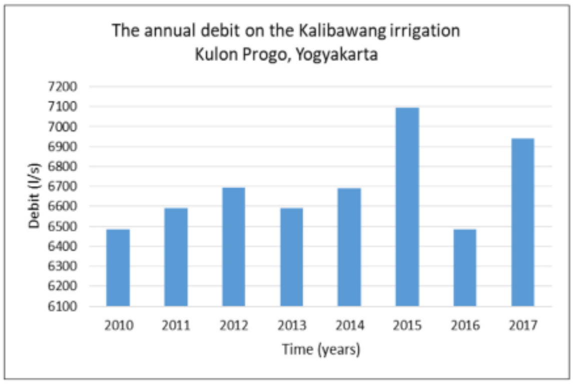

Fig. 2. The annual debit of the Kalibawang irrigation canal, Kulon Progo, Yogyakarta.

L/s. The annual flow rate data on the Kalibawang irrigation canal, Kulon Progo, Yogyakarta is shown in Fig. 2.

The potential power generated from a micro-hydro power plant on the Kalibawang irrigation canal is 622 kW. This potential was obtained by calculations using Eq. (4), based on head height data for the Kalibawang irrigation canal. The head height is 12.20 m, and the efficiency is 80%. The water density is 997 kg/m^3, the cross-sectional area of water flow 17.84 m^2, and the velocity of water flow is 0.412 m/s. The velocity is taken from the average measurement results in April to May 2018, as shown in Table 2.

As the principle of supplying electrical energy that in addition to available supply, information on demand must also be obtained. In this case, supply is the capacity of micro-hydropower plants. At the same time, demand is the profile of the electricity load at the study site, namely Banjarharjo Village, Kalibawang District, Kupon Progo Regency, Yogyakarta Special Region province, Indonesia. Like Indonesia in general, there are only two seasons in this tropical country, namely summer and rainy season. Changes in electricity load characteristics for the two seasons are not too significant. Thus, the electrical load profile for each year is assumed to be the same. Based on data obtained from the Central Statistics Agency of Kulon Progo Regency, the number of potential households as electricity customers in 2018 is 962 houses. Thus, data on 962 houses are used as a reference for the number of electricity customers who need to be supplied.

The electricity load in this study is entirely a household expense, following survey results and data from the Central Statistics Agency. Naturally, the nature of a household type of electrical load is random, where the tendency is to experience a peak load at night, from 18:00 to 21:00. In this study, the nature of the daily electrical load is assumed to have a 15% variance over an hour. The average electricity used in one day is 4,628 kWh. The highest peak load in one year that occurs in the time range of 18:00 to 21:00 is 643 kW. In each day, the average electricity load every hour is 193 kW with a load factor of 0.3. A profile of monthly electricity expenses in one year in Yogyakarta, Indonesia, as shown in Fig. 3. The profile shows the electricity load profile from January to December for 2018. The profile of daily electricity load for each month for 2018 is shown in Fig. 4. In the figure, it can be seen that the peak load always occurs at night, which is from 18.00 to 21.00. The lowest load generally occurs in the early hours of 00.00 to 04.00.

The flow rate of irrigation channel of 6500 L/s is the average water flow rate in the Kalibawang irrigation channel, Kulon Progo, Yogyakarta. The profiles of the monthly water flow rates in one year on the irrigation channel are shown in Fig. 5. In the figure, it can be seen that from January to December, the flow rate of the irrigation canal is relatively stable at 6500 L/s. This fact is indeed following the real conditions in Yogyakarta that in one year, the Kalibawang irrigation canal which has a water supply from the Progo River is relatively stable.

2.3. Solar photovoltaic power plants

In its application, a photovoltaic solar power generation system can be classified into an on-grid system and an off-grid system (Sher et al., 2018). An on-grid system is a system where a photovoltaic solar power plant is connected to an existing grid system; for example, the distribution network of a state electricity company in Indonesia. An off-grid system is a system where a stand-alone photovoltaic solar power plant that only serves a specific electricity load, for example, for household needs, office buildings, rural areas, and others. This off-grid system is widely applied in Indonesia (Syahputra and Soesanti, 2020). Off-grid solar photovoltaic power generation systems are widely applied in Indonesia, especially in remote areas, remote islands, hilly areas, or isolated areas, which have not yet been electrified by state electricity companies. However, off-grid type of solar photovoltaic systems can also be installed in urban for specific purposes such as when renewable energy power plants are required because of environmental problems or because it is too expensive to tap electricity from the electricity network. Yogyakarta Special Region, Indonesia has a significant portion of its territory with conventional electricity networks owned by state electricity companies. However, there are still areas that have not been served by the electricity network. Solar energy is thus very appropriate for use in the regions that are in dire need.

Before discussing more solar power generation, a mathematical model of solar photovoltaic devices is introduced. The representation of a solar photovoltaic module can be started with a simplified circuit model, as shown in Fig. 6. The representation of a solar photovoltaic module in this study refers to the representation described in research (Vinod and Singh, 2018; Bana and Saini, 2019; Ibrahim et al., 2020). This figure shows that solar photovoltaic is modeled with a current source (I_{ph}) connected in parallel with a diode. By Kirchhoff's first law, the output current (I) can be expressed in the following equation,

$$I = I_{ph} - I_d \quad (5)$$

where I is the output current of a solar photovoltaic module (A), I_{ph} is photo-current of a solar photovoltaic module (A) and I_d is diode current (A).

The Shockley diode current equation describing the current–voltage characteristics of solar photovoltaics is stated as follows,

$$I_d = I_s \left[e \frac{qV_{oc}}{N_s K A_D T_o} - 1 \right] \quad (6)$$

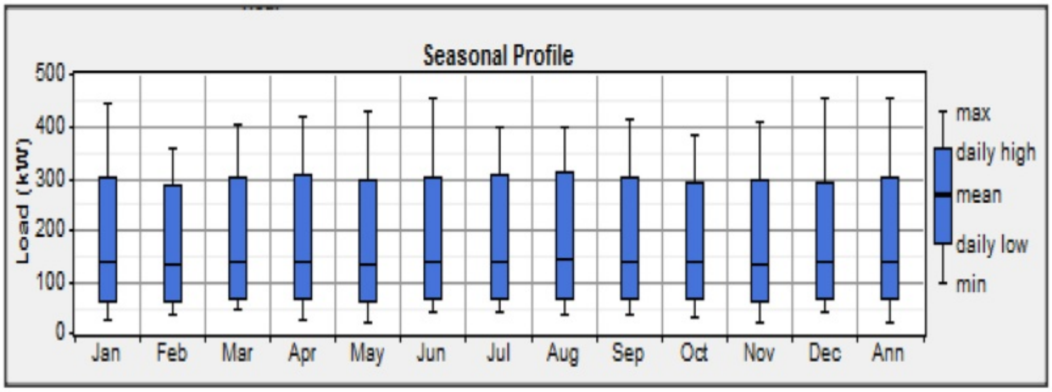

Fig. 3. Profile of monthly electricity expenses in one year in Yogyakarta, Indonesia.

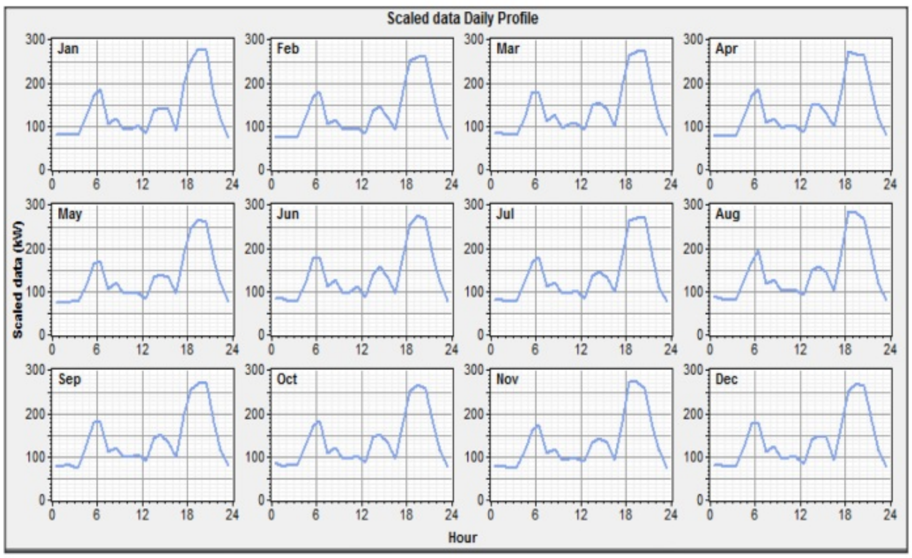

Fig. 4. Hourly electricity load profiles for each month of the year in Yogyakarta, Indonesia.

where I_s is short-circuit current (A), e is exponential function, q is charge of an electron (1.602×10^{-19} °C), V_{OC} is open-circuit voltage (V), N_S is photovoltaic cells number connected in series, K is Boltzmann's constant (1.380×10^{-23} J/K), A_D is diode constant, and T_O is real-time temperature (K).

