Optimal Sizing of Micro Hydropower to Improve Hybrid Renewable Power System

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***Abstract*—This paper presents an analysis of optimal micro hydropower (MH) capacity of hybrid systems to improve renewable energy based power systems. The electricity system was designed by considering river water flow data and solar radiation data at the research location of Universitas Andalas (Unand). Optimal results obtained for the configuration of the Grid, MH, and photovoltaic (PV) with a head height of 30 m and a flow rate of 800 L/s with the lowest Cost of Energy (CoE) value of $ 0.065. As an optimal sizing system has been able to increase the composition of renewable energy generation in the Unand electrical network. The renewable energy fraction has increased from 26.4% to 36.5%. Therefore, determining the optimal capacity will increase the use of renewable energy generation. Conversely, an increase in electricity supply from renewable energy plants will reduce electricity consumption from the State Electricity Company (Perusahaan Listrik Negara, PLN) grid. The latest excess power generation at a low load can be sold to the PLN grid.**

***Keywords*—Optimal sizing, Solar-Hydro hybrid system, and Renewable fraction.**

I. INTRODUCTION

Electrical energy has become a primary need in Indonesia today. In Indonesia, there are still many power plants that use fossil fuels such as coal, oil, and gas. Over time and the continued use of fossil fuels in power plants, several problems arise, such as the depletion of fossil fuels and the pollution caused by their use. The use of fossil fuels is not only considered economical but also pollutes the environment.

Renewable Energy Resources (RER) development can reduce environmental pollution and minimize costs in many countries in the world. As reported in ref [1] is known in 2016 that more than 170 countries have adopted at least one type of RES such as solar, wind, water, and biomass. The Indonesian government has a target within the next five years later, the capacity of electricity generation from renewable energy must reach 23% in 2025. Therefore, the government, PLN, and stakeholders of related interests must work hard together and seriously in pursuing these targets. The PV and micro hydropower system have been the renewable Distributed Energy Resources (DER) that fast spread as an alternative source of electrical energy in Indonesia.

Universitas Andalas as a public campus in the city of Padang that wants to contribute to developing RER based on solar and hydro energy. The city area of Padang has an average solar exposure time of 6.13 hours in June 2020 [2]. Solar energy is the most widely used renewable energy due to its free and abundant availability. Although solar energy has abundant availability, it does not rule out the possibility that solar energy also has some obstacles due to fluctuating radiation. Because solar energy sources are intermittent, it is more suitable to be used as a hybrid system than a single system [3]. The design of the RER power plant is divided into two types, namely individual or hybrid [4]. In this study, a hybrid system with a combination of solar energy and water connected to the grid is expected to be able to help supply electricity to the average daily load of Universitas Andalas 1500kW with an average of 8 hours of operation.

In designing an optimal system, accurate economic calculations are also needed so that the costs incurred efficiently. This design is assisted using software that can do the process of simulation and optimization of the system to be designed. The software is Homer (Hybrid Optimization Model for Electric Renewable), in which several studies have been conducted in the use of this software. The designing of on-grid solar systems for household scale reported in [5], rural desert areas in Oman [6], and rural health clinic (RHC) [7].

The results of these researchers concluded that Homer is supporting software for designing a renewable energy generation system that can be able to do economic calculations of a system. The components obtained from the Homer output are estimated cost of installation, power and energy production, economic feasibility parameters, which are the parameters of this study. Further studies by varying the parameters of micro hydro design, will be able to increase the use of renewable energy plants that still needs to be done. Therefore, this paper will present the results of the analysis of the electricity network with the addition of a renewable energy-based hybrid assembly for a variety of micro hydro designs.

II. DATA AND INFORMATION

A. Load Profile

The electrical power load of Universitas Andalas is around 2 MW, almost all are supplied by PLN [8]. The modified Unand load profile by assumption of random variability from day-to-day 10 % and timestep 12% were used in this study, where the load profile is as shown in Fig 1. The daily average electrical energy needs of the electrical system at Universitas

Andalas is 12.000 kWh/day. The design of a hybrid solar-hydro system connected to the grid is designed to meet the average daily load.

