Optimal Cost Valuation for Renewable Power Plants Using PSO in Rural Area

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Abstract: Cost is the main factor to run a project. Projects of renewable hybrid power plants that typically built in rural area have limited development funds. Thus, these plants should be based on an effectiveness and efficiency in order to meet the load demands with a certain reliability index. This work explains minimum cost by optimizing the cost of the power plants, Nett Present Cost or NPC, with an Equivalent Loss Factor (ELF) index to supply typical villages needs (200 kW), with the source of wind, solar, micro hydro and fuel cell. The result of this optimization includes batteries are used as an energy storage, which are considered as a source in the optimization process. The simulation by PSO method is proposed to solve the optimization problems. The simulation produces the equation function between Cost of Energy, LCOE and a reliability ELF index by y = -0.016ln (x) + 0.0131. The lower ELF index the higher LCOE value, according to the equation function.

Keywords: particle swarm optimization, load demand, renewable, hybrid renewable power plants, HRPP, minimum cost, simulation.

1. Introduction

Electricity is a vital issue now and in the future, it appears as an important indicator for the quality and welfare for the community. Consumption of electric energy is closely linked with the communities of economic growth. Not all communities have the opportunity to obtain it. Many villages do not have access to grid, like rural areas, coastal areas and small islands.
To meet electricity demand for the villages, electric power has been generated from its potential energy sources. A good choice is renewable energy sources because they are friendly on environmental side. Some renewable energy sources are influenced by seasons, weather and environmental conditions such as wind and solar. Meanwhile, load patterns depend on the consumers in the village. Therefore, hybrid power supply is important to fulfill demands.

A few papers about the hybrid power plants have been published. Generally, they used the combination of the wind solar[1], and batteries as a strorage, [2][3]. Navaeefard et al. (2010) created a combination of wind, solar, battery and fuel cell [4], the combination of wind, solar, tidal and batteries [5], Or any other combinations [6][7][8][9][10][11][12]. This paper will use a combination of wind, solar, microhydro, fuel cells, and batteries as power strorage.

In its implementation, the development of hybrid system requires no small cost. However, the development of rural areas has limited funds. Thus, to overcome these problems must be done by optimization step.

2. Problem Formulation

The main issue of this research is how to find minimum cost of generating renewable hybrid systems (wind, solar, micro-hydro, fuel cells, and batteries) method in order to optimize the amount of each component of the hybrid system, thus align the needs of the load with a certain degree of reliability of power supply as defined in ELF Index. This renewable generation hybrid system has a lifetime benefit for twenty years.

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A. System Cost Analysis

The objective of this work is to minimize the cost function which consists of investment costs (capital costs), cost of replacement (replacement cost), operation and maintenance costs (operation and maintenance -OM- cost). Calculation of selected cost system is using Net Present Cost (NPC) method which is selected to calculate the cost system. It is formulated by this following equation (1) [3][4][5][9]:

$$min\ NPC = \sum_{i=1}^{L} N_i (CC_i + RC_i \cdot K_i + MC_i \cdot PWA(ir, R)) \quad (1)$$

L stands for the number of renewable energy sources which consist of wind turbines, solar cells, micro-hydro, battery, and fuel cell (electrolysis, hydrogen tanks and fuel cells). N_i represents number of generating units of each of the renewable energy sources, which will be evaluated using the optimization method. The investment cost ($/unit) is represents by CC_i , while RC_i stands for replacement cost ($/unit). MC_i shows the operating and maintenance costs ($/unit-year).

In order to evaluate the economic feasibility on one plant, the analysis of comparable energy costs (levelized), should be considered for all of these components. Analysis of the energy costs, called Levelized Cost of Energy (LCOE), this LCOE is calculated by the following equation [13]:

$$LCOE = \frac{Total\ annualized\ cost\ (USD/year)}{Annual\ load\ served\ (kWh/year)} (USD/kWh) \quad (2)$$

Finding the LCOE value, total value of the project NPC should be converted into series of annual cash flows known as total annualized cost. The following equation (3) is used to calculate the total annualized cost.

$$\text{Total annualized cost}(\$/\text{year}) = \text{Total NPC} \times \text{CRF} \quad (3)$$

CRF is the capital recovery factor as it is represented by this following formula:

$$CRF(ir, n) = \frac{(ir \cdot (1+ir)^n)}{(1+ir)^{n-1}} \quad (4)$$

B. Equivalent Loss Factor (ELF) Index

Equivalent Loss Factor (ELF) index provides information on the number of energy load cannot be supplied by Hybrid Renewable Power Plant (HRPP) at each time interval. The advantage of this index is able to determine the generation capacity with or without taking into account the possibility of the unexpected. ELF index can be expressed by equation 5 follows [4][5][10][14].

$$\text{ELF} = \frac{1}{T} \sum_{t=1}^{T} \frac{Q_t}{D_t} \quad (5)$$

Where, Q_t is a total loss of load each time interval and D_t is the total load demand each time interval. Meanwhile, T is the total number of time interval (1 hour). The data used in this study is one year, which means 8760 hours.

In an ideal system, where the load demand will always be supplied, the ELF value will equal to 0. Therefore, when the value of the ELF >0, that means sometimes the load demand cannot be met by HRPP. Some utility companies in developing countries set ELF <0.0001 for mikrogrid applications that are not connected to the grid. While in some underdeveloped countries usually set ELF <0.01 [7][14][15].

