ECONOMIC STUDY OF HYBRID PV-BATTERY-DIESEL SYSTEM FOR HOTEL BACKUP GENERATOR

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ABSTRACT
The power outage causes economic and environmental problems in society, especially for hotel business that must have additional cost to provide a backup generator so that the electrical energy is always available. This condition is getting worse due to the price of a backup generator fuel used in diesel generator tends to increase. Hybrid system generation is known to be more economical than diesel generator because it is can saving fuel consumption if supported by optimal size and operating strategy. Simulation based on PSO method was performed, then the configuration with minimum LCC and COE value for generating hybrid PV-battery-diesel system is obtained. The optimal size backup hybrid system generator consists of 1 x 400kW diesel generator, 167 x 0.25kWp PV modules, 66 x 2.22kWh unit battery and 1 x 400kW inverter. The fuel consumed as much as 602,500 liters, more frugal 492,500 liters or 44.97% compared to using diesel generators. LCC-saving system can be $778,646.99, was reduced by 30.69% compared to using diesel generator only. COE system also dropped to $0.2002/kWh, was reduced by 21.94% compared to using diesel generator only. This system absorbs the use of renewable energy with an RF value of 38% of the total energy generated backup generators.

KEYWORDS: *Renewable energy, power outage, hybrid generation system, photovoltaic, life cycle cost*

I. INTRODUCTION

Electrical energy has become a very important requirement at this time. It is marked by the increasing demand for electricity for household use, education, business and industry [1-2]. These increases were not followed by the production of electric energy in Indonesia, which in some areas is known to be quite low, including the province of North Sumatra. As a result, the province has experienced a high frequency of power outages. The power outage causes economic and environmental problems in society. It is felt also by the manager of the hotel business, where the power outage may result in additional costs to provide a backup generator so that the electrical energy is always available. This condition is getting worse due to the price of a backup generator fuel used in diesel generator tends to increase [3].

Until now, research on economic value of a backup generator has never been done, therefore it is important to be investigated. This paper will discuss the hybrid systems generation as an economical solution to the problem of backup diesel generators. Hybrid system generation is known to be more economical than diesel generator if it is supported by optimal size and operating strategy [4]. Optimization method and operating strategies is used to obtain an economical hybrid system generation will be presented in this paper. Comparative analysis of the economic value of backup generators that use diesel generators and hybrid systems is also presented. Results of the study will be recommended to be used as a backup generator.

1.1 Research Boundaries

Boundaries of this study are as follows;

a. Days and hours of outages during the year will be randomized with the reliability of the grid in this study is considered fixed for 25 years.
b. The interest rate that is used refers to the interest rate of Bank Indonesia (BI) on December 12, 2013 of 7.5% and lifetime system is 25 years.
c. In this study, loss of power supply probability (LPSP) on the system will be ignored.

II. Research Object

2.1. Load Energy Consumption Profile

Hermes Palace is a 3-star hotel in Medan located at $3^0$35' North and $98^0$40' East [5]. Hotel electrical energy consumption is 1.2 GWh/year with an average consumption is 139kWh/hour and 176kW peak load which commonly occurs in June and July as it is shown in Figure 1.

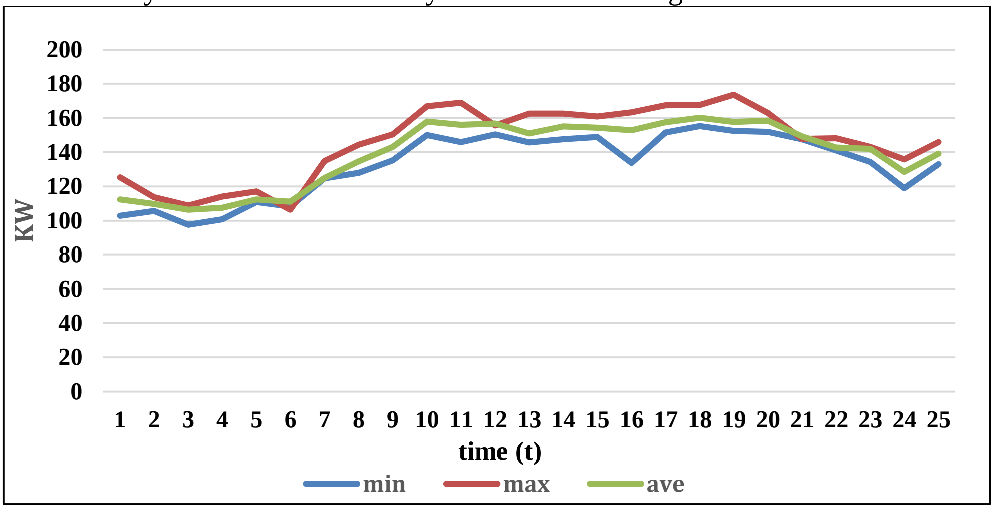


Figure 1. Load energy consumption profile.