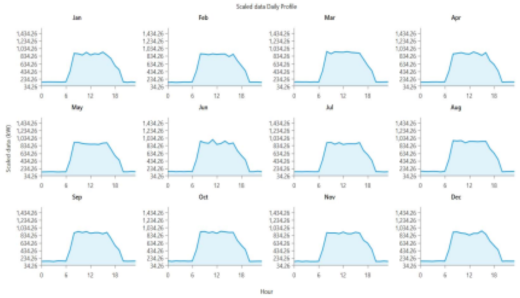
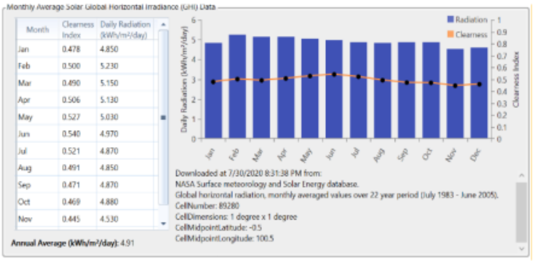


Fig 1. Load Profile of Universitas Andalas

B. *Solar Resource Profile*

Solar resource profile data is obtained through the Homer software, which is connected directly to NASA's website [9]. In figure 2 for the Padang City area, Unand can be seen as the index of solar radiation transmitted through the atmosphere to the ground surface with an average of 4.91 kWh/m^2/day.



Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.478	4.850
Feb	0.500	5.230
Mar	0.490	5.150
Apr	0.506	5.130
May	0.527	5.030
Jun	0.540	4.970
Jul	0.521	4.870
Aug	0.491	4.850
Sep	0.471	4.870
Oct	0.469	4.880
Nov	0.445	4.530

Annual Average (kWh/m²/day): 4.91

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Fig. 2. Solar Resource Profile

C. *Hydro Resource Profile*

The hydro module consists of the hydro resource and the hydro component. The hydro module is ideal for users who model systems that include conventional, small, or micro hydropower. Fig 3 shows the hydro resource profile data used for the hydro generator in Homer. In Fig 3, shows that the annual average streamflow value of 789.58 L/s with a residual flow of 100 L/s have been chosen as the core condition for micro hydropower.

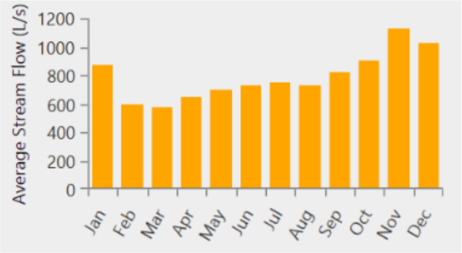

Fig. 3. Hydro Resource Profile.

D. *Grid Tariff*

The grid tariff used is based on new energy & resources regulations [10], which contains the Electricity Tariff provided by PT. PLN (Persero). University is stated as a P2 expense with a tariff of IDR 1,114.74 / kWh [11]. If converted to the US Dollar exchange rate, the unit will be obtained $ 0.08 the same as the grid sell back price.

E. *Economics*

Economic data is very influential in the calculation of cost analysis. Inflation Rate values are considered with the latest inflation release value as of June 2020 of 1.98%, this value is the lowest since May 2020 and is under the Central Bank target set 2-4% [12]. The Discount Rate value is also considered in calculating the cost analysis of this system using Homer, Bank Indonesia (BI) lowered the 7-day reverse by 25 bps to 4.0% as of July 2020. Hence, the discount rate was 4.0% and made it the lowest level since 2016 [13]. This is due to the support of the economy amid the COVID-19 pandemic that struck in 2020.

III. SYSTEM CONFIGURATION

Homer is a software that has been developed by NREL that can be used to design a hybrid electric power system with renewable energy source [14]. Homer is also a program that can run on-grid and off-grid system optimization simulations consisting of a combination of a grid system and several renewable energy plants [15]. Besides, Homer is also able to analyze and design an optimal renewable energy power generation system.

The system design is shown in figure 4, which includes load profile components, photovoltaics, converters, hydrokinetic turbines, and grid. The photovoltaic element is connected to the DC busbar, so it requires a converter to convert the DC current output from the photovoltaic into an AC current that will be transmitted to the load. While for the grid and hydrokinetic turbine is connected to the AC busbar.