3. Hybrid Renewable Power Plant Model

In this work, renewable hybrid system resources are contained of sunlight, wind and river flow. Energy storage system which consisted of battery and fuel cells are important to maintaining the balance supply and demand of the energy. Figure 1 shows the renewable hybrid power system consisting of solar cells, wind turbines, micro hydro, fuel cells and batteries.

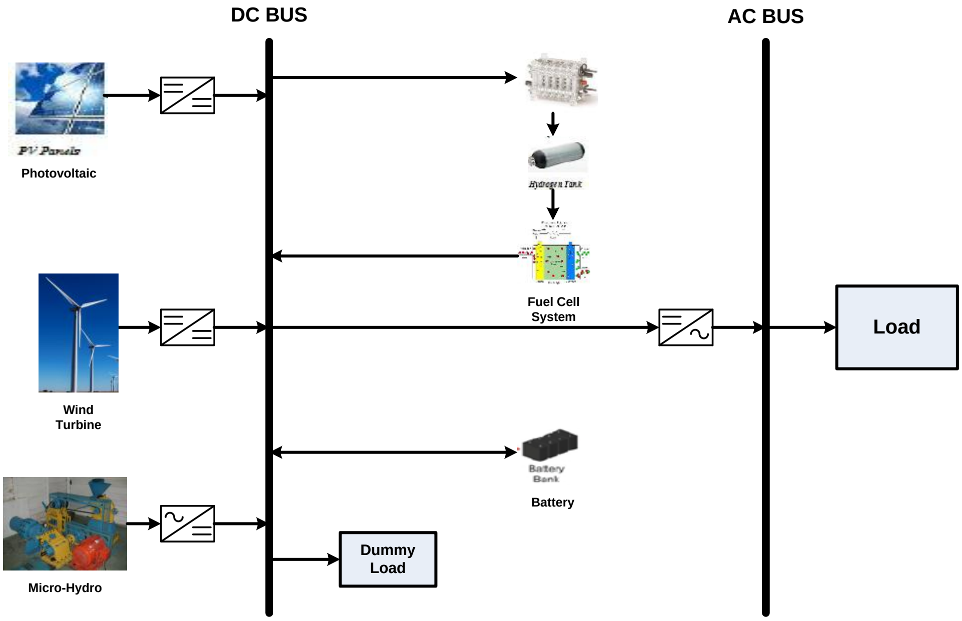

Figure 1. Hybrid Renewable Power Plant consist of Photovoltaic, Wind Turbine, Microhydro, Fuel Cell and Battery

A. Wind Turbine

The determination of an appropriate model of wind turbines is important, since the characteristics of the power output from wind turbine can be different depending on the type also power value (rated). In this work, a BWC Excel-R/48 wind turbines type is used, which the power output characteristic shown in figure 2.

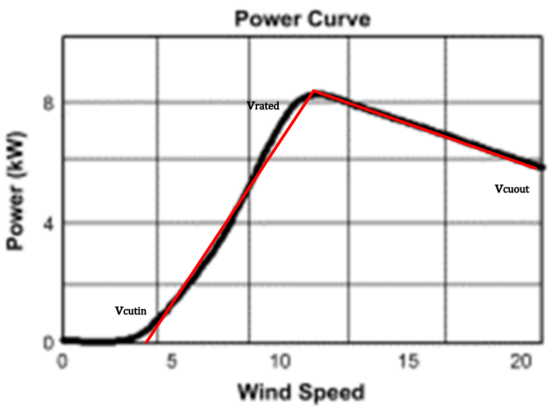

Figure 2. Excel-R/48 power output characteristic [11]

Based on figure 2, the characteristics of the wind turbine output power ($P_{wg,t}$) in term of wind speed is shown in equation (6) follows [4][5][9]:

$$P_{wg,t} = \begin{cases} 0 & v_t < v_{cutin},\ v_t > v_{cutout} \\ P_{max}\left(\frac{v_t - v_{cutin}}{v_{rated} - v_{cutin}}\right) & v_{cutin} \le v_t \le v_{rated} \\ p_{max} + \left(\frac{p_{furl} - p_{max}}{v_{cutout} - v_{rated}}\right).(v_t - v_{rated}) & v_{rated} < v_t \le v_{cutout} \end{cases} \quad (6)$$

Where, v_t is wind speed at a single time interval, $v_{cutin}$is value of the cut-in wind speed, $v_{cutout}$is value of the cut outwind speed and v_{rated} is value of wind rate speed (m/s).p_{max} is the maximum output power and $p_{furl}$is the output power at the cut-out speed (kW) calculated after passing through the inverter.

B. Photovoltaic

The output power of the solar cell system is strongly influenced by the level of solar radiation and ambient temperature which affects the solar cell. There are several methods that can be used to calculate the output power from the solar cell system. The easiest method is using comparison between output power (darimana) which generated by the output power of the factory. Test results in STC (Standard Test Conditions irradiance 1000W/m2, AM1.5 spectrum with 25°C of solar cell temperature), as shown in equation (7) [2][5][9]. This equation can used the assumption that the surface temperature of the solar cells is constant in 25°C during the day throughout the year.

$$P_{pv,t} = \frac{G_t}{G_{stc}} \cdot P_{PV,rated} \cdot \eta_{PV,conv} \quad (7)$$

Where G_t is the solar radiation on photovoltaic array every time of interval (W/m2), G_{stc} is the standard radiation test on the photovoltaic equipment equal to 1000 (W/m2). $P_{PV,rated}$ is rate power of each photovoltaic array (kW) and $\eta_{PV,conv}$ is solar cells efficiency due to temperature rise and DC/DC converter for each of photovoltaic array.