2.2. Outage Condition

Power outage is a condition where the grid cannot supply enough electrical energy that is required by consumers in a region. Outage can be caused by internal disruption (instrument failure, capacity shortage), external disruption (disaster) and treatment (maintenance). Hotel engineering division recorded an average number of outages that is experienced by the hotel every year as many as 438 hours. So the additional costs that must be spent to operate the plant reserves (using diesel generators) amounted to $1,123,450 and the system cost of energy (COE) is amounted to $ 0.2565/kWh. Fuel consumption by generators reached 1,750,950 liters per year with fuel prices of 0.8/liter.

2.3. Solar Resource

Solar resources now has become the attention of researchers and practitioners plants, especially renewable energy power plants. This is done to reduce reliance on fossil fuels to generate electrical energy. Solar radiation data is needed to determine the electrical energy that can be produced at a given location. The amount of solar radiation in a location can be determined by using the data from HOMER software integrated database directly from NASA by entering latitude and longitude [4]. The average solar radiation to its location is 4,45kWh / m2 / day with the lowest radiation of 4.017kWh/m^2/day and the largest radiation of 4.990kWh/m^2/day as shown in Table 1.

2.4. Reliability Model

The reliability of the grid is the grid's ability to continue to provide the necessary electrical energy to the hotel. Blackouts in the hotel shows that the reliability of the grid is not 100%. Based on interviews of the technician, the number of power outages is 438 in 2013. The percentage of the reliability of the grid affects the life cycle cost (LCC) and COE of hotel's reserve generation. Percentage reliability of the grid can be calculated using Equation 1 [6].

$$EENS = \sum_{i=1}^{8760}(LD) \tag{1}$$

Where EENS is expected energy not supplied (kWh), L is the average annual power load (kW), D is duration of unavailability of load (hours).

EENS energy is then used to calculate the index ratio (EIR) to determine the percentage of reliability of the grid as in Equation 2.

$$EIR = 1 - \left(\frac{ENNS}{E_0}\right) \tag{2}$$

Where E_0 is the total annual energy needs of the load (kWh).

Table 1. Solar resource data.

Month	Clearness index	Daily radiation
	Index	(kWh/m²/day)
January	0,446	4.315
February	0,493	4.990
March	0,468	4.888
April	0,470	4.866
May	0,445	4.431
June	0,461	4.464
July	0,440	4.303
Augustus	0,448	4.540
September	0,421	4.358
October	0,416	4.225
November	0,413	4.017
December	0,429	4.067
Average	0,446	4.45

III. Hybrid PV-Battery-Diesel System

3.1 Hybrid System Configuration

In this study, the proposed plant hybrid system consisting of PV, battery and diesel generator. Inverter is also used to convert DC power into AC. The type of configuration used is AC-coupled system as shown in Fig 2.

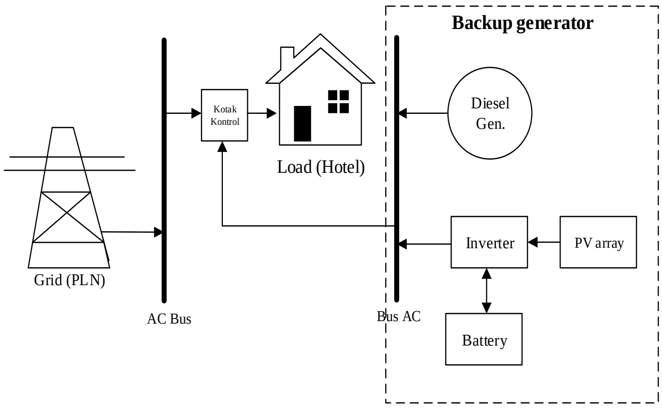


Figure 2. Proposed hybrid system configuration.

Technical data of each plant components that is used are shown in Table 2. The cost is calculated in the currency of USD or $ (assuming that $1 = Rp12, 000).

3.2 Operation Strategy and Optimization

Backup hybrid system generation consists of several components of plants that each has different characteristics and prices. Operation and optimization strategy is needed to be able to maintain the availability of spare generating energy from the hybrid system at the same time saving fuel consumption. The goal is to get the backup generator more economical than using only diesel generator.

3.2.1. Operation Strategy

In this study, some provisions of the operating strategies is applied, namely,

a. If the capacity of the electrical energy from the grid and PV is equal to the needs of hotel power load, then the diesel generator is not operated, no charging process (charging) battery and no more energy is sold to the grid.
b. If the capacity of the electrical energy from the grid and PV is greater than the hotel electrical load demand, then the generator is not operated, charging process occurs if the battery capacity is under the state of charge (SOC) minimum. In this condition, more energy can be sold to the grid.
c. If the capacity of the electrical energy from the grid and PV is less than the hotel electrical load (grid in the fail condition), then the battery into the priority energy source to supply the load, a diesel generator is not lit and there is no more energy is sold to the grid. When the battery capacity is lower than the hotel load requirement, the diesel generator is operated and the excess of generated energy is used to charge the battery and there is no more energy sales to the grid.

