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Design and Optimization of Solar, Wind, and Distributed Energy Resource (DER) Hybrid Power Plant for Electric Vehicle (EV) Charging Station in Rural Area

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***Abstract*—Electric vehicles offer many advantages ranging from easy access and abundance of electrical energy sources. The objective of this paper is to obtain the best configuration of the hybrid power systems for charging station in a rural area such as Labuan bajo, Indonesia. Thus, the best configuration obtained is then installing with three types of energy storage namely Lead Acid and UNS Lithium battery such as Lithium Ion and Lithium Ferro Phosphate (LFP) to determine the minimum cost of operation and energy cost in a year. The results showed by implementing hybrid systems from PV and DER is the best configuration for off grid charging station. The most optimal battery in off grid system achieved by installing UNS LFP batteries. As a conclusion, by utilizing hybrid power generation technology, the potential for renewable energy in rural areas can be the main key in realizing the availability of charging stations in rural areas with affordable price for supporting electric vehicles infrastructure.**

Keywords— Renewable Energy, Hybrid Power Plant, EV Charging Station.

I. INTRODUCTION

Energy consumption has increased and will triple in a 50-year period by 2025. The use of fossil fuels as an energy source has many limitations. There are a number of pollutants that have been identified as outputs from fossil fuel use and they are serious health hazards [1].

Today, the use of renewable energy as a resource for various kinds of needs, ranging from electricity generation to electric vehicles will be able to reduce the consumption of non-renewable energy in the world and reduce dependence on fossil fuels as raw materials for conventional power plants and fossil-fueled vehicles. Significant developments in the world of renewable energy power plants and electric vehicles to touch the world market increasingly bring massive benefits to society.

Problems arise when looking at access to rural areas which results in a lot of limitations, ranging from the provision of generating infrastructure to the needs of electric vehicle equipment. Far from the grid, limited availability of materials is a challenge that must be faced by researchers in realizing even distribution of electric vehicle technology and even increasing electrification ratios.

The main disadvantage of a renewable energy generating system such as solar and wind energy is energy fluctuations, resulting in uneven power generation and causes problems if the supply is not reliable and sustainable. So this type of problem can be overcome by using a hybrid system, which is a system that combines aspects of renewable energy, such as solar and wind turbine simultaneously. Hybrid power systems can be defined as a combination of different energy sources. Complementary energy generation systems can be provided by renewable or mixed energy (with reserves from DER). The hybrid system provides better features of each energy resource compared to conventional sources and also provides electricity.

The main advantage of hybrid systems is when a resource is lack for supporting energy, other resource can be supported as a main energy source. Solar panels are less effective on cloudy and windy days so they will produce lower energy levels while wind generators can produce a lot of energy. Similarly, for wind power plants the main problem is the location of the plant which has a certain amount of wind regularly. The main use of non-conventional energy makes this system almost independent and reduces energy prices in the long run, and a combination of diesel generators is used as a backup in emergencies such as high loads or low availability of renewable power [2].

A rural area may provide many natural potentials energy resources that gives a lot of benefits. The availability of renewable energy in rural areas is the main key in realizing the distribution of electric vehicle technology and also increasing the electrification ratio. With renewable energy, a reliable power plant can be built by combining natural components as the main potential of electrical energy sources. By utilizing solar, wind and small-scale DER, construction of charging stations infra structure for EV can be realized especially to support implementation of electric vehicle technology and reducing consumption of fossil energy for transportation.

II. STATE OF THE ART

A. Wind Energy

As one of the input parameters in the preparation of a hybrid power plant, wind energy from one location may be specified in accordance [3] with the formulation of the law of exponents follows:

$$V = V_{ref} \times (\frac{H}{H_{ref}})^{\gamma} \tag{1}$$

in which href is the height used, Vref is the speed at the height of Href, H is the height of the designed wind turbine, and γ is the exponent that determines how wind speed varies with the height from ground, usually using 1/7.

Using the formulation above, the power generated by the turbine per unit swept area W is calculated through the following equation:

$$W = 0.5 \times C_P \times \rho \times V^3 \quad (2)$$

Power coefficient (CP) changes depending on wind speed.

B. Solar Energy

As an input for hybrid power plant parameters, solar energy is calculated according to the specifications of each solar panel used, such as solar panel efficiency, and the cost parameters for solar panels in accordance with local market conditions. Using hourly solar irradiation data information, the power generated from one solar panel is calculated based on the following formulation:

$$S = A \times I \times \eta \quad (3)$$

Where S is the power produced by solar panels, A is the solar panel area, I is the solar panel irradiation, and η is solar efficiency panel.

C. EV Charging Station

To formulate an EV charging station as the main system load, according to [3], charging station power consumption can be formulated as follows:

$$P_{consumption} = \int_{t_0}^{t_0+T} P(t)dt = (1 - SOC_{inl})Q_r \quad (4)$$

Where $P_{consumption}$ is the power consumption for time T, SOC_{inl} is the initial SOC of the EV battery, Q_r is the rated capacity of EV battery, t_0 is starting time charging, T is charging duration, and P (t) is charging power at time t.