By substituting the diode current (I_d) in Eq. (6) into Eq. (5), the following equation is obtained,

$$I = I_{ph} - I_s \left[e \frac{qV_{oc}}{N_s K A_D T_o} - 1 \right] \tag{7}$$

Finally, the output power of a solar photovoltaic module for a simplified model can be expressed by the following equation,

$$P = V \left(I_{ph} - I_s \left[e \frac{qV_{oc}}{N_s K A_D T_o} - 1 \right] \right) \tag{8}$$

where P is the real output power of a solar photovoltaic module (W) and V is the output voltage of a solar photovoltaic module (V).

The ideal representation of solar photovoltaic module can be represented by a real circuit model, as shown in Fig. 7. The model has added a resistance (R_d) connected in parallel with the diode.

As with the previous model, Kirchhoff's first law equation for the output current of solar photovoltaic (I) is stated as follows,

$$I = I_{ph} - I_d - I_p \tag{9}$$

where I_p is the parallel current (A).

The Shockley diode current equation describing the current–voltage characteristics of solar photovoltaics is stated as follows,

$$I_d = I_s \left[e \frac{q(V_{oc} + IR_s)}{N_s K A_D T_o} - 1 \right] \tag{10}$$

where R_S is the series resistance of a solar photovoltaic module (Ω).

And, the parallel current (I_p) is stated as follows,

$$I_p = \frac{V_{oc} + IR_s}{R_s} \tag{11}$$

By substituting the diode current (I_d) in Eq. (10) and parallel current (I_p) in Eq. (11) into Eq. (9), the following equation is obtained,

$$I = I_{ph} - I_s \left[e \frac{q(V_{oc} + IR_s)}{N_s K A_D T_o} - 1 \right] - \frac{V_{oc} + IR_s}{R_s} \tag{12}$$

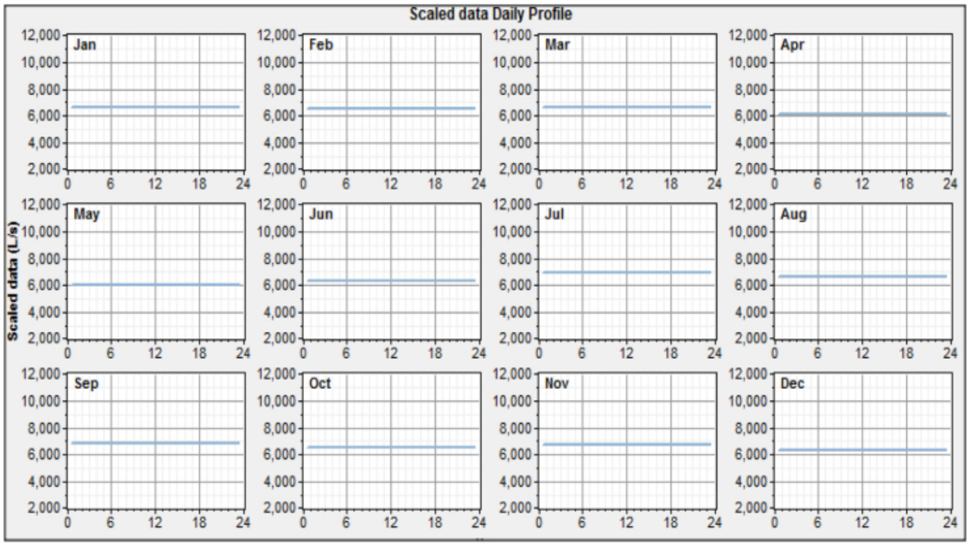

Fig. 5. Profiles of the monthly water flow rate in one year on the Kalibawang irrigation channel, Kulon Progo, Yogyakarta.

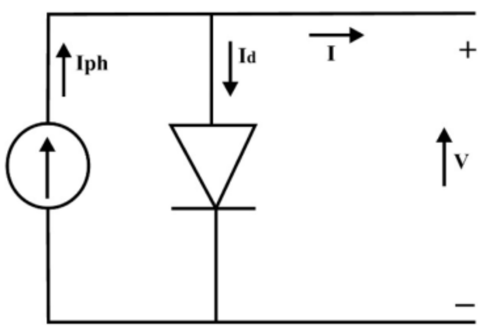

Fig. 6. Model of simplified circuit of solar photovoltaic.

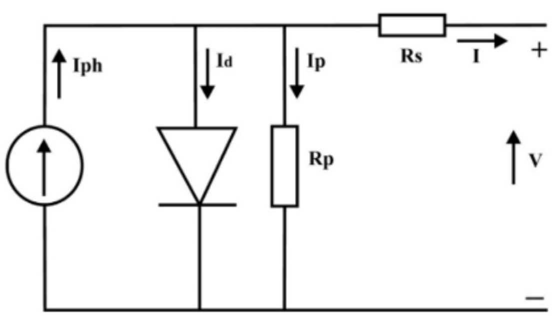

Fig. 7. Model of real circuit of solar photovoltaic.

Finally, the output power of a solar photovoltaic module for a real circuit model can be expressed by the following equation,

$$P = V\left(I_{ph} - I_s\left[e\frac{q(V_{oc} + IR_s)}{N_s K A_D T_o} - 1\right] - \frac{V_{oc} + IR_s}{R_s}\right) \tag{13}$$

In its installation, an on-grid type of solar photovoltaic system involves a battery bank as a storage medium for electrical energy. Generally, the batteries used for photovoltaic solar power generation systems are deep cycle types that can be recharged. This type of battery has characteristics that correspond to the storage needs of electrical energy from solar cells, because of its deep-cycle nature makes the battery has a relatively long service life. Batteries are handy in solar photovoltaic power plant installations for the use of electrical energy when there is very little or no sunlight, such as at night.

Fig. 8 shows the typical scheme of an on-grid solar photovoltaic system. In photovoltaic solar systems, the devices needed are solar panels with the appropriate power capacity, solar charge controller systems, battery banks for storing electricity, and power inverters. The function of photovoltaic solar panels is as a device that converts light energy from the sun into electrical energy in the form of direct current (DC). The output voltage of photovoltaic solar cells in the form of DC voltage varies depending on the intensity of sunlight that hits the solar cell. The higher the intensity of sunlight, the voltage produced by photovoltaic solar cells is also higher. A solar charge controller is a device that functions to control the output voltage of photovoltaic solar cells that enter the battery to store an electric charge. The input voltage to the battery is controlled such that it is still within the safe limit of the battery charging voltage. A power inverter is a device that functions to change the DC voltage generated by a battery or photovoltaic solar cell directly into an AC voltage that is ready for use by electrical loads.

Surface meteorology and solar energy (SMSE) data from the National Aeronautics and Space Administration (NASA) were used as information sources for solar radiation in the Kulon Progo area, Yogyakarta. The SMSE-NASA database comes from meteorological and solar energy parameters that have been recorded for 27 years by more than 200 satellites, with data accuracy ranging from 6% to 12%. Solar energy data for the Kulon Progo region, Yogyakarta, are shown in Table 3, and the clearness index is shown in Fig. 9. The Kulon Progo region has a relatively good level of solar radiation even though it is slightly lower than the ideal solar radiation from 5 to 6 kWh/m^2/day, and its clearness index is very sufficient.

It is very interesting to utilize the potential of available renewable energy resources if the power plants are combined into

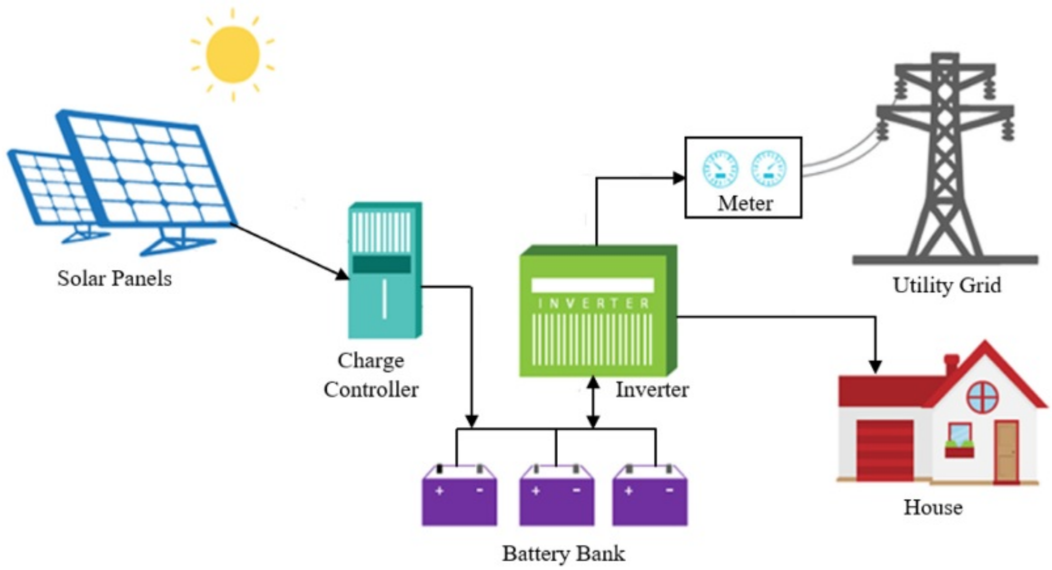

Fig. 8. Typical on-grid solar photovoltaic systems.