C. Micro-hydro Power plant (MHP)

In this work, MHP is designed to supply the base load. Thus, the expected power output from the MHP will always constant throughout the year. Shortly, the constant of water flows and head are required. As shown in this following equation (8).

$$P_{mh} = \rho \cdot g \cdot H \cdot Q \cdot \eta \quad (8)$$

The power generated by the MHP (P_{mh}) is depends on the discharge Q (m3/s) and the head H (m). In order to get the value of constant discharge and head, the micro-hydro power plants (MHP) are using a run-of-river scheme.

To get the value of a constant discharge, flow duration curve can be used. From these curves will get mainstay discharge, which is a minimum discharge at the highest possibilities in river flows. Due to the value of the constant discharge and head, then the MHP output power will be considered constant in every time interval.

D. Battery Charging and Discharging State

Battery is a traditional electrical energy storage device that has a high efficiency. Similar a water tank, battery will accommodate the producing of electrical energy using the renewable generator of its suit capacity. Further, battery will supply the load when needed and drain the energy to a minimum (depth of discharge) capacity. The difference between the power generation and load demand are depended on the condition of charging. The principle of charging and discharging depends on the state ($P_{ren,t}$) and the load power demand at time t($P_{load,t}$).

Basic principle of battery operation explained as follows. The power from battery is needed when the renewable hybrid generation($P_{ren,t}$) is not able to provide power according to the load demand ($P_{load,t}/\eta_{inv}$,). When the renewable generation produced higher power than the load demand, remained generating power from renewable generation will be stored to the battery. Every hour, battery charge status is associated with the state before it charging. Production of energy absorbed by the battery during the time $(t-1)$ to (t) are described on this following equation (9) [12].

$$C_{bat,t} = C_{bat,(t-1)} \cdot (1-\sigma) + P_{batc,t} \quad (9)$$

$C_{bat,t}$ and $C_{bat,(t-1)}$, are the number of the energy which available inside of the battery, When time (t) and the previous time (t-1), is the personal used value of battery per hour, some studies assumed 0.002 [12]. While $P_{batc,t}$ is power generated by the renewable energy sources to charge batteries per time interval, conditions can be described mathematically by the following equation (10) [2].

$$P_{batc,t} = (P_{ren,t} - P_{load,t}/\eta_{inv})\eta_{charge} \quad (10)$$

$P_{load,t}$ stands for demand (kW), η_{inv} and η_{charge} each are the efficiency inverter DC / AC (90%) and charging efficiency (90%)[4].

When the renewable power plants are not possible to fulfill the load demand, load demand will get power supply from the battery and fuel cell sequentially.
Mathematical equation for battery consumption is written in this following sequence (11).

$$P_{batd,t} = (P_{load,t}/\eta_{inv} - P_{ren,t})/\eta_{discharge} \quad (11)$$

When battery is going to discharge, it will certainly reduce capacity. Reduced capacity of the battery at the time of discharge during the time $(t-1)$ to (t) is described in this following equation (12) [2].

$$C_{bat,t} = C_{bat,(t-1)} \cdot (1-\sigma) - P_{batd,t} \quad (12)$$

E. Fuel Cell Charging and Discharging State

E.1. Electrolyser Mathematical Formulation

When the battery fully charged to capacity, the excess power will be used for the process of electrolysis to produce hydrogen. Power results from the electrolysis electrolizer, $P_{el,t}$ can be calculated using following equation 13[4][9].

$$P_{el,t} = (P_{ren,t} - P_{load,t}/\eta_{inv}) \cdot \eta_{el} \quad (13)$$

Since, $P_{el,t}$ electrolyzer sent from renewable generation, and η_{el} is the efficiency of elektrolyzer.

E.2. Hydrogen Tank Mathematical Formulation

Energy supplied to hydrogen tank for each time of interval can be calculated by the following equation (14):

$$C_{tank,t} = C_{tank,(t-1)} + P_{el,t} \cdot \eta_{storage} \quad (14)$$

$C_{tank,t}$ and $C_{tank,(t-1)}$, are the availability of energy in the hydrogen tank when the time (t), the previous time$(t-1)$, and $\eta_{storage}$ stands for the efficiency of the storage system that assumed 95 % [4][9].