The capacity of the generator during operation was 100% and the state of charge (SOC) or limit discharge and charging is limited to the capacity of 0% to 95% for the minimum and maximum to avoid overcharging.

Table 2. Technical data of PV, battery, inverter and diesel generator.

Specification	Components			
	PV module	Battery	Inverter	Generator diesel
Module power (kW)	0.25	-	-	-
Capacity (Ah)	-	650	-	-
Voltage (v)	-	2	-	-
Power (kW)	-	-	400	400
Efficiency (%)	15	85	97	-
Capital cost ($/kW)	1000	250	25	500
O&M cost ($/kW)	0	0	0	0.05
Life time(year)	25	10	25	15000
Fuel consumption (l/h)	-	-	-	100

3.2.2. Particle Swarm Optimization

Particle swarm optimization (PSO) is an optimization technique that is efficient with a simple and effective algorithm to optimize a variety of functions [7]. This optimization technique is used to optimize the size of the PV and battery used that is based on the objective function of the total cost of generating or life cycle cost (LCC). Stages of optimization are as follows:

a. Initialize the population (N) particles / swarm that will be raised,
b. generate initial particle and particle velocity, with a range x_a and x_b randomly in order to get x_1, x_2, ..., x_n. After that, the particle *i* and the speed at iteration k is denoted as x_{ij}^{k} and v_{ij}^{k},
c. evaluate the fitness function, and determine the best value of the particle x_{ij}^{0} with expressed as p_{best}^{0},
d. determine the best value for all particles x_{ij}^{0} and expressed as g_{best}^{0} *(* N_{bat}*)*,
e. set iteration k = 1,
f. update speed and position of each particle in accordance with the Equations 3 and 4, by generating random numbers r_1 and r_2 in the range [0-1] and specify the acceleration coefficient c_1 which is cognitive and c_2 scale factor which is a factor of the social scale,

$$v_{ij}^{k+1} = wv_{ij}^{k} + c_1 \times r(\ \ ) \times \left(p_{best,ij} - x_{ij}^{k}\right) + c_2 \times r(\ \ ) \times (g_{best,j} - x_{ij}^{k}), \quad (3)$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1}, \quad (4)$$

g. evaluate the restraints that $N_{bat} > 0$ and repairs particles then evaluate the fitness function. Evaluation of the fitness function is done in accordance with the simulation is for a period of one year (t = 8760) taking into account the three conditions of the system as shown in Equation 5 to 7.

$$E_{grid} + E_{pv} = E_{load}, \quad (5)$$
$$E_{grid} + E_{pv} > E_{load}, \quad (6)$$
$$E_{grid} + E_{pv} < E_{load}, \quad (7)$$

where, E_{grid} is energy supplied by grid (kWh), E_{pv} is electrical energy that is produced by PV, E_{load} is the energy required by load (kWh).

h. update the best value so far of x_{ij}^{k} (coordinates particle *i* at coordinates *j*) and declared as p_{best}^{k}, with the lowest value of the objective function (minimization case),

i. update the best value for all the particles x_{ij}^{k} that are g_{best}^{k}, with the smallest objective function value or the minimum among all the particles,

j. PSO optimization process will stop after reaching the specified maximum number of iterations, if it has not reached the maximum iteration condition, then repeat steps f - i for the second iteration (k = 2) until it reaches the maximum iteration.

Simulation begins with the initialization process of several parameters such as the value of the particle/swarm as many as 30. The weight of inertia were also added to control the impact of speed (v) of each particle. Weight of inertia (θ) maximum used was 0.4 to 0.9 and a minimum weight. Weight of memory in the form of cognitive scale factor values (c_1) and the value of the social scale factor (c_2) also was added to the simulation process to ensure that the particles approached the target with the value of difference was 2. The maximum iterations was set as much as 100 times. The lower and upper bond for batteries were 63 and 371, respectively. The respective lower and upper bond of PV were 129 and 180. This was based on the available area for the PV array installation was only 300m^2 and research [8] was to optimize the battery capacity of 1-6 autonomy. Table 3 shows these parameters.

Table 3. Parameters used in PSO optimization method.

Parameters	N	w_{max}	w_{min}	c_1	c_2	k_{max}	*upper bond1*	*lower bond1*	*upper bond2*	*lower bond2*
Value	30	0.9	0.4	2	2	100	371	63	180	129

The process of optimizing the size of the PV and battery with PSO optimization techniques and strategies of the operation of the backup generator hybrid system is shown in the form of a flowchart in Figure 3.

3.3 Objective Function

Simulations carried out to obtain the number of batteries and to obtain optimal PV systems with a minimum value of LCC and COE and to know the RF from the system.