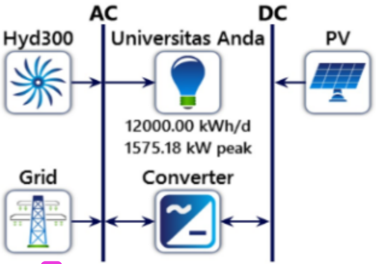

Fig 4. Schematic diagram of the MH-PV grid system

The inverter as a converter is a tool to convert DC output current from PV into AC current, which will be transmitted to the load [16]. The financial specifications of the converter can be seen in Table I.

TABLE I CONVERTER FINANCIAL SPECIFICATION

Parameter	Specification
Capital Cost ($) / kW	250
Replacement Cost ($) / kW	250
O&M Cost ($/years)	0
Life Time (years)	25
Efficiency (%)	95
Relative Capacity (%)	100

The PV module is a source that will be used to meet the electricity load. This PV capacity is chosen according to the peak load demand that will be met. The financial specifications of PV can be seen in Table II.

TABLE II PV MODULE FINANCIAL SPECIFICATION

Parameter	Specification
Capital Cost ($) / kW	715
Replacement Cost ($)	0
O&M Cost ($/years) kW	10
Derating Factor (%)	80
Life Time (years)	30
Efficiency (%)	95

The hydroelectric turbine is the second source of electrical energy that will be combined into a hybrid system with a photovoltaic system. The nominal power output of micro hydropower using the following equation [17]:

$$P = 9.8\eta \; h_{design} \; Q_{design} \qquad (1)$$

Where:

P = nominal power output of the micro hydro turbine [kW]
η = hydro turbine efficiency [%]
h_{design} = available head [m]
Q_{design} = the design flow rate of the micro hydro turbine [m^3/s]

Multiplying P by the number of hours in period t yields the kilowatt-hours (kWh) of energy (E) produced from an average flow rate of Q, therefore

$$E = P.t \qquad (2)$$

The 300kW hydroelectric turbine financial specifications can be seen in the following Table III.

TABLE III. TURBINE HYDROELECTRIC FINANCIAL SPECIFICATION

Parameter	Specification
Capital Cost ($)	689,757.50
Replacement Cost ($)	344,884.50
O&M Cost ($/years)	13,795.00
Pipe Head Loss (%)	15
Life Time (years)	25
Efficiency (%)	80

Economic analysis of the system is needed in determining the optimal sizing of a plan, from which it will be designed. This economic analysis includes CoE, Payback Period (PP), and Net Present Value (NPV). CoE is the average value of an electrical energy per kWh produced by the system [18]. The CoE value calculates using the following equation:

$$CoE = \frac{LCC \times CRF}{kWh_{Total}} \qquad (3)$$

Where:

LCC = Life Cycle Cost ($)
CRF = Cost Recovery Factor
kWh_{Total} = Total PV Energy Generated (kWh)

NPV is the net present value incurred during a project carried out with a certain period [19]. The NPV value can be calculated using the following equation:

$$NPV = \sum_{t=0}^{m} \frac{CIF_t}{(1+k)^t} - Invest \qquad (4)$$

Where:

m = Lifespan of the PV system in the year
CIF = Cash in flow ($)
k = Discount rate

Payback Period (PP) is the return on capital costs calculated using a discount factor [20]. Payback period value can be calculated using the following equation:

$$PP = y_i \; (year) + \left(\frac{F_{i-1}}{F_D}\right) * 12 \; (month) \qquad (5)$$

Where:

PP = Payback Period
yi = Year at full recovery or net cash flow equal to zero
F_{i-1} = Unrecovered cost at the beginning of last year
F_D = Cash flow during the year

IV. RESULT AND DISCUSSIONS

The simulation results of the MH-PV hybrid system using Homer Pro are shown in tables IV and V. The optimal system design of the simulation consists of six conditions. If sorted according to the lowest NPC and CoE, the most optimal system is displayed for the six design conditions.

TABLE IV. THE ARCHITECTURE OF RENEWABLE COMPOSITION

Head (m)	**Flow Rate (L/s)**	**PV (kW)**	**Hydro (kW)**	**Converter (kW)**
25	1000	300	196.2	250
25	1200	300	235.44	250
25	800	300	156.96	250
30	1000	300	235.44	250
30	1200	300	282.528	250
30	800	300	188.352	250

The composition of renewable energy plants that have been designed for two variations of altitude and water flow is shown in Table IV. The largest size of a hydro plant is obtained when using a design with a head height of 30 m and a water discharge of 1200 L/s. In contrast, the smallest hydro generating capacity is at an altitude of 25 m with a water discharge of 800 L/s.