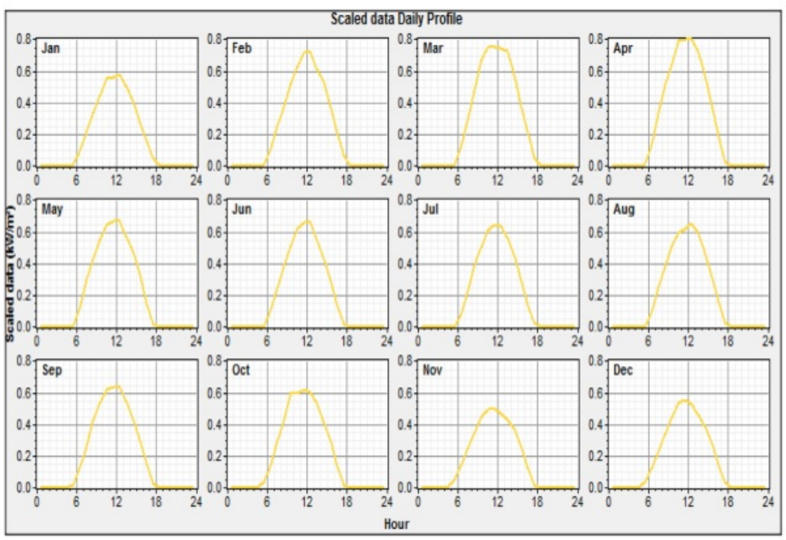

Fig. 9. Profile of monthly sunlight illumination in one year in Yogyakarta, Indonesia.

a hybrid power plant. As discussed in this article, two types of potential renewable energy power plants in Yogyakarta, Indonesia, are micro-hydro and solar photovoltaic power plants. Besides increasing the capacity of the generating system, this hybrid power plant also increases system reliability. For example, at night, the solar photovoltaic generator does not work, so it does not produce electrical energy stored in the battery bank. At that time, micro-hydropower plants still play a role in producing electrical energy. On the other hand, during the dry season, when the water supply is reduced, the micro-hydro power plant's electrical energy is not optimal. At that time, the sun's rays are at their peak during the day to produce the maximum energy stored in the battery bank. Fig. 10 shows the typical scheme of an on-grid hybrid micro-hydro and solar photovoltaic systems.

2.4. Objective function and optimization of hybrid systems

Analysis of micro-hydro and solar PV-based hybrid power plants includes annual total costs consisting of annual cost of capital, annual operating and maintenance costs, annual replacement costs, grid sales, cost of energy, and net present value.

The annual electricity generation costs (GC) can be defined as follows:

$$GC = C_{ann}/P_G \quad (14)$$

where C_{ann} is the total year-long cost of the hybrid systems, and P_G is the absolute electric power generated by hybrid power plants in kW.

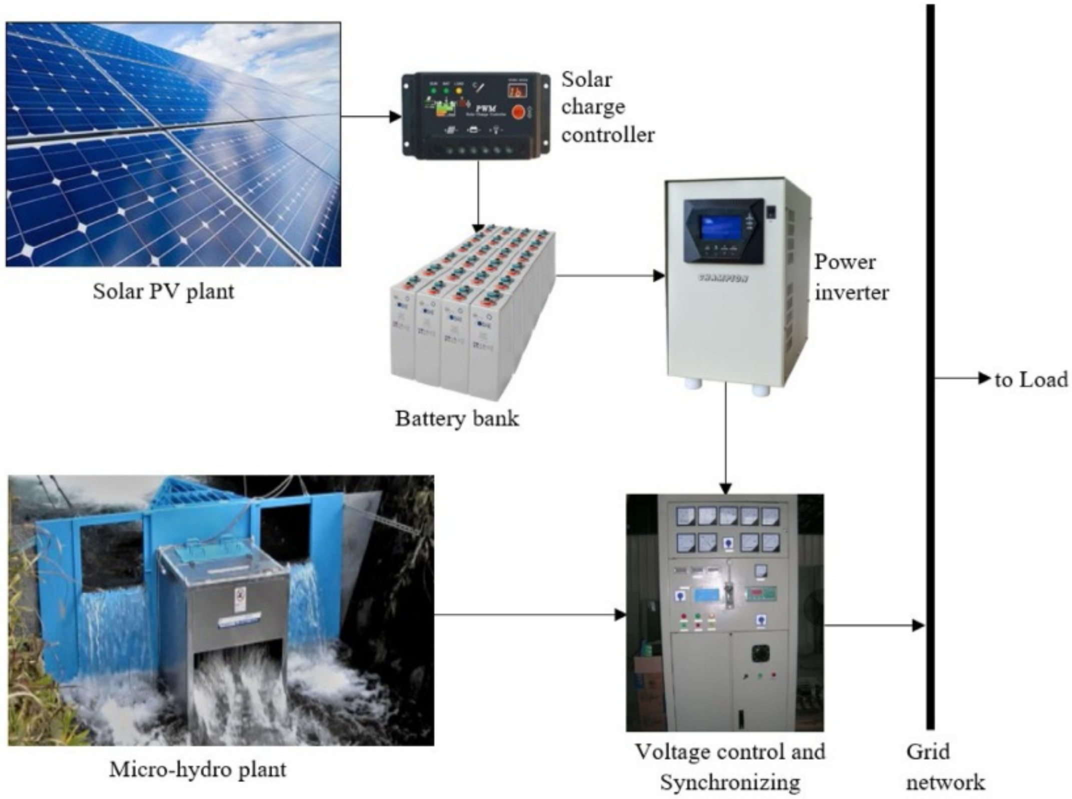

Fig. 10. Typical on-grid hybrid micro-hydro and solar photovoltaic systems.

Table 3
Solar energy data for the Kulon Progo region, Yogyakarta.

Number	Month	Sun radiation (kWh/m^2/day)	Clearness index
1	January	4.214	0.392
2	February	5.104	0.473
3	March	5.751	0.547
4	April	5.920	0.604
5	May	4.926	0.550
6	June	4.605	0.543
7	July	4.550	0.525
8	August	4.678	0.496
9	September	4.720	0.464
10	October	4.709	0.443
11	November	3.895	0.364
12	December	4.095	0.384
Average		4.761	0.478

The cost of energy (COE) of a hybrid system can be defined as follows:

$$COE = C_{ann}/P_L \tag{15}$$

where P_L is the total electrical load power that is served by hybrid power plants in kW.

The total net present value (NPV) of a hybrid system can be defined as follows (Murni et al., 2012):

$$NPV = \frac{C_{ann}}{CRF(1, R_{proj})} \tag{16}$$

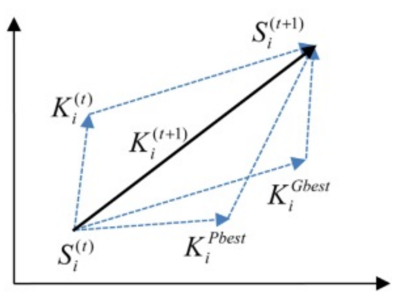

Fig. 11. The Optimization Concept Using PSO.

where i is the annual real discount rate in %, R_{proj} is the project lifetime in years, and *CRF()* is a function that returning the capital recovery factor.

The total power generated by a hybrid system is not always the same as the system load. This fact is due to a power surplus or power deficit that occurs. Therefore, the COE and GC values can be different. In this study, the optimization of the hybrid generating system is based on net present value (NPV).

In this study, optimization of the renewable energy system is using extended PSO algorithm (Syahputra et al., 2015). The method was inspired by a swarm in trying to find food. This food search process is used as a great optimization model. This optimization model of foraging by swarms is represented in a velocity vector, as shown in Fig. 11. The resultant velocity vector can be expressed in an equation as follows:

$$K_i^{(t+1)} = \beta \cdot K_i^{(t)} + c_1 \cdot ran_1(\circ) \cdot (Qbest_i - S_i^{(t)}) + c_2 \cdot ran_2(\circ) \cdot (Rbest_i - S_i^{(t)}) \quad (17)$$

where $S_i = (s_{i1}, \ldots, s_{id}, \ldots, s_{in})$ is the position of the *i-th* particle; $K_i = (k_{i1}, \ldots, k_{id}, \ldots, k_{in})$ is the speed of the *i-th* particle; $Qbest_i = (qbest_{i1}, \ldots, qbest_{id}, \ldots, qbest_{in})$ is the particle's best experience *i-th*; $Rbest_i = (rbest_1, \ldots, rbest_d, \ldots, rbest_n)$ the best global position for swarm search; t is the iterations; $i = (1, 2, \ldots, N)$ is the index of particle; $ran_1(\circ)$ and $ran_2(\circ)$ are random number from 0 to 1; and N is the number of swarm.