Calculate the output energy from the hydrogen tank to the fuel cell used the following equation(15):

$$C_{tank,t} = C_{tank,(t-1)} - P_{fc,t} \tag{15}$$

E.3. Fuel cell Mathematical Formulation

This work used Proton Exchange Membrane (PEM) fuel cell type. PEM has a reliable performance in non-continuous operating conditions [4][8]. The output power from the fuel cell is directly proportional to the input power of hydrogen, η_{fc} efficiency can be assumed as constant, meanwhile, output power of the fuel cell at time interval$P_{fc,t}$ can be calculated using the equation (16)[4].

$$P_{fc,t} = (P_{load,t}/\eta_{inv} - P_{ren,t})/\eta_{fc} \tag{16}$$

4. Optimization of Hybrid Renewable Power Plant by Particle Swarm Optimization

A. Particle Swarm Optimization Theory

Optimization technique is an action that attempts to obtain the best results in certain circumstances. Optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function. One of the modern optimization methods which are usually used is the Particle Swarm Optimization. The Particle Swarm Optimization (PSO) [16] method is a multi-agent parallel search technique which keeps a group of particles and each particle as a representation potential solution in a population. The main job of branch in PSO called particles, and a group or a population of particles called swarm. Each particle consists of a vector as a potential solution in the optimization problem that has its own position X and velocity V. Each particle also keeps track of the coordinates in the problem space and updates its position based on its own best exploration associated with the best solution (fitness). The following example is an updated velocity equation (17) and position (18) in the PSO.

$$V_j(k+1) = \omega V_j(k) + c_1 r_1 \left[P_{best,j} - X_j(k)\right] + c_2 r_2 \left[G_{best} - X_j(k)\right]; \quad j = 1,2,\ldots,N \tag{17}$$

$$X_j(k+1) = X_j(k) + V_j(k+1); \; j = 1,2,\ldots,N \tag{18}$$

There is a weighting factor (ω) to manipulate the impact of history speed to the current speed. Usually the value of ω is made, so the increasing of iteration are passed, the smaller of particle velocity. r_1r1 and r2$r_2$are random numbers uniformly distributed in the interval 0 to 1.$c_1 r_1$ and $c_2 r_2$ are learning rates for individual ability (cognitive) and social influences (group). c_1 and c_2 indicates the weight of memory (position) of a particle to memory (position) of the group (swarm). Value of $c_1 r_1$ and $c_2 r_2$ usually on a same value, so the multiplication $c_1 r_1$ and$c_2 r_2$ ensure that the particles will approached the target about half the difference. $P_{best,j}$ (k) is the best position particle j ever experienced until iteration k and G_{best} (k) is the best position discovered by the particles in the entire swarm.

B. Implementation of Particle Swarm Optimization to Optimize Size of Hybrid Renewable Power Plant

The PSO mechanism to optimize HRPP can be seen in figure 3 and described in accordance with the following steps:

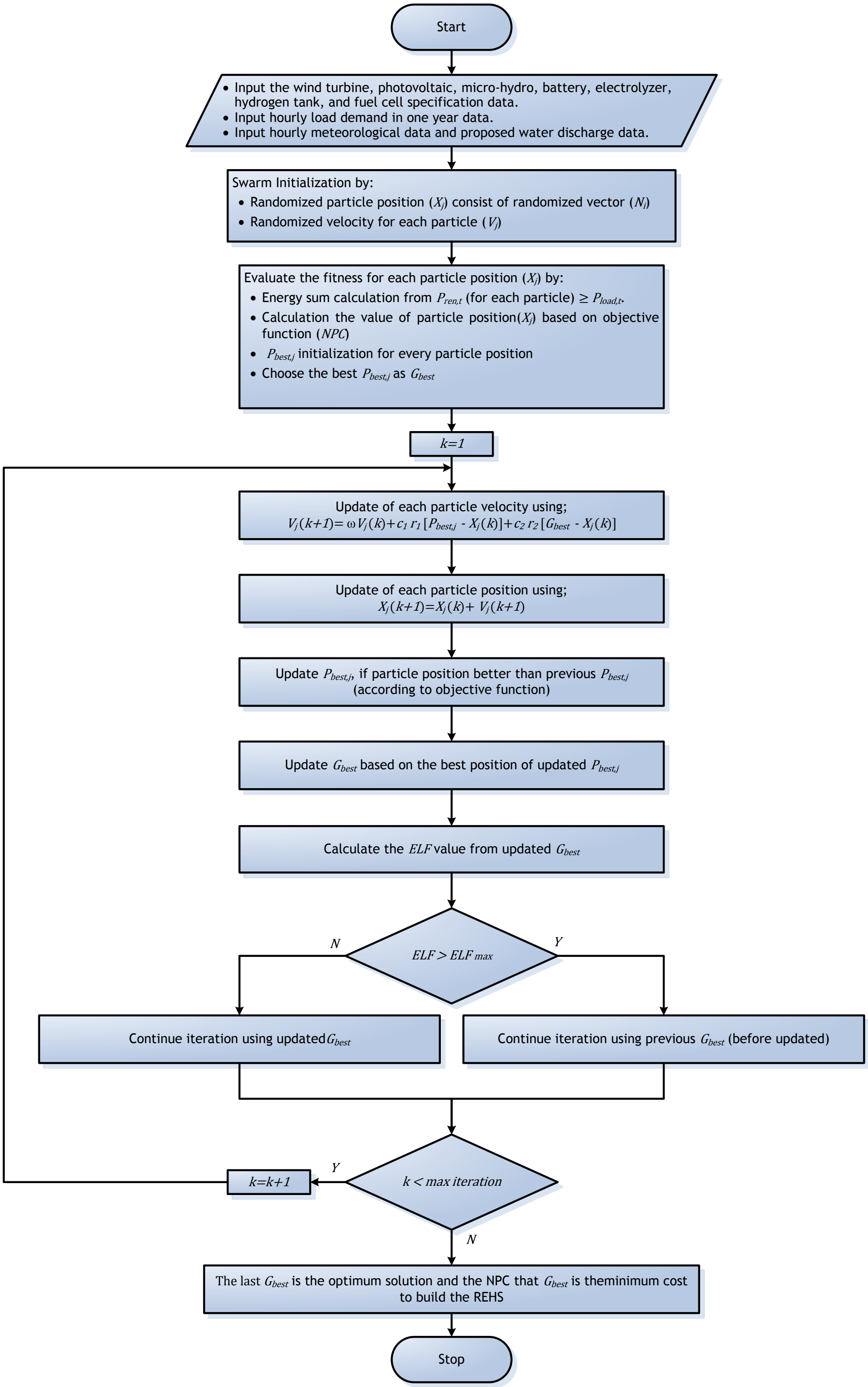

Figure 3. PSO algorithm application HRPP simulation

C. Equivalent Loss Factor Calculation Simulation

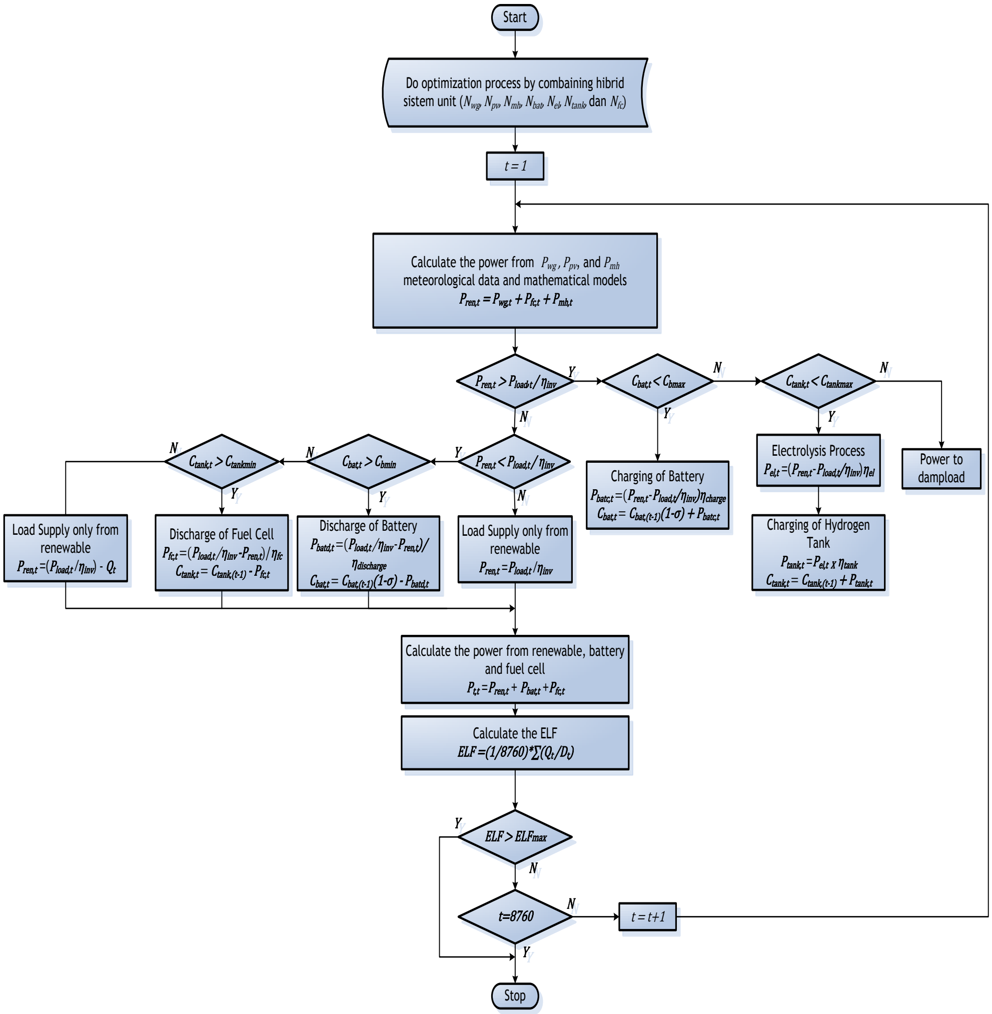

Figure 4. Hybrid renewable power plant operation system

In an electric power system, a generation system made to meet the needs of the electricity customers. Electricity producers will meet the load demands in accordance with certain reliability index. In this study, ELF is determined as power supply reliability index that compares the difference in energy supply to load requirement in one year. Calculation simulation to obtain ELF is consists of three (3) stages:
Stage-1, calculate the renewable power generation based on the number of each generating unit derived from PSO simulation results, equation model of each component of the power plant as well per hour of meteorological data for one year. This was done to determine the capacity of the power that can be generated by renewable generation within an hour during the year.

Stage-2, hourly power generated by renewable generation will be simulated according the following three circumstances or states:

- 1[st]state

$$P_{ren,t} = \frac{P_{load,t}}{\eta_{inv}} \tag{19}$$

First stage (1), assume all the power generated by renewable generators (wind turbines, solar cells, micro-hydro) in accordance with the load power demand. Means the power is routed through DC / AC inverter to the load. This causes the capacity of the hydrogen tank and battery not to change.