3.2.3. Life Cycle Cost

The objective function used in this study is the plants life cycle cost (LCC). Economical plant is generating the minimum LCC value. LCC system can be calculated using Equation 8.

$$\min f(LCC) = min(f_1 + f_2) + (c_3 + c_4) - c_5, \quad (8)$$

Where, min f (LCC) is minimum function of LCC system ($), f_1 is a function of the total cost of battery ($), f_2 is a function of the total costs of PV ($), c_3 is the total cost of the inverter ($), c_4 is the total cost of a diesel generator ($), c_5 is the cost of the total sales of excess energy to the grid ($).

Function of the total cost of battery (f_1) consists of capital costs, operating costs and maintenance and battery replacement costs during plant operation. Total cost of the battery is calculated using Equation 9.

$$f_1 = (CM_{bat} + C_{rep.bat}) + CRF * (CM_{bat} + C_{rep.bat}) + C_{O\&M.Bat}, \quad (9)$$

Where CM_{bat} battery is capital cost ($), $C_{rep.bat}$ is batteries replacement cost ($), $C_{O\&M.bat}$ is operational and maintenance cost of battery ($), CRF is cost recovery factor.

CM_{bat} is the result of multiplying the number of batteries at a price per unit of battery used. The number of batteries obtained from the optimization and CM_{bat} calculated using Equation 10.

$$CM_{bat} = N_{bat} * Bat_{price}, \quad (10)$$

Where CM_{bat} battery is capital cost ($), N_{bat} is the total battery used (unit), and Bat_{price} is battery unit price ($/unit).
Operating costs and battery maintenance ($C_{O\&M.Bat}$) in this study was considered $0, while the cost of replacement batteries can be calculated by Equation 11.

$$C_{rep.bat} = N_{bat} * Bat_{price} * (\frac{U_{sys}}{U_{bat}} - 1), \quad (11)$$

Where U_{sys} is the life of the plant hybrid system (years), U_{bat} is battery life (years). CRF or capital recovery factor is calculated to determine the annual cost should it is returned to the bank. CRF is only found in the capital and replacement costs that are generally originated from the bank. CRF can be calculated using the Equation 12.

$$CRF = \frac{r(1+r)^{U_{sys}}}{(1+r)^{U_{sys}} - 1}, \quad (12)$$

Where r is the interest rate (%).