The best solution shown by the particle position in final is expressed by:

$$S_i^{(t+1)} = S_i^{(t)} + S_i^{(t+1)} \quad (18)$$

Inertia weight β in Eq. (17) can be solved by:

$$\beta^{(t+1)} = \beta_2 - \frac{\beta_2 - \beta_1}{t_m} \times t \quad (19)$$

where β_1 and β_2 are the minimum and maximum inertia weights, respectively, t_m is the maximum iteration. In our works, the weight β decreases linearly (from 0.9 to 0.5). The extended PSO algorithm flow-chart was shown in Fig. 12.

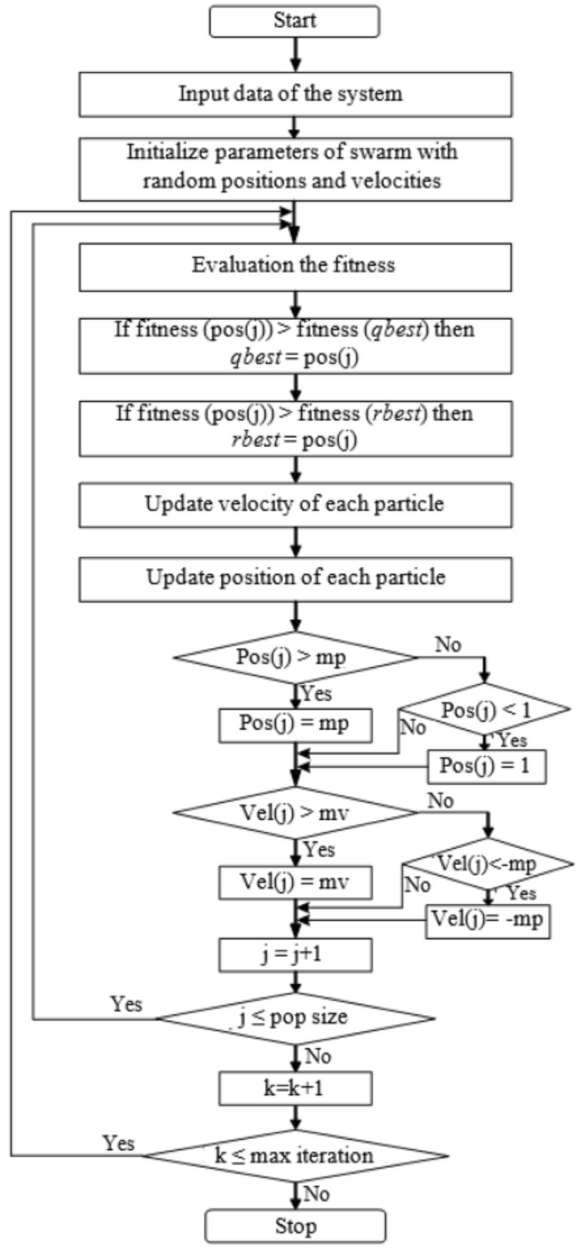

Fig. 12. The extended PSO technique flow-chart.

3. Methodology

The method used in this study includes three main stages: the study of dynamic loads, studies of potential renewable energy, and system design. The three stages are focused on the research location in Semawung hamlet, Kulon Progo district, Yogyakarta Special Region. The site chosen as the basis for the research plan was the irrigation channel in Banjarharjo Village. The village is administratively included in the District of Kalibawang, Kulon Progo Regency, Special Region of Yogyakarta, Indonesia. Geographically, the village is located at coordinates 7.7° South Latitude and 110.21° East Longitude. The area on the map, which is part of Java island, Indonesia, is shown in Fig. 13. Data regarding the potential of micro-hydropower plants have been described in Section 2.2. The electrical load data at the research location has also been described in the section.

The detailed steps of this study are shown in Fig. 14. The procedures for the testing and analysis steps in this study include load data collection and calculation, taking and measuring water flow, data collection of sunlight intensity, modeling using Homer software, a software by HOMER Energy LLC, Boulder, Colorado USA. The software is to design and analysis the optimal power generation system in terms of electricity, economy and emissions produced as an electricity source in Banjarharjo Village, Kulon Progo district, Yogyakarta Special Region, Indonesia.

Photovoltaic solar energy, which is discussed in this study, is a renewable energy source that is being actively developed by Indonesia. Several regions in Indonesia have built large capacity photovoltaic solar power plants through the local government's cooperation and the ministry of energy and mineral resources. The potential of solar energy in Indonesia, located in the equatorial region, is shown in Fig. 15 (Suri et al., 2017). Fig. 15 shows a map of solar radiation in Indonesia, which consists of Eastern Indonesia and West Indonesia. The distribution of electrical energy potential for the eastern region is 5.1 kWh/m^2/day with a monthly variation of around 9%, while for the western region, it is 4.5 kWh/m^2/day with a monthly variation of 10%. Yogyakarta Special Region is located in the western part of Indonesia, so this research refers to solar energy's potential in the region.

The potential of solar energy in Indonesia has attracted the International Renewable Energy Agency (IRENA) to examine the development of power plants in this tropical country. Based on IRENA projections, Indonesia will experience rapid growth in solar power generation until 2030. This projection is in line with the government's commitment to developing renewable energy, as stated in Government Regulation No. 79 of 2014 concerning national energy policies. IRENA estimates that the capacity to generate electricity from solar energy until 2030 is 47 GW. This estimate is based on the 2017 Roadmap for the Future of Renewable Energy, as shown in Fig. 16 (Liebman, 2019).

Fig. 13. The research location on the map, which is part of the island of Java, Indonesia.

Table 4
Specifications of the micro-hydropower plant.

Parameters	Units
Generator type	AC
Power capacity	622 kW
Cost of capital	US$ 1,317,312.32
Cost of replacement	US$ 950,000
Cost for operational and maintenance	US$ 52,692
Efficiency	80%
Available head turbine	12.2 m
Flow rate of channel	6,500 L/s
Flow ratio in minimum	80%
Flow ratio in maximum	110%
Lifetime	25 years

Table 5
Specifications of the PV system.

Parameters	Units
PV panel type	Poly crystals
Power capacity	30 kW
Cost of capital	US$ 50,000
Cost of replacement	US$ 50,000
Cost for operational and maintenance	US$ 0
Lifetime	25 years
Derating factor	80%
Slope	7.12 deg
Azimuth	180 deg
Ground reflectance	20%
Efficiency	17%

4. Results and discussion

4.1. Micro-hydro system design

In this study, the capacity design and analysis of the micro-hydro power system were carried out using Homer software. The specifications of the micro-hydropower plant to be applied in Kulon Progo, Yogyakarta are shown in Table 4. From the specifications of the micro-hydropower plant as shown in Table 4, it can be seen that the electrical machine type used is an alternating current (AC) machine with a nominal power of 622 kW. Moreover, in terms of economic calculation, the generator capital cost is US$ 1,317,312.32, with a cost of replacement of US$ 950,000. Costs for operations and maintenance of the micro-hydropower plant is US$ 52,692. The generator lifetime is estimated to be 25 years. For the turbine physical specifications, the available turbine head is 12.2 m, flow rate of channel is 6500 L/s, the minimum flow ratio is 80%, the maximum flow ratio is 110%, and the turbine efficiency is 80%.

4.2. Photovoltaic system design

The design of a photovoltaic (PV) systems consists of 3 main parts. There are unit size, cost, and capacity were considered in this study. The price of a PV system with an output power of 300 watts is US$ 500. Assuming that if there is damage to the system, it must then be replaced by the overall components, with the replacement cost the same as the cost of capital. The PV capacities considered are 0 kW, 10 kW, 20 kW, 30 kW, and 40 kW, respectively.

The specifications of the PV system to be implemented in Kulon Progo, Yogyakarta are shown in Table 5.

As generally renewable energy power plants, so especially for the type of photovoltaic solar power plants combined with micro-hydropower plants requires an electrical energy storage media. Electric energy storage media that are commonly used are batteries. Storage in the battery is intended to optimize the electrical energy generated by the generator, so that as much as possible the energy can be utilized, by minimizing wasted energy. The battery system design in this study consists of three main parts, namely the unit size, capacity, and cost for supplying batteries. The battery used is a 4KS25P Surrette branded battery with a nominal voltage of 4 Volts and a nominal electric charge storage capacity of 1900 Ah. The cost of procuring this type of battery is US$ 1444. The assumption used in this study is that if the battery is damaged, the action taken is to replace the battery with a new battery with the same capacity and brand. Thus, the cost of procuring a battery is the same as the capital cost when supplying a battery in the initial design.