- 2nd state

$$P_{ren,t} > \frac{P_{load,t}}{\eta_{inv}} \quad (20)$$

Second state (2), the power generated by renewable generation is larger than the load demand. In this situation, most of the power generated by renewable power is consumed by the load. If the capacity of the battery and hydrogen tank has not reached 100%, the excess power will be stored to the battery and hydrogen tank. If the capacity of the battery and hydrogen tank is 100% or 100% after charging time, the surplus power will be consumed by the dummy load.

- 3rd state

$$P_{ren,t} < \frac{P_{load,t}}{\eta_{inv}} \quad (21)$$

In the third state (3), the power generated by renewable power generation is less than the load demand. Thus, all of the power generated by renewable power will be supplied to the load. The drawback will be supplied by the battery during battery capacity greater than or equal to the depth of discharge and the fuel cell as long as there is supply of hydrogen in the tank. If the battery and the fuel cell can no shortage of power supply, there will be load shedding or load barrier. In the above circumstances, the constraints have to be considered and all the system equations must be considered

Stage-3, calculate the supply reliability index (ELF) of Hybrid Renewable Power Plant based on the number of components units were obtained from the simulation results of PSO. PSO simulation is repeated to get the best value from the PSO population into an optimal solution of the problem. With this simulation, the PSO will try to find the optimal size of the system.

5. Simulation and Analysis

A. Data and Hybrid System Component Specification

A.1. Load Data

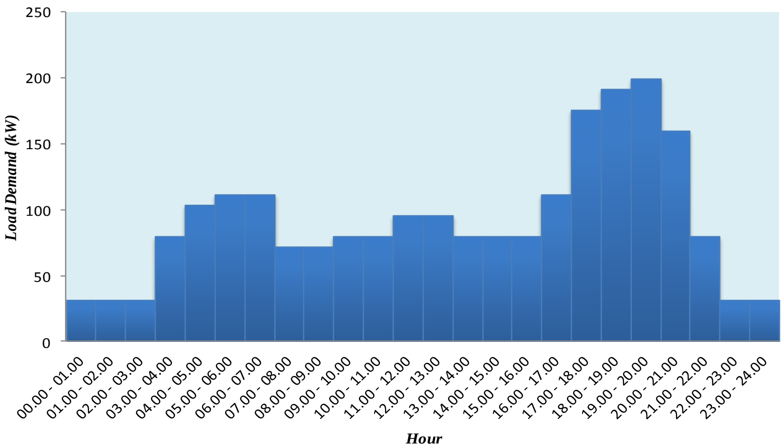

Figure 5. Hourly load profile curve in a day

HRPP is simulated to meet the load demand in a village in a rural area that has not electrification previously with an estimated peak load of around 200kW with 811.760kWh energy consumption per year. Load curve of the year is the sum of the daily load profile assuming daily rural community activities is the same for all year.

A.2. Wind Speed and Wind Turbine Specification Data

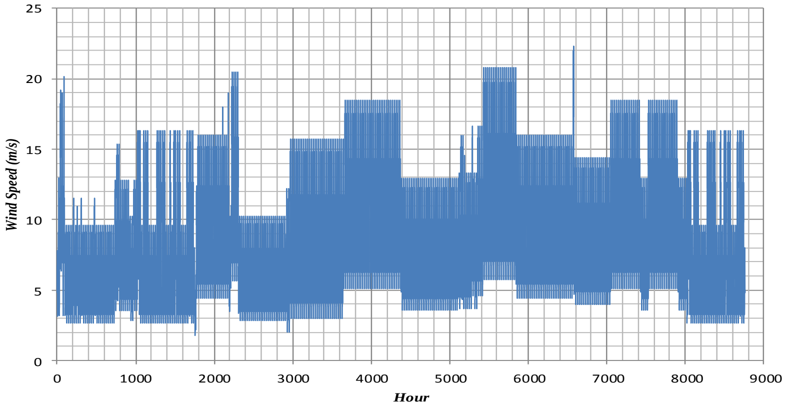

Figure 6. Hourly wind Speed in one year

This work is using the BWC Excel-R / 48 from Bergey Wind Power's consider of the wind resource potential with maximum speed of 22.32 (m/s) and 1.76 (m/s) as the minimum number with an average of about 8.66 (m/s) (figure 6). This turbine rated power capacity is 7.5 kW with 48 volts (dc) as output voltage. The full specifications and costs of the wind turbine are shown in table 1 [4][5][9].