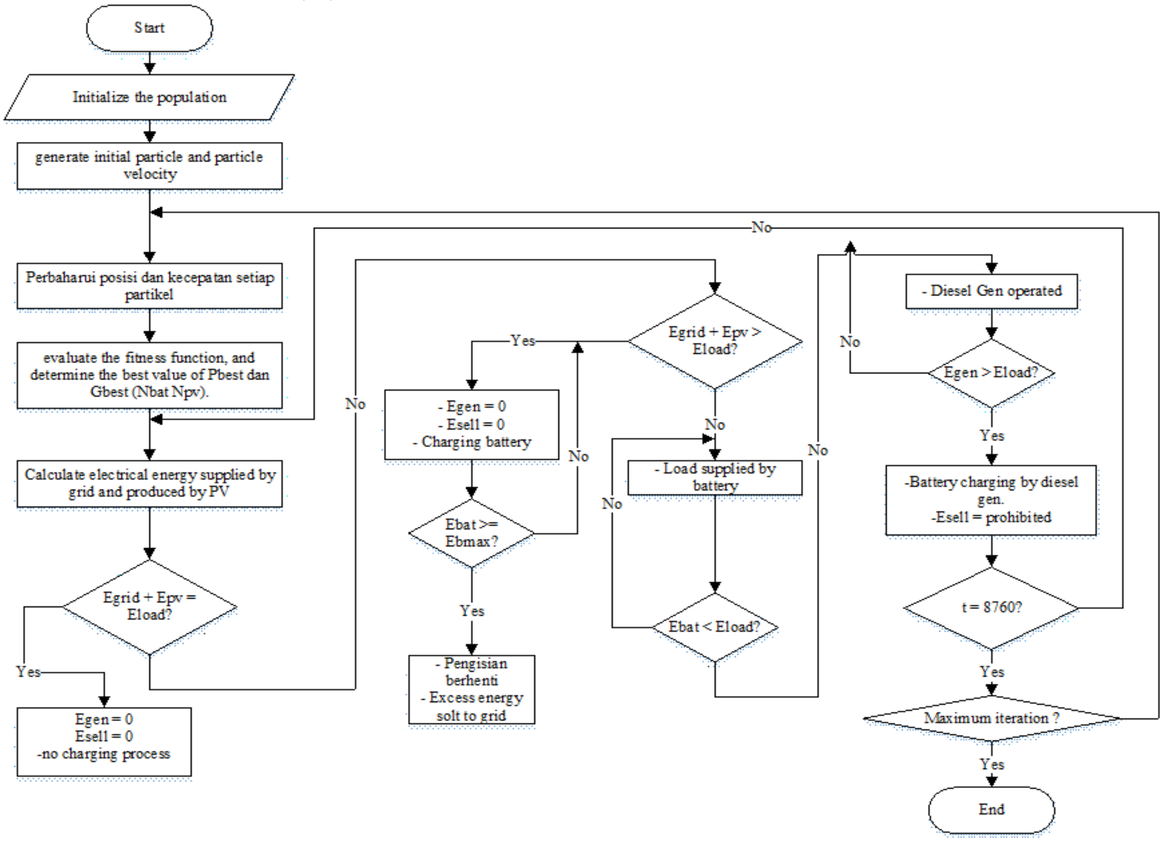


Figure 3. The simulation process flow chart

Function of the total cost of PV (f_2) consists of capital costs, operating costs and maintenance as well as replacement costs of PV during plant operation. Total cost of PV is calculated using the Equation 13.

$$f_2 = (CM_{PV} + C_{rep.PV}) + CRF * (CM_{PV} + C_{rep.PV}) + C_{O\&M.PV}, \quad (13)$$

Where CM_{pv} is PV capital costs ($), $C_{rep.pv}$ is the cost of replacement PV modules ($), $C_{O\&M.pv}$ is operational and maintenance costs of PV ($).
CM_{PV} is the result of multiplying the power capacity at a price per kWp PV used. Total PV obtained from the optimization and CM_{PV} calculated using the Equation 14.

$$CM_{pv} = P_{pv} * PV_{price}, \quad (14)$$

Wherein CM_{pv} is PV capital costs ($), P_{PV} is the PV power output (kWp), PV_{price} is the price of one PV module ($/kWp).
PV power (P_{PV}) is the result of the calculation of the number of PV modules used with PV power capacity per module, while the price of PV (PV_{price}) is fixed. PV power is calculated using the Equation 15.

$$P_{pv} = N_{pv} * P_{mod.pv}, \tag{15}$$

Where N_{PV} is the total PV modules used, $P_{mod.pv}$ is the power capacity per PV module (kWp).
Operational and maintenance costs of PV ($C_{O\&M.pv}$) in this study was Considered $0, while the replacement cost PV ($C_{rep.pv}$) can be calculated by Equation 16.

$$C_{rep.pv} = P_{pv} * PV_{price} * (\frac{U_{sys}}{U_{pv}} - 1), \tag{16}$$

Where the U_{PV} is the lifetime of PV modules (year).
Total inverter cost (c_3) consists of capital costs, operating and maintenance costs as well as the cost of replacing the inverter during plant operation. Total cost of the inverter is calculated using the Equation 17.

$$c_3 = (CM_{inv} + C_{rep.inv}) + CRF * (CM_{inv} + C_{rep.inv}) + C_{O\&M.inv}, \tag{17}$$

Where CM_{inv} is the capital inverter cost ($), $C_{rep.inv}$ is inverter module replacement costs ($), $C_{O\&M.inv}$ is operational and maintenance costs of the inverter ($).
CM_{inv} is the result of multiplying the power capacity of the inverter is used in energy prices. The capital inverter cost calculated using the Equation 18.

$$CM_{inv} = P_{inv} * Inv_{price}, \tag{18}$$

Where CM_{inv} is the capital cost of the inverter ($), P_{inv} is capacity inverter power (kW), Inv_{price} is inverter price ($/kW).
Operating costs and maintenance inverter ($C_{O\&M.inv}$) in this study was considered $0, while the cost of replacing the inverter can be calculated by Equation 19.

$$C_{rep.inv} = P_{inv} + Inv_{price} + \left(\frac{U_{sys}}{U_{inv}} - 1\right), \tag{19}$$

Where $C_{rep.inv}$ is the cost of replacement inverter for generating both operational period ($), U_{inv} is the lifetime of the inverter (year).
Total cost of the generator (c4) consisting of capital costs, operating and maintenance costs, replacement generator costs during plant operation and fuel costs. Total cost of the generator is calculated using the Equation 20.

$$c_4 = (CM_{diesel} + C_{rep.diesel}) + CRF * (CM_{diesel} + C_{rep.diesel}) + C_{O\&M.inv} + C_{tot.fuel}, \tag{20}$$

Where, CM_{diesel} is the capital cost of diesel generator ($), $C_{rep.diesel}$ is the cost of replacement diesel generator ($), $C_{O\&M.diesel}$ is operational and maintenance costs of diesel generator ($), $C_{tot.fuel}$ is the total fuel cost ($).
CM_{diesel} is the result of multiplying the power capacity at a price per kW diesel generator used. The capital diesel generator cost calculated using the Equation 21.

$$CM_{diesel} = P_{diesel} * D_{price}, \tag{21}$$

Where, P_{diesel} is capacity diesel generator power used (kW), is D_{price} purchase price per kW diesel generator ($/kW).
Operational and maintenance costs can then be calculated using the Equation 22.