The design of this renewable energy power generation system is to use a battery device as a storage medium for electrical energy. Therefore a power inverter is also needed. The power inverter functions to change the DC power voltage which is the output from the battery or the output of a solar power plant directly into an AC power voltage to serve the electrical load or to be injected into an available grid system. The power inverter design in this study must meet four main criteria, namely unit

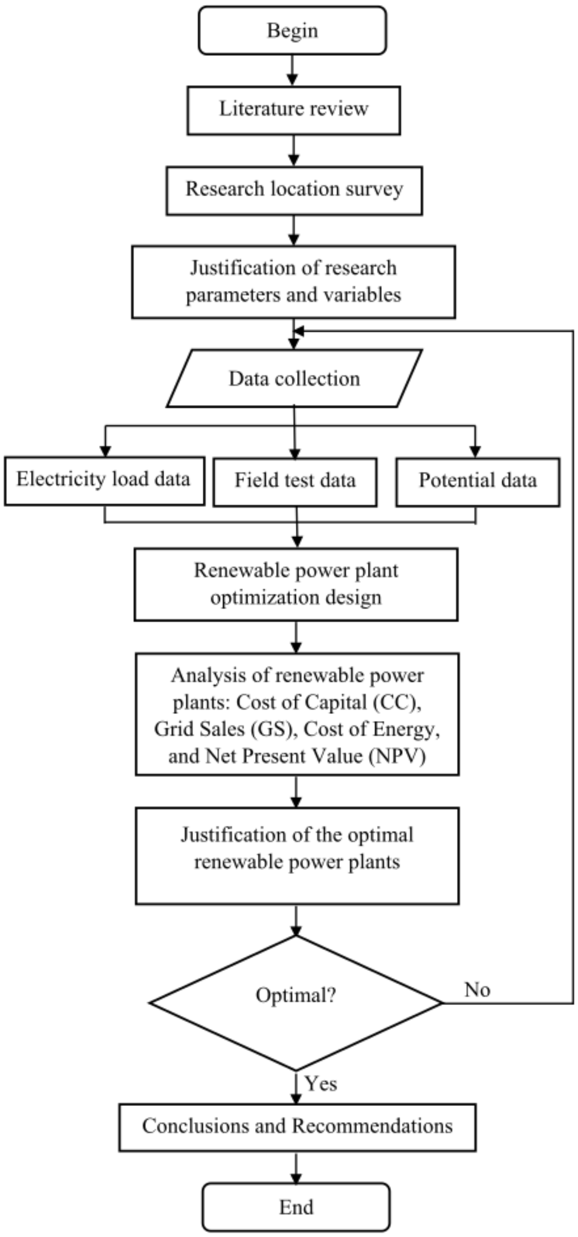

Fig. 14. A flowchart which shows the steps in this study.

size, procurement costs, power capacity, and efficiency. The total power capacity of this power inverter is adjusted to the total capacity of the solar power plant, which is possible at 40 kW. The combination of solar power plants hybridized with micro-hydro is made in five scenarios, namely capacities of 0 kW, 10 kW, 20 kW, 30 kW, and 40 kW, respectively.

Furthermore, the recommended power inverter efficiency in this study is a power inverter with 90% efficiency. This efficiency is in accordance with the power inverters on the market. The cost of procuring a power inverter is US$ 2000 for each kW. The amount of this fee is obtained based on information from high-quality power inverter distributors in Indonesia. In this study, it

Table 6
Total of cost of capital for some combination of the renewable energy systems.

Number of combination	Combination of renewable power systems	Total of cost of capital (US$)
1	Grid system + micro-hydro + Solar PV of 0 kW	1,317,310
2	Grid system + micro-hydro + Solar PV of 10 kW	1,465,961
3	Grid system + micro-hydro + Solar PV of 20 kW	1,482,627
4	Grid system + micro-hydro + Solar PV of 30 kW	1,499,294
5	Grid system + micro-hydro + Solar PV of 40 kW	1,515,961

is assumed that if the power inverter is damaged in its operation, then a new inverter must be replaced. Thus, the cost required to replace a new inverter is the same as the capital cost of the power inverter.

4.3. Design of renewable energy systems based on micro-hydro and solar photovoltaic

In our work, planning, operations, and maintenance simulations were conducted for renewable energy system based on micro-hydro and solar photovoltaic using Homer Energy software. Simulations were conducted using input system configurations and component data to produce several comparisons of predetermined parameters. Comparisons of each parameter from all settings used included cost of capital, grid sales, cost of energy, and net present value.

Total of costs of capital can be defined as costs that must be spent to finance the entire project, in this case, for financing the construction of renewable energy based on micro-hydro and solar photovoltaic energy. In this work, the total cost is the initial costs incurred to build a renewable energy power generation system based on micro-hydro and solar photovoltaics. The total of cost of capital for some combination of the renewable energy systems are shown in Table 6 and Fig. 11.

Both Table 6 and Fig. 17 show an evaluation of the cost of capital of a micro-hydro and solar photovoltaic renewable energy generation system. The evaluation results indicate the lowest to highest investment costs that must be spent to build a renewable energy power generation system with various combinations of generating power capacity. The lowest cost of capital is a renewable energy generation system with a combination of a grid and micro-hydro system, where solar photovoltaic plants are assumed to have a capacity of 0 kW. The lowest cost of capital is US$ 1,317,310. Furthermore, the highest cost of capital is a renewable energy generation system with a combination of a grid system, a micro-hydro generator, and a solar photovoltaic generator with a capacity of 40 kW. The highest cost of capital for this combination is US$ 1,515,961. The capacity of solar photovoltaic power plants determines the value of investment costs that must be spent, the greater the capacity, the higher the investment costs. This fact is since in this study the capacity of micro-hydro plants is considered to be fixed at 622 kW because it takes into account the potential of irrigation canals that are used as energy sources for micro-hydro plants.

After the cost of capital, the subsequent analysis will be grid sales for micro-hydro and solar photovoltaic renewable energy generation systems. Grid sales can be defined as the cost of sales obtained from a managed system, in this case, the costs obtained from excess electrical energy caused by excess energy needed by the load served by renewable energy power generation systems.

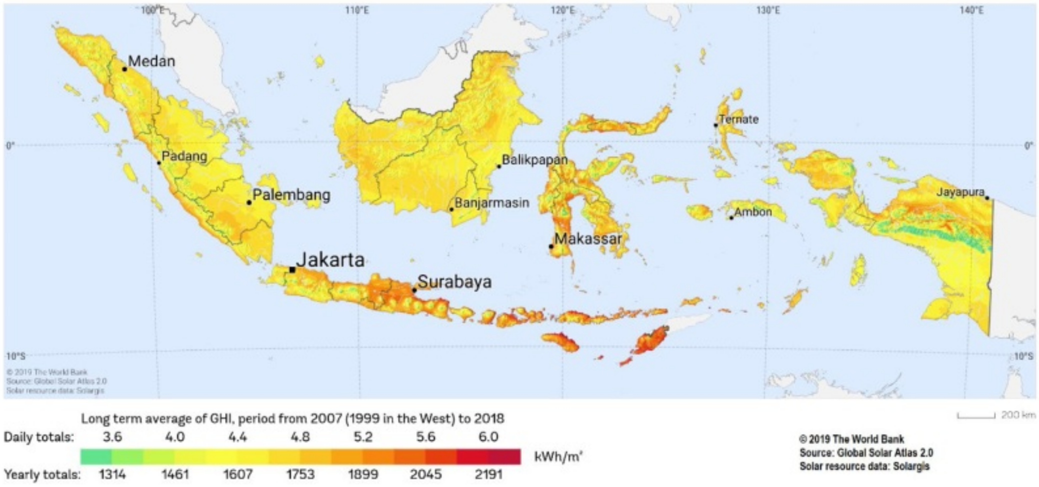

Fig. 15. Solar radiation map of the Indonesian area (Suri et al., 2017).

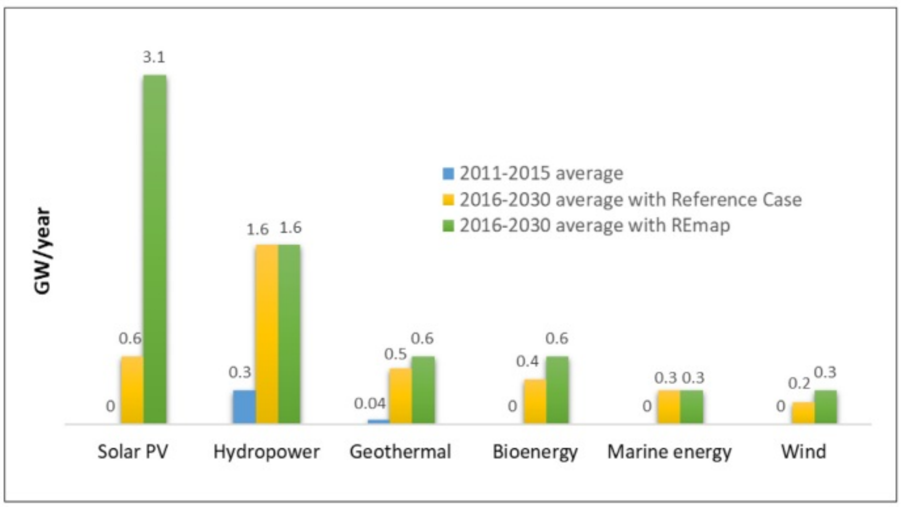

Fig. 16. Renewable energy power generation capacity in Indonesia and its projections until 2030 (Liebman, 2019).