Table 1. Wind Turbine Specification

Cut-in Speed	v_{cutin}	3(m/s)
Cut-out Speed	v_{cutout}	25(m/s)
Rated Speed	v_{rated}	15(m/s)
Maximum Power Output	p_{max}	8,1(kW)
Cut-out Power Output	p_{furl}	5,8(kW)
Capital Cost	CC	16.400($/Unit)
Replacement Cost	RC	13.000($/Unit)
Operation and Maintenance Cost	MC	400($/Unit-year)

A.3. Solar Radiation and Photovoltaic Specification Data

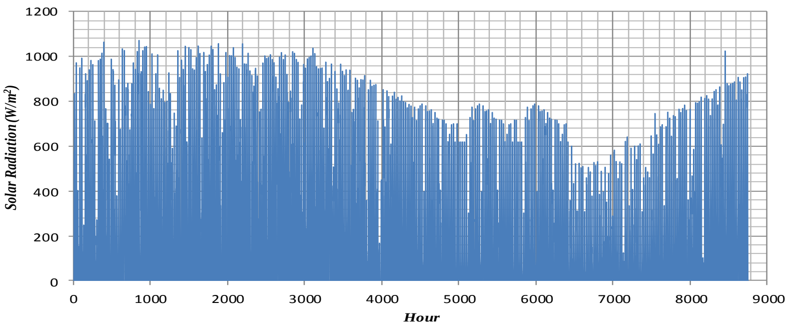

Figure 7. Hourly solar radiation in one year

Solar radiation data derived from regions close to the equator, the availability of solar energy always be available throughout the year (figure 7). This work using Canadian Solar CS6P-240P as the Solar cell modules. The specific data of Canadian Solar CS6P-240P can be seen in table 2 [13].

Table 2. Photovoltaic Specification

Photovoltaic Rated Power	$P_{PV,rated}$	0,96(kW)
Efficiency	$\eta_{PV,conv}$	0,9
Lifetime		20 (year)
Capital Cost	CC	3.000($/Unit)
Replacement Cost	RC	1.300($/Unit)
Operation and Maintenance Cost	MC	20($/Unit-year)

A.4. Micro-hydro Specification Data

Micro-hydro power plant that will be used in this study has specification as follow in table 3.

Table 3 Micro-hydro Specification

Micro-hydro Rated Power	$P_{MH,rated}$	10,8(kW)
Rated Discharge	q_{rated}	0,3(m3/s)
Head	H	6(m)
Lifetime		20 (year)
Capital Cost	CC	25.000($/Unit)
Replacement Cost	RC	1.300($/Unit)
Operation and Maintenance Cost	MC	750($/Unit-year)

A.5. Storage Component Specification Data

This work will use two kind of storage systems, Surrette-6CS25P with a nominal voltage of 6 volts and 6.94 energy rate (kWh) battery and fuel cell systems, assumed the battery lifetime is 10 years, with the depth of discharge about 80%. The cost of batteries and other parameters are shown in table 4[5].

Table 4. Battery Specification

Battery Capacity		6,94 (kWh)
Charging Efficiency	η_{charge}	0,8
Discharging Efficiency	$\eta_{discharge}$	0,8
Lifetime		10 (year)
DOD		0,8
Capital Cost	CC	1.250($/Unit)
Replacement Cost	RC	1.000($/Unit)
Operation and Maintenance Cost	MC	20($/Unit-year)

Fuel cell systems consist of Electrolyser, Hydrogen Tank and Fuel Cell. Specifications of fuel cell system are shown in the following table 5, table 6, table 7.

Table 5. Electrolyser Specification [20]

Electrolyser Capacity		1kWh
Electrolyser Efficiency	η_{el}	0,9
Lifetime		20 (year)
Capital Cost	CC	3.000($/Unit)
Replacement Cost	RC	2.500($/Unit)
Operation and Maintenance Cost	MC	40($/Unit-year)

Table 6. Hydrogen Tank Specification [21]

Hydrogen Tank Capacity	m	2kg
Hydrogen Tank Efficiency	$\eta_{storage}$	0.8
Lifetime		20 (year)
Capital Cost	CC	3.360($/Unit)
Replacement Cost	RC	3.200($/Unit)
Operation and Maintenance Cost	MC	15($/Unit-year)

Table 7. Fuel Cell Specification [20]

Fuel Cell Capacity		0,5kWh
Fuel Cell Efficiency	η_{fc}	0,7
Lifetime		20(year)
Capital Cost	CC	3.000($/Unit)
Replacement Cost	RC	2.500($/Unit)
Operation and Maintenance Cost	MC	175($/Unit-year)

6. Simulation Result and Analysis

PSO simulation program using the code of matlab m-files have been developed to determine the optimal configuration of Hybrid Renewable Power Plants. Simulations run on computers with a processor speed of 1.6 GHz and 2 GB of RAM. This configuration optimization based on load profile data by one hour in a year based on the daily load profile in figure 5 is considered to be constant during the year. PSO simulation program is run based on the parameters listed in table 8.

Table 8. PSO Simulation Parameter

Population	c_1	c_2	ω_{max}	ω_{min}
20	1.2	1.2	0.9	0.3

The simulation was done several times using different initial values by maximum iteration is 100 iterations. Simulation was conducted for different ELF_{mak} between 0.1, 0.01 and 0.0001. Suppose that for $ELF_{mak} = 0.01$, the convergence is obtained in 65th iterations from 100 iterations in 10 minutes, as shown in figure 8.