$$C_{O\&M.diesel} = D_{o\&M.price} * U_{diesel}, \tag{22}$$

Where $D_{O\&M.price}$ is diesel generator operational and maintenance costs per hour ($/hour), U_{diesel} is the life of the diesel generator (hours).
Generator replacement cost and the total cost of fuel during the operation of backup generators that have been determined can be calculated if the total time of generator operation (on) has been known. Total time generator operates can be calculated using the Equation 23.

$$T_{tot.op} = \sum_{i=1}^{8760} D_{on} * t_i * 25, \tag{23}$$

Where $T_{tot.op}$ is total time diesel generator operated (hours), D_{on} is the diesel generator in operation, t_i is time at hour-$_i$.
Total time generator operation that has been known to be used to calculate the cost of replacing diesel generators and the total cost of fuel. Generator replacement cost is calculated using the Equation 24.

$$C_{rep.diesel} = P_{diesel} * D_{price} * \left(\frac{T_{tot.op}}{U_{diesel}} - 1\right), \quad (24)$$

Fuel consumption of diesel generator is 100 liters/hour, therefore the total fuel consumption during reserve plant operational is calculated using the equation 25.

$$N_{tot.fuel} = T_{tot.op} * 100, \quad (25)$$

Where $N_{tot.fuel}$ is total fuel consumption (liter),
The total fuel cost of diesel generator backup hybrid system generation can be calculated by Equation 26.

$$C_{tot.fuel} = N_{tot.fuel} * f_{price}, \quad (26)$$

Where $C_{tot.fuel}$ is total fuel cost ($), f_{price} is the price of fuel ($/liter).
Cost of sales of excess energy (c5) is an entrance fee earned by the hotel if there are an excess of energy from backup hybrid system generation. This energy sales only occurs if the hotel has received approval from the national electric company to sell excess energy to the grid. If the hotels do not get approval, then they are not allowed to sell energy to the grid, so that the cost of energy sales over (C_5) is ignored. Provision of energy sales listed on PERMEN ESDM No.4 Tahun 2012. Selling costs of excess is energy calculated using the Equation 27.

$$c_5 = E_{tot.sell} * S_{price} , \quad (27)$$

Where $E_{tot.sell}$ is the total energy sold to the grid (kWh), S_{price} is the selling price of electricity to the grid per kWh ($/kWh). $E_{tot.sell}$ is calculated using the Equation 28.

$$E_{tot.sell} = \sum_{i=1}^{8760} E_{sell} * t_i * 25 , \quad (28)$$

Where E_{sell} is the energy sold to the grid (kWh).

3.2.4. Cost of Energy

Cost of energy (COE) is the cost required to produce each 1 kWh of electrical energy, which is the result of division between annual fee with an annual energy production by generating hybrid system backup. COE value of each scenario is using the Equation 29.

$$COE = \frac{\text{TAC}}{E_{tot.sys}} , \quad (29)$$

Where $E_{tot.sys}$ is total annual energy of hybrid system backup generation (kWh). TAC is the total annualize cost or annual total costs incurred for the backup generators ($). TAC calculated using the Equation 30.

$$TAC = \frac{\min(LCC)}{U_{sys}} , \quad (30)$$

3.2.5. Renewable Fraction

RF is a portion of the electrical energy that comes from renewable energy sources of the total energy that is generated by backup generators. Electrical energy from renewable energy sources only comes from PV module, so that the RF is calculated using the Equation 31.

$$RF = \frac{E_{tot.pv}}{E_{tot.sys}} * 100\% , \quad (31)$$

Where $E_{tot.pv}$ is total electric energy produced by the PV modules (kWh), $E_{tot.sys}$ is the total electrical energy generated generation hybrid system (kWh). $E_{tot.pv}$ calculated using the Equation 30.

$$E_{tot.pv} = \sum_{i=1}^{8760} E_{pv,i} * 25, \quad (32)$$

Where $E_{PV,i}$ is the electrical energy produced by the PV modules in hour-i.

IV. RESULT

4.1 Optimal Sizing Result

Simulation based on PSO method was performed, then the configuration with minimum LCC and COE value for generating hybrid PV-battery-diesel system is obtained. The optimal size backup hybrid system generator scenarios 1 and 2 consists of 1 x 400kW diesel generator, 167 x 0.25kWp PV modules, 66 x 2.22kWh unit battery and 1 x 400kW inverter as shown in Table 4.

Table 4. Optimal Sizing Result

Description	Capacity	Number
Diesel Gen. (kW)	400	1
PV (kWp)	0.25	167
Battery (kWh)	2.22	66
Inverter (kW)	400	1

Converging state is achieved within 192.7987 seconds and graph is shown in Figure 4.