This excess energy can be sold to the state electricity company through a grid distribution system available in the Kulonprogo area, Yogyakarta Special Region. Grid sales for some combinations of renewable energy systems could be seen in Table 7 and Fig. 18.

Table 7 and Fig. 18 show the evaluation results on the sale to the grid for renewable energy power generation systems in this study. The lowest selling value to the network is when the combined power plant consists of a grid system, a micro-hydro generator with a capacity of 622 kW, and a solar photovoltaic plant with a capacity of 0 kW. In this composition, it can also be said that the only reliable power plants are micro-hydro plants. The electrical energy that can be sold to the grid in this combination is 4,263,921 kWh in one year. Based on the optimization results, it can be seen that the higher the capacity of integrated solar photovoltaic power plants, the higher the electrical energy that can be sold to the grid. Optimization results show that the most considerable electricity that can be sold to the network is for the composition of renewable energy plants consisting of a grid system, a micro-hydro plant with a capacity of 622 kW, and a solar photovoltaic plant with a capacity of 40 kW. In this combination, the electricity that can be sold to the grid in this combination is 4,295,454 kWh in one year.

Table 7
Grid sales for some combination of the renewable energy systems.

Number of combination	Combination of renewable power systems	Grid sales (kWh/year)
1	Grid system + micro-hydro + Solar PV of 0 kW	4,263,921
2	Grid system + micro-hydro + Solar PV of 10 kW	4,271,803
3	Grid system + micro-hydro + Solar PV of 20 kW	4,279,687
4	Grid system + micro-hydro + Solar PV of 30 kW	4,287,570
5	Grid system + micro-hydro + Solar PV of 40 kW	4,295,454

In this study also analyzed the cost of energy (COE). Cost of energy is the cost incurred to produce electrical energy of 1 kWh.

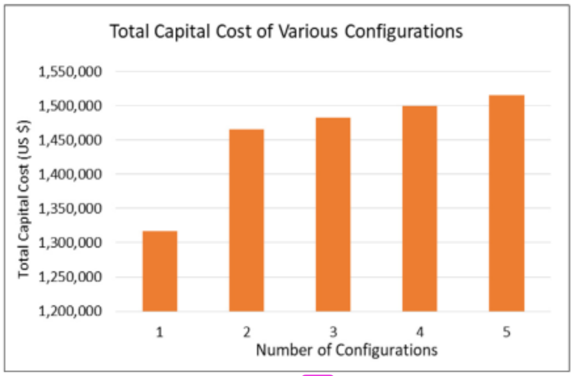

Fig. 17. Total of cost of capital for some combination of the renewable energy systems.

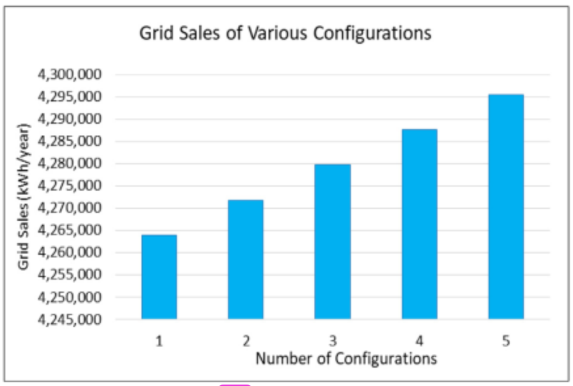

Fig. 18. Grid sales for some combination of the renewable energy systems.

In conventional power plants, the cost of energy is calculated based on the consumption of fuel oil, coal, or gas, to produce electricity every 1 kWh. In connection with this research is the application of renewable energy power plants, where the fuel used is water and sunlight obtained free of charge. The cost of energy is minimal to a minus value. This fact can be seen from the calculation of the cost of electricity from some combinations of renewable energy systems, as shown in Table 8 and Fig. 19. The cost of energy for various combinations of renewable energy power systems is minus. This fact is due to the cost of free fuel and renewable energy generation systems capable of selling excess energy to the grid system. The highest price of electricity is for a combination of a grid system, a micro-hydro plant with a capacity of 622 kW, and a solar PV generator with a capacity of 40 kW, which is valued at US$ -0,131 per kWh. The cost of energy value is the same as the composition of the grid system, a micro-hydro generator with a capacity of 622 kW, and a solar PV generator with a capacity of 30 kW. The best cost of energy value, in this case, the lowest price per kWh, is the composition of the grid system, a micro-hydro generator with a capacity of 622 kW, and a solar PV generator with a capacity of 0 kW, which is US$ -0,147 per kWh. In other words, the composition of the generation system with the best energy costs is a generating system that relies on micro-hydro.

In this study, an optimization of the COE using the extended PSO technique was also carried out to ensure optimal results from Homer software further. Optimization results for both COE and NPV using the Extended PSO method have been being compared

Table 8
Cost of energy for some combination of the renewable energy systems.

Number of combination	Combination of renewable power systems	Cost of energy (US$/kWh)
1	Grid system + micro-hydro + Solar PV of 0 kW	−0.147
2	Grid system + micro-hydro + Solar PV of 10 kW	−0.133
3	Grid system + micro-hydro + Solar PV of 20 kW	−0.132
4	Grid system + micro-hydro + Solar PV of 30 kW	−0.131
5	Grid system + micro-hydro + Solar PV of 40 kW	−0.131

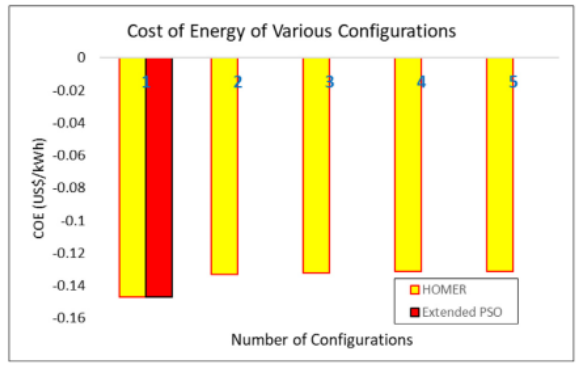

Fig. 19. Cost of energy for some combination of the renewable energy systems, comparison based on HOMER and Extended PSO.

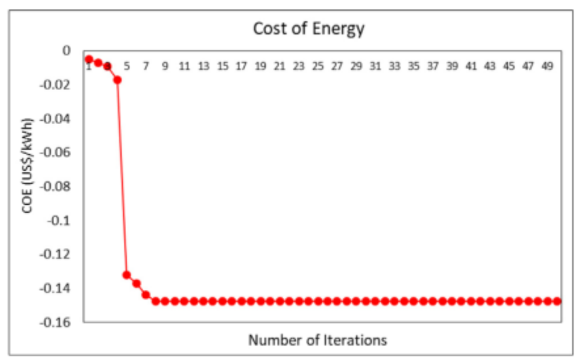

Fig. 20. Cost of Energy optimization using extended PSO technique.

with HOMER. The PSO parameter used is a population of size 20 with the highest number of iterations is 50. The results of COE optimization using the extended PSO technique are shown in Fig. 20. As shown in Fig. 20, the optimal COE is US$ -0,147 per kWh obtained in the 8th iteration of the 50 iterations tested.

The final analysis in this work is the net present value (NPV) of the renewable energy power generation system. Net present value can be defined as the difference between expenditure and income, which has been reduced by the cost of capital. Net present value can also be understood as estimated future cash flows discounted at this time. In determining the net present value, data on estimated investment costs, operational costs, and maintenance costs, as well as estimated benefits from the planned project, are needed.

Table 9
Net present value for some combination of the renewable energy systems.

Number of combination	Combination of renewable power systems	Net present value (US$)
1	Grid system + micro-hydro + Solar PV of 0 kW	−1,961,277
2	Grid system + micro-hydro + Solar PV of 10 kW	−1,772,556
3	Grid system + micro-hydro + Solar PV of 20 kW	−1,761,662
4	Grid system + micro-hydro + Solar PV of 30 kW	−1,750,766
5	Grid system + micro-hydro + Solar PV of 40 kW	−1,739,872

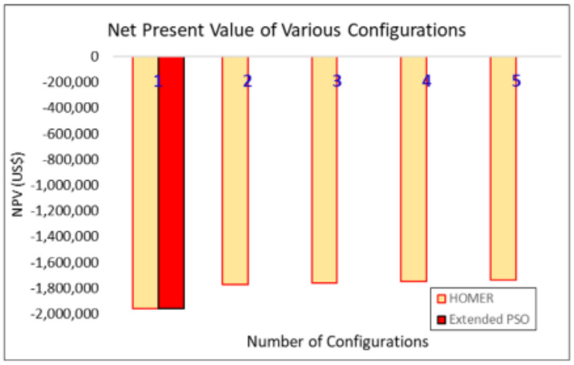

Fig. 21. Net present value for some combination of the renewable energy systems, comparison based on HOMER and Extended PSO.