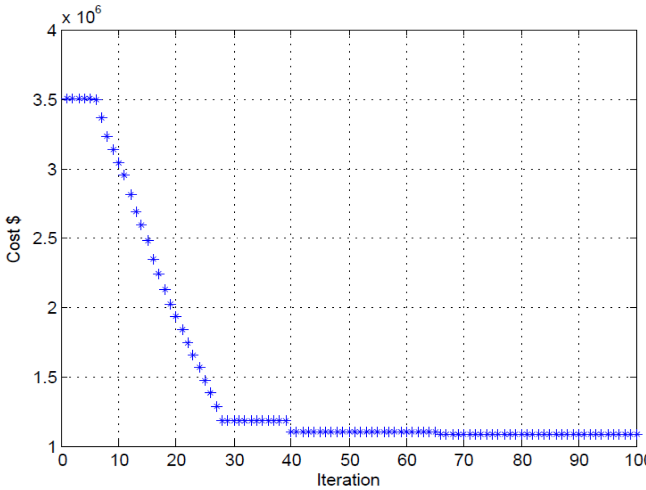

Figure 8. Convergence of the PSO optimization for $ELF_{mak} = 0,01$

After several run was obtained convergence simulation result with the low NPC value as shown in table 9.

Table 9. Simulation result of optimized parameter and cost of hibrid system

No	ELF	N_{wg}	N_{pv}	N_{mh}	N_{bat}	N_{el}	N_{tank}	N_{fc}	NPC ($)
1	0.0001	38	66	3	134	0	0	0	1,510,100
2	0.001	34	45	3	108	0	0	0	1,235,400
3	0.01	34	41	3	51	0	0	0	1,087,700
4	0.02	28	39	3	52	0	0	0	972,010
5	0.03	26	34	3	48	0	0	0	893,120
6	0.04	27	24	3	46	0	0	0	833,980
7	0.05	22	26	3	53	0	0	0	776,880
8	0.06	22	25	3	41	0	0	0	744,650
9	0.07	19	25	3	51	0	0	0	713,820
10	0.08	18	22	3	52	0	0	0	677,020
11	0.09	18	14	3	63	0	0	0	642,190
12	0.1	18	21	3	34	0	0	0	632,280

Simulation results shown the value electrolizer, hydrogen tank, and fuel cell components is zero, which indicates if today, compared to the battery, fuel cell technology is still really expensive for energy storage applications in HRPP. Smaller the ELF value, greater the cost (NPC) are shown on the tabel above. Since the number of components to serve load demand increases, especially inside of the energy storage system, the equation (2) and (3) are used to calculate the LCOE

From the result of the conducted simulation, different configurations of the proposed were found. The best configuration of a hybrid system based on renewable energy equipment specification data, load and meteorological obtained:

Table 10. Kofiguration Optimization of HRPP

No	ELF	N_{wg}	N_{pv}	N_{mh}	N_{bat}	NPC ($)	LCOE ($/kWh)
1	0.0001	38	66	3	134	1,510,100	0.12
2	0.001	34	45	3	108	1,235,400	0.10
3	0.01	34	41	3	51	1,087,700	0.09
4	0.02	28	39	3	52	972,010	0.08
5	0.03	26	34	3	48	893,120	0.07
6	0.04	27	24	3	46	833,980	0.07
7	0.05	22	26	3	53	776,880	0.06
8	0.06	22	25	3	41	744,650	0.06
9	0.07	19	25	3	51	713,820	0.06
10	0.08	18	22	3	52	677,020	0.05
11	0.09	18	14	3	63	642,190	0.05
12	0.1	18	21	3	34	632,280	0.05

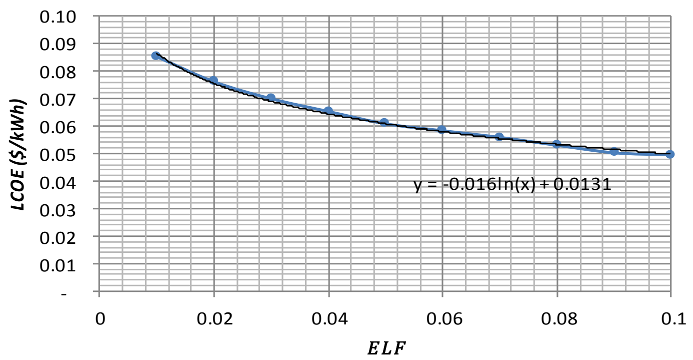

Figure 9. Comparison between ELF indexes with LCOE of HRPP

7. Conclusion

This research has proposed a hybrid renewable energy system to meet the 811.760kWh electricity need of 200kW peak loads in rural areas for the 20 year project lifetime. The proposed hybrid system consists of a wind turbine, solar cells, micro-hydro generator as a generator component and battery, elektrolizer, hydrogen tanks and fuel cell as an energy storage system. The purpose of this study is to conduct optimization on the number of units generating HRPP based on the hourly load and meteorology for one year data. Then, the simulation was made to optimize HRPP unit or component using the Particle Swarm Optimization (PSO) method. This simulation was made based on minimizing costs to meet the Equivalent Loss Factor (ELF) index. The ELF index limitation in this study was between 0.1 and 0.0001.

From the simulation results, it can be seen that the cost is determined by the level of reliability that can be achieved; renewable energy sources and specifications and pricing tools that used. In addition, for the current time that the optimal configuration of HRPP is not included the fuel cell storage system. The configuration of generating units, NPC and LCOE for each ELF can be seen in table 10. From the table, it shows that the greater the ELF index, then the lower the costs. Conversely, the lower the ELF index (higher service quality) the higher costs. Figure 9 informs the function of equation chart among the LCOE in every ELF index.

8. Reference

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