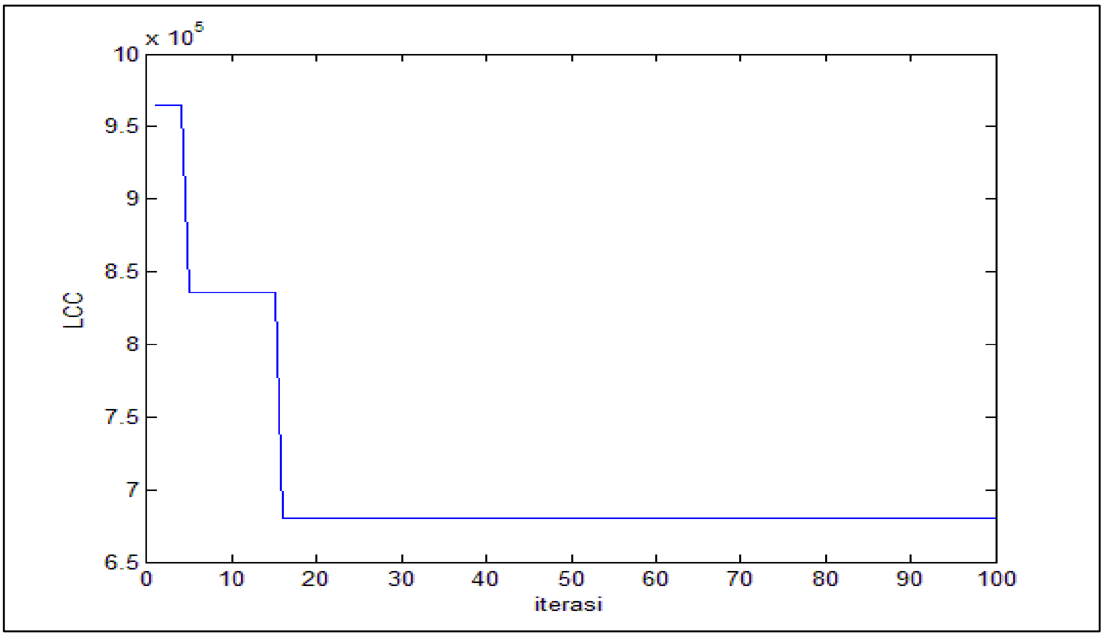


Figure 4. Simulation converging time.

4.2 Analysis Result

The simulation results of optimization and operating strategies hybrid system generation are later analyzed based on (a) the economic value of plants consisting of, fuel consumption, electric energy production, generation costs or life cycle cost (LCC), the cost of energy (COE), and (b) the rate of absorption renewable energy sources, namely Recovery factor (RF).

4.2.1. Economic value of optimal hybrid PV-battery-diesel system (scenario 1).

Economic value of backup system generation using hybrid PV-battery-diesel scenario 1 is shown in Table 5.

Table 5. Economic value of optimal hybrid system (scenario 1).

Assessment criteria	System operation time 876 X 25 (hour)
Fuel consumption (l)	602.500
Total energy production (kWh)	3.889.100
LCC ($)	778.646,88
COE ($/kWh)	0,2002
RF (%)	38

Based on the attached data in Table 5, it is known that the fuel consumed as much as 602,500 liters, more frugal 492,500 liters or 44.97% compared to using diesel generators. Production of electrical energy by 3,889,100 kWh with LCC saving system can be $778,646.99, was reduced by $344,803.12 or 30.69% compared to using diesel generator only. COE system also dropped to $0.2002/kWh, was reduced by $0.0563, or 21.94% compared to using diesel generator only. This system absorbs the use of renewable energy with an RF value of 38% of the total energy generated backup generators. The calculation is done for the past 25 years in hotel operations backup generator.

4.2.2. Economic value of optimal hybrid PV-battery-diesel system (scenario 2).

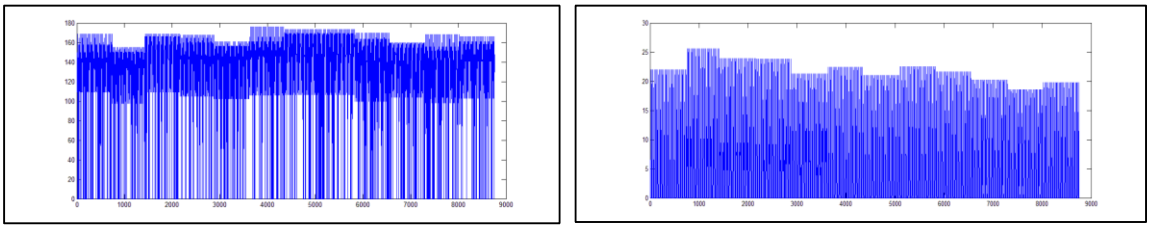
Generating economic value backup system using hybrid PV-battery-diesel scenario 2 is shown in Table 6.

Table 6. Economic value of optimal hybrid system (scenario 2).