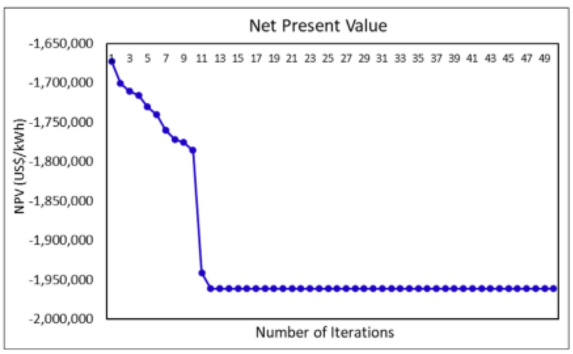

Fig. 22. Net present value optimization using extended PSO technique.

Table 9 and Fig. 21 show the net present value for a combination of the renewable energy systems in this study, comparison based on HOMER and Extended PSO. The net present value for all combinations of renewable energy generation is negative. This negative value is due to the high income obtained from renewable energy generation systems by selling electricity to the existing grid system. The best net present value is a renewable energy electricity generation system with a combination of a grid system, a micro-hydro generator with a capacity of 622 kW, and a solar photovoltaic plant with a capacity of 0 kW. In this composition, the net present value is US $ -1,961,277. In other words, the most optimal renewable energy generation is a combination that relies on micro-hydro generation.

Table 10
Optimal renewable energy power generation systems.

Number	The parameters considered	Values
1	Solar photovoltaic size (kW)	0
2	Micro-hydro size (kW)	622
3	Battery of S4KS25P	0
4	Power inverter size (kW)	0
5	Grid size (kW)	1000
6	Cost of capital (US$)	1,317,310
7	Cost for operating (US$/year)	−318,269
8	Net present value (US$)	−1,961,277
9	Cost of energy (US$/kWh)	−0,147
10	Renewable fraction	1

An optimization of the NPV using the extended PSO technique was also carried out to ensure optimal results from Homer software further. The PSO parameter used is a population of size 20 with the highest number of iterations is 50. The results of NPV optimization using the extended PSO technique are shown in Fig. 22. As shown in Fig. 22, the optimal NPV is US$ -1,961,277 obtained in the 11th iteration of the 50 iterations tested.

The net present value evaluation results are an important parameter in determining the combination of renewable energy power generation systems in this study. The best net present value resulting from optimization shows the most optimal renewable energy power generation system. Based on this net present value, the best combination of renewable energy generation is a grid system and a micro-hydro generator with a capacity of 622 kW. The parameters of the best renewable energy power generation system are shown in Table 10.

The evaluation results using Homer software and extended PSO method as summarized in Table 10, that the electrical energy produced by micro-hydro plants is 5,458,713 kWh per year. In this condition, the purchase of the grid system is 0%, meaning that this renewable energy generation system does not require additional electrical energy from the grid system. Electricity consumption for 962 households is 1,194,642 kWh per year. This energy consumption is only about 22% of the total electrical energy produced by the micro-hydro system. Thus, 78% of the remaining electrical energy generated by this micro-hydro system can be sold to the existing grid system. The value of 78% of electrical energy is equivalent to 4,263,921 kWh per year.

Fig. 23 shows the electrical power produced by renewable energy systems on average every month. The highest average power in this study is in July 2018, which is 665 kW. This highest power is caused by high rainfall in the month, which results in very high water discharge in irrigation canals. Conversely, the lowest power produced by renewable energy systems is in May 2018, which is 586 kW. This relatively small power is caused by low rainfall which causes the water discharge in the irrigation canal to be quite. Besides, Fig. 24 shows electric power generated from renewable energy systems on average every month that can be sold to the grid system. In the figure, it can be seen that the electricity sold to the grid system follows the pattern of household load characteristics. The peak burden for household consumers occurs at 6:00 to 09:00 PM. In this period, consumer electricity demand is very high, so electricity that can be sold to the grid system is low. Conversely, in the time range of 00.00 to 04.00 AM, the consumption of electrical power by consumers is relatively small, so that excess electrical power that can be sold to the grid system is high.

5. Conclusions

Based on the results of the analysis in this study, Kulon Progo Regency, located in the Special Region of Yogyakarta, Indonesia

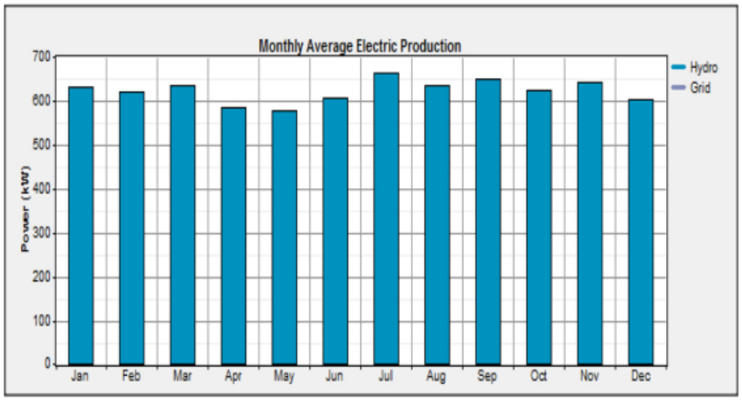

Fig. 23. Electrical power produced by renewable energy systems on average every month.

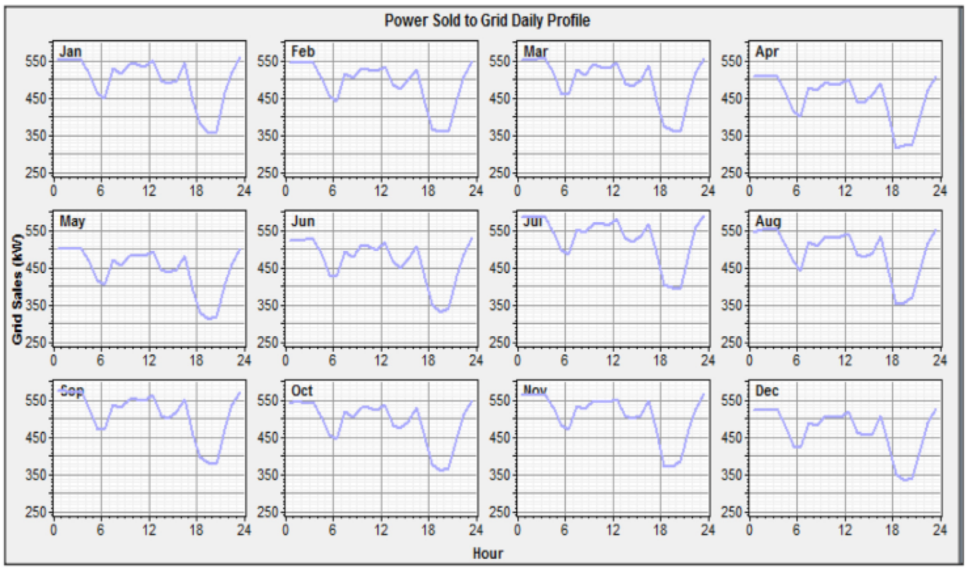

Fig. 24. Electricity generated from renewable energy power generation systems on average every month that can be sold to the grid system.

has concluded that the potential of renewable energy sources in the area is very high, especially micro-hydropower and photovoltaic solar power. Micro-hydro and solar photovoltaic plants have the opportunity to be used as an alternative solution in providing electricity to rural communities. Irrigation channel originating from the river Progo, capable of producing an average water flow of 6696 L/s at a head height of 12.2 m. If a micro-hydropower plant is built on the irrigation channel, an output power of up to 622 kW can be produced. This enormous power capacity is significant for rural communities in the Kulon Progo region. Based on simulation results using Homer software, electrical energy can be generated from micro-hydropower plants or in combination with solar photovoltaic power plants. This combined power plant can service the electrical load of 962 households. The production of electricity to supply the domestic housing load is 3273 kWh per day. In addition to meeting the needs of the local area, excess electrical power from micro-hydro and solar photovoltaic plants can also be sold to available grid systems. Based on the analysis, the excess electricity that can be sold every year is 4,263,951 kWh.