TABEL V. SUMMARIZED COST OF ENERGY OF SYSTEM INSTALLATION

Head (m)	**Flow Rate (L/s)**	**NPC ($)**	**CoE ($/kWh)**	**Operat cost ($/yr)**
25	1000	6.1M	0,071	263,148.0
25	1200	6.3M	0,074	274,368.6
25	800	5.9M	0,069	253,965.8
30	1000	5.8M	0,068	248,865.8
30	1200	6.1M	0,071	262,330.5
30	800	5.6M	0,065	237,847.1

The Homer simulation results for economic parameters, as shown in Table V above. The most optimal value based on the lowest CoE price is the condition with a 30 m head design and a flow rate of 800 L/s, which is $ 0.065. In line with these results, the optimal system will also require a lower operating cost of $ 237,847.1 per year. Therefore, a system with 30 m head and 800 L/s water discharge was chosen as the most optimal system.

The electrical power generated for the optimal system is shown in Fig 5. From Fig 5, it is seen that during the day when sunlight is available, it will produce a large output power compared to the night. At night the micro hydro generator still supplies power in the form of a flat output power curve while the PV does not contribute power supply.

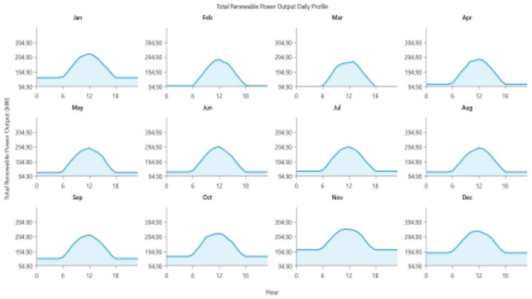

Fig. 5 Total Renewable Output for Optimal Configuration

The installation of a renewable energy-based distributed energy resources in Unand network can reduces electricity peak load in the daytime and for the night can replace the electricity source from the PLN grid, as shown in Fig 6. Excess power at night can be transferred to the utility network with electricity tariffs as large as the CoE of the plant.

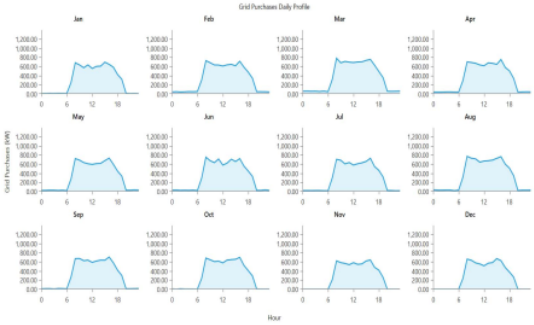

Fig. 6 Monthly power supply from the grid

TABEL VI. SUMMARIZED RENEWABLE FRACTION

Head (m)	Flow R (L/s)	Ren Frac (%)	PV (kWh/yr)	Grid Purch (kWh)	Hydro Output (kW)
25	1000	29,6	429651.9	3098170	10,19
25	1200	26,4	429651.9	3238127	85,89
25	800	32,2	429651.9	2983429	115,00
30	1000	33,4	429651.9	2951829	122,28
30	1200	29,6	429651.9	3118840	103,07
30	800	36,5	429651.9	2814282	138,00

The selection of optimal sizing MH power plant has been able to increase the composition of renewable energy plants in the Unand network. The amount of renewable energy fraction for the six configurations is 26.4% to the highest 36.5% as in Table VI. Therefore, determining the optimal capacity will increase the use of renewable energy generation. Conversely with an increase in electricity supply from renewable energy plants will reduce electricity consumption from the PLN grid.

V. CONCLUSSION

The simulation results of the solar-hydro system connected to the grid found the most optimal system with an NPC of $5.64M and a CoE value of $0.065. This system has configurations of the Grid, MH and PV with a head height of 30 m and a flow rate of 800 L/s. The initial investment cost is $992.257.50 but the investment value is expected to be replaced in the 10th year. As an optimal sizing system has been able to increase the composition of renewable energy generation in the Unand electrical network. The renewable energy fraction has increased from 26.4% to 36.5%. Therefore, determining the optimal capacity will increase the use of renewable energy generation. Environmental impact analysis needs to be considered for further research to reduce CO_2 emissions.

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