Assessment Criteria	System operation time 876 X 25 (hour)
Fuel consumption (l)	602.500
Total energy production (kWh)	3.889.100
LCC ($)	883.132,37
COE ($/kWh)	0.2271
RF (%)	38

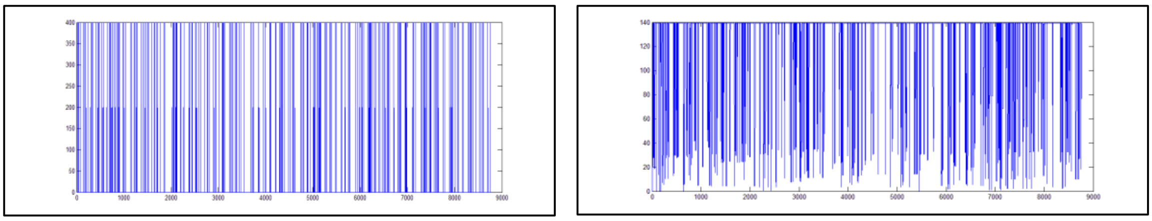
Based on the data in the attached table 6 is known that fuel consumption is known as much as 602,500 liters, more frugal 492,500 liters or 44.97% compared to using diesel generators. Production amounted to 3,889,100 kWh of electrical energy to the LCC system for $ 883,132.37 higher $105,702.37 or 13.59% compared to scenario 1, but it is lower $240,317.63 or 21.39% compared to using diesel generator only. COE known at $0.2271 / kWh higher $0.0272/kWh or 13.60% compared to scenario 1, but still lower at $0.0291/kWh or 11.46% of the COE plants that use diesel generators only. RF is the same value amounted to 38.03% of the total energy produced by plants of the hybrid system backup. The calculation is done for the past 25 years in hotel operations backup generator.

Supply of electrical energy from the electrical grid to electrical load of the hotel, the production of electrical energy by each PV modules and diesel generator are shown in Figures 5 (a), 5 (b), 6 (a). The condition of the battery charging and discharging shown in Figure 6 (b).



(a) (b)

Figure 5. (a) Supply of electrical energy to the electrical load of the hotel for a year, (b) Production of electric energy by the PV array.



(a) (b)

Figure 6. (a) Electrical energy production by diesel generators, (b) Battery state of charge.

While energy sales charts over the system to the grid (for scenario 1) is shown in Figure 7.

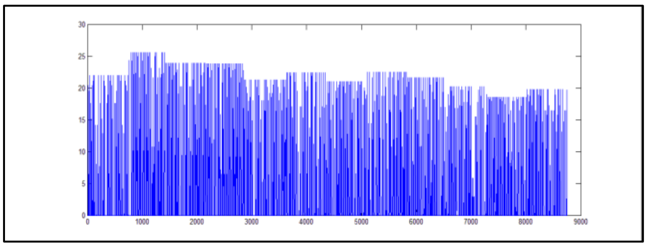


Figure 7. Energy sales during the year (for scen.-1).

Hotel electrical load requirement is 1.2GWh a year and the number of power outages that occurred during the year known as 438 hours so that the energy ratio index (EIR) grid only 0.95 based hotel engineering division reports. Backup generation hybrid PV-battery-diesel system with optimal size that uses PSO optimization techniques is able to provide 12% of electricity load demand with PV modules produce 5% and diesel generators produce 7% as shown in Figure 8. Revenue derived from the excess produced energy by the system is equal to $ 4,179.42 in a year reduces the total LCC in scenario 1.

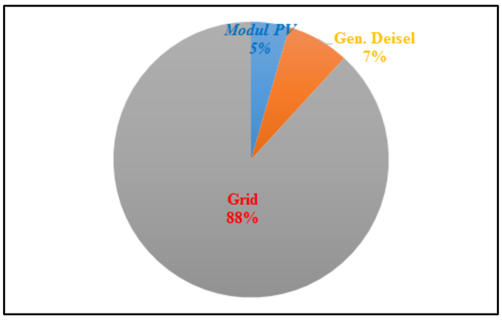


Figure 8. Composition energy mix which supplies the hotel with a backup generators using hybrid system.

V. Conclusions

Optimization result is backup hybrid system generator scenarios 1 and 2 which consists of 1 x 400kW diesel generator, 167 x 0.25kWp PV modules, 66 x 2.22kWh unit battery and 1 x 400kW inverter. Result analysis for backup hybrid system generator shown that fuel consumption is known frugal 44.97% compared to using diesel generators. Energy production amounted to 3,889,100 kWh of electrical energy with scenario 1 can save 30.69% LCC system compared to using diesel generator. Scenario 2 also can save 21.39% LCC system compared to using diesel generator. Scenario 1 and scenario 2 has COE system lower 21.94% and 11.46% compared to using diesel generator. This system absorbs the use of renewable energy with an RF value of 38% of the total energy generated backup generators.

VI. Future Work

Based on these results, it is necessary to further study on the implementation of the hybrid system plants as a backup generator hotel. Further research can also be done with large-scale hotels and small scale, the hotel at different locations and also the effect of generating a hybrid system to reduce the production of hazardous gases.

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