Nomenclature

A	Cross-sectional area of water flow [m^2]
A_D	Diode constant
A_{area}	Water catchment area of the micro-hydro power plant [m^2]
A_{gauge}	Catchment area of the gauge at the power plant site micro-hydro power plant [m^2]
β_1	Minimum inertia weights
β_2	Maximum inertia weights
C_{ann}	Total year-long cost of the hybrid systems
COE	Cost of energy [US$]
CRF	Function that returning the capital recovery factor
E	Hydro-potential energy [J]
g	Gravitational acceleration constant (m/s^2)
GC	Annual electricity generation costs [US$]
h	Head of water source (m),
i	Annual real discount rate [%]
I	Output current of a solar photovoltaic cell module [A]

I_d	Diode current [A]
I_s	Short-circuit current [A]
I_p	Parallel current (A).
I_{ph}	Photo-current of a solar photovoltaic cell module [A]
K	Boltzmann's constant = 1.380×10^{-23} J/K
K_s	Scaling constant
m	Mass of water (kg),
N_s	PV cells number connected in series
N_p	PV cells number connected in parallel
NPV	total net present value of a hybrid system [US$]
P	Real output power [kW]
P_G	Absolute electric power generated by hybrid power plants [kW]
P_L	Total electrical load power served by hybrid power plants [kW]
q	Charge of an electron = 1.602×10^{-19} °C
Q_{area}	Water discharge available at the micro-hydro power plant site [m^3/s]
Q_{gauge}	Water discharge in the gauge [m^3/s]
R_s	Series resistance of a solar photovoltaic module [Ω]
R_p	Parallel resistance of a solar photovoltaic module [Ω]
R_{proj}	Project lifetime [years]
ρ	Water density [kg/m^3]
T_o	Real-time temperature [K]
t_m	Maximum iteration
V	Output voltage of a solar photovoltaic module [V]
v	Velocity of water flow [m/s]
V_{OC}	open-circuit voltage (V)

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Ahmed, J., Salam, Z., 2018. An enhanced adaptive P & O MPPT for fast and efficient tracking under varying environmental conditions. IEEE Trans. Sustain. Energy 9 (3), 1487–1496.

Al Hasibi, R.A., Hadi, S.P., Sarjiya, 2018. Integrated and simultaneous model of power expansion planning with distributed generation. Int. Rev. Electr. Eng. 13 (2), 116–127.

Bana, S., Saini, R.P., 2016. A mathematical modeling framework to evaluate the performance of single diode and double diode based SPV systems. Energy Rep. 2 (2016), 171–187.

Ghasemi, M.A., Ramyar, A., Eini, H.I., 2018. MPPT method for PV systems under partially shaded conditions by approximating I–V curve. IEEE Trans. Ind. Electron. 65 (5), 3966–3975.

Hauck, M., Rumeau, A., Bratcu, A.I., Bacha, S., Munteanu, I., Roye, D., 2018. Identification and control of a river-current-turbine generator—Application to a full-scale prototype. IEEE Trans. Sustain. Energy 9 (3), 1365–1374.

Hui, J.C.Y., Bakhshai, A., Jain, P.K., 2015. A sensorless adaptive maximum power point extraction method with voltage feedback control for small wind turbines in off-grid applications. IEEE J. Emerg. Sel. Top. Power Electron. 3 (3), 817–828.

Ibrahim, I.A., Hossain, M.J., Duck, B.C., Fell, C.J., 2020. An adaptive wind-driven optimization algorithm for extracting the parameters of a single-diode PV cell model. IEEE Trans. Sustain. Energy 11 (2), 1054–1066.

Kalla, U.K., Singh, B., Murthy, S.S., Jain, C., Kant, K., 2018. Adaptive sliding mode control of standalone single-phase microgrid using hydro, wind, and solar PV array-based generation. IEEE Trans. Smart Grid 9 (6), 6806–6814.

Khan, M.R.B., Jidin, R., Pasupuleti, J., Shaaya, S.A., 2014. Optimal combinations of PV, wind, micro-hydro and diesel systems for a seasonal load demand. In: PECon 2014, 1–3 Dec. 2014.

Kumar, B.S., Sudhakar, K., 2015. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. Energy Rep. 1 (2015), 184–192.

Kusakana, K., Munda, J.L., Jimoh, A.A., 2009. Feasibility study of a hybrid PV-micro hydro system for rural electrification. In: IEEE AFRICON 2009, 23–25 Sept. 2009.

Li, Y., Hu, W., Xu, Q, Huang, X., Chen, G., Han, X., Chen, Z., 2019. Optimized operation of hybrid system integrated with MHP, PV and PHS considering generation and similarity. IEEE Access 7, 107793–107804.

Liebman, A., 2019. Indonesia: A nation rich in unrealized solar energy potential Solar magazine.

Metry, M., Shadmand, M.B., Balog, R.S., Abu-Rub, H., 2017. MPPT of photovoltaic systems using sensorless current-based model predictive control. IEEE Trans. Ind. Appl. 53 (2), 1157–1167.

Mosobi, R.W., Gao, S., 2018. Performance analysis of hybrid solar-wind-microhydro system in Islanded mode. In: 2018 IEEE Region Ten Symposium, 4–6 July 2018.

Murni, S., Whalea, J., Urmeea, T., Davisa, J., Harries, D., 2012. The role of micro hydro power systems in remote rural electrification: a case study in the Bawan Valley, Borneo. Procedia Eng. 49, 189–196.

Patel, H., Chowdhury, S., 2018. Cost effective microhydro-based microgrid schemes for rural electrification in South Africa. In: proceedings of 2018 53rd International Universities Power Engineering Conference (UPEC), pp. 1–6.

Peng, B.R., Che, K., Liu, Y.H., 2018. A novel and fast MPPT method suitable for both fast changing and partially shaded conditions. IEEE Trans. Ind. Electron. 65 (4), 3240–3251.

Rajadurai, M.J., Shaanmaadhuran, M., Vimal Amaladoss, J., Gowri Sankar, S., Kirubakaran, V., 2017. Integration of solar PV — Micro hydro-power system for household application. In: 2017 International Conference on Advances in Electrical Technology for Green Energy (ICAETGT), 23–23 Sept. 2017.

Raza, A., Yousaf, Z., Jamil, M., Gilani, S.O., Abbas, G., Uzair, M., Shaheen, S., Benrabah, A., Li, F., 2018. Multi-objective optimization of VSC stations in multi-terminal VSC-hvdc grids, based on PSO. IEEE Access 6, 62995–63004.

Ronad, B.F., Jangamshetti, S.H., 2015. Optimal cost analysis of wind-solar hybrid system powered AC and DC irrigation pumps using HOMER. In: 2015 International Conference on Renewable Energy Research and Applications (ICRERA), Palermo, Italy, 22–25 Nov. 2015.

Roncallo, O.P., Ingham, D., Pourkashanian, M., 2020. Techno-economic benefits of grid-scale energy storage in future energy systems. Energy Rep. 6 (5), 242–248.

Sher, H.A., Addoweesh, K.E., Al-Haddad, K., 2018. An efficient and cost-effective hybrid MPPT method for a photovoltaic flyback microinverter. IEEE Trans. Sustain. Energy 9 (3), 1137–1144.

Suri, M., Cebecauer, T., Suriova, N., Schnierer, B., Skoczek, A., Betak, J., Madlenakova, V., Chrkavy, D., 2017. Solar Resource and Photovoltaic Power Potential of Indonesia Renewable Energy Resource Mapping and Geospatial Planning – Indonesia. World Bank Group, Global ESMAP Initiative, Bratislava, Slovakia.

Suyanto, H., Shidiq, M., Ferdianzah, A.N., Utomo, T., Musirin, I., Awalin, L.J., 2018. Dynamic stability impact of the hybrid wind and microhydro renewable energy sources on the distribution system. In: EECCIS.

Syahputra, R., Robandi, I., Ashari, M., 2014. Optimization of distribution network configuration with integration of distributed energy resources using extended fuzzy multi-objective method. Int. Rev. Electr. Eng. 9 (3), 629–639.

Syahputra, R., Robandi, I., Ashari, M., 2015. Performance improvement of radial distribution network with distributed generation integration using extended particle swarm optimization algorithm. Int. Rev. Electr. Eng. 10 (2), 293–304.

Syahputra, R., Robandi, I., Ashari, M., 2016. Performance enhancement of distribution network with DG integration using modified PSO algorithm. J. Electr. Syst. (JES) 12 (1), 1–19.

Syahputra, R., Soesanti, I., 2019. Performance improvement for small-scale wind turbine system based on maximum power point tracking control. Energies 12 (20), 3938.

Syahputra, R., Soesanti, I., 2020. Planning of hybrid micro-hydro and solar photovoltaic systems for rural areas of central Java, Indonesia. J. Electr. Comput. Eng.

Tang, L., Xu, W., Mu, C., 2017. Analysis for step-size optimisation on MPPT algorithm for photovoltaic systems. IET Power Electron. 10 (13), 1647–1654.

Tudu, B., Mandal, K.K., Chakraborty, N., 2014. Optimal design and performance evaluation of a grid independent hybrid micro hydro-solar-wind-fuel cell energy system using meta-heuristic techniques. In: ICONCE 2014, 16–17 Jan. 2014.

Vinod, R. Kumar, Singh, S.K., 2018. Solar photovoltaic modeling and simulation: As a renewable energy solution. Energy Rep. 4 (2018), 701–712.

Wang, L., Chen, S.J., Jan, S.R., Li, H.W., 2013. Design and implementation of a prototype underwater turbine generator system for renewable microhydro power energy. IEEE Trans. Ind. Appl. 49 (6), 2753–2760.

Younas, M., Kamal, R., Khalid, M.S., Qamar, A., 2018. Economic planning for remote community microgrid containing solar PV, biomass gasifier and microhydro. In: proceedings of 2018 Clemson University Power Systems Conference (PSC), pp. 1–7.

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