D. Battery Charging Power

Calculation of the battery charging power is the calculation of the maximum amount of power that can be absorbed by the battery, the first according to the equation based on the maximum charge rate is as follows:

$$P_{batt,cmax,mcr} = \frac{(1-e^{-\alpha_C \Delta t})(Q_{max}-Q)}{\Delta t} \quad (5)$$

where:

αc = the storage's maximum charge rate [A/Ah]

Qmax = the total capacity of the storage bank [kWh]

the calculation of the latter is the calculation-based storage component's maximum charge current according to the following equation:

$$P_{batt,cmax,mcc} = \frac{N_{batt} I_{max} V_{nom}}{1000} \quad (6)$$

where:

N_{batt} = the number of batteries in the storage bank

I_{max} = the storage's maximum charge current [A]

V_{nom} = the storage's nominal voltage [V]

Both of the above calculations are modeled based on the charging losses assumptions as follows:

$$P_{batt,cmax} = \frac{MIN(P_{batt,cmax,mcr}, P_{batt,cmax,mcc})}{\eta_{batt,c}} \quad (7)$$

E. Battery Discharging Power

Conversely, battery discharging power is the battery's ability to discharge to power the load with the equation is as follows:

$$P_{batt,dmax} = \eta_{batt,d}(P_{batt,cmax,mcr}, P_{batt,cmax,mcc}) \quad (8)$$

III. Methodology

Methodology in designing and optimizing hybrid power plants in rural areas is done by carrying out by the following steps:

A. Step 1

Step 1 was designed by combining elements of hybrid power plants with components in the form of PV, Wind Turbine, and DER. The battery in the off-grid system used is taken from one type of battery, namely Lead Acid battery with 6 scenarios listed in TABLE I. The main purpose of step 1 is to find the best composition of the proposed plants at the installation based on the potential and reliability of the resource.

TABLE I. Combination of Power Plant Scenario

Scenario	Power Plant Combination	Battery Type
1	Solar	Lead Acid
2	DER	Lead Acid
3	Solar + DER	Lead Acid
4	Solar + Wind	Lead Acid
5	Wind + DER	Lead Acid
6	Solar + Wind + DER	Lead Acid

B. Step 2

In this step, the best scenario from step 1 is then installing with three types of energy storage technology such as Lead Acid, UNS Li-Ion (NCA), and UNS LFP. The purpose of step 2 is to find the best storage technology that can be applied at the system testing location. The scenario in step 2 is as shown in TABLE II.

TABLE II. Scenarios With Vary Types of Battery

Scenario	Power Plant Combination	Battery Type
1	Best from Step 1	Lead Acid
2	Best from Step 1	Li-Ion (NCA)
3	Best from Step 1	LFP

C. Step 3

The final step in this methodology is to compare the composition of the sum of each component, starting from the battery and generator at the most optimum value. In this step two scenarios will be compared, namely the scenario of installing batteries with defined capacity, the second is to use the Derivative-Free Optimization Algorithm quantity calculation. The purpose of this step is to choose which is the better composition of each components for designing the charging station.

TABLE III. STEP 3

Scenario	Power Plant and Battery Type	Battery Quantity
1	Best from Step 2	Defined
2	Best from Step 2	Derivative-Optimization Algorithm

D. Net Present Cost (NPC)

Net present cost (NPC) used to represent the life-cycle cost of a system. The total NPC condenses all the costs and revenues that occur within the project lifetime into a single lump sum in year-zero dollars, with future cash flows discounted back to year zero using the discount rate. Costs may include capital costs, replacement costs, operating and maintenance costs, fuel costs, the cost of buying electricity from the grid, and miscellaneous costs such as penalties resulting from pollutant emissions. Revenues may include income from selling power to the grid, plus any salvage value that occurs at the end of the project lifetime.

With the NPC, costs are positive and revenues are negative. This is the opposite of the net present value (NPV). As a result, the NPC differs from NPV only in sign. So the NPC could be formulated as bellow:

$$NPC = C_0 - \sum_{i=1}^{T} \frac{C_i}{(1+r)^i} \qquad (9)$$

Where

C_0 = Initial investment

T = Project Lifetime

C_i = Cash Flow

r = Discount Rate

This formulation can also derive to this formulation:

$$NPC = \sum_{t=0}^{T} C_{ct} + C_{om,t} + C_{r,t} + C_{f,t} - R_{s,t} \qquad (10)$$

Where T is the lifetime of the project, Cc,t represents the capital cost for the system in year t, Com,t represents the cost of operation and maintenance in year t, Crep,t represents the cost for replacement in tear t, Cf,t represents the cost of fuels in year t, and Rs,t represents the salvage price in year t.

E. Operating Cost

The operating cost is the annualized value of all costs and revenues other than initial capital costs using this equation:

$$C_{operating} = C_{ann,tot} - C_{ann,cap} \qquad (11)$$

where:

$C_{ann,tot}$ = the total annualized cost [$/yr]

$C_{ann,cap}$ = the total annualized capital cost [$/yr]

IV. DESIGNED SYSTEM MODEL

A. Location

Fig. 1. Testing Location

The selected test location is in Labuan Bajo, Komodo District, West Manggarai Regency, East Nusa Tenggara. This location was chosen because it has an abundance of potential new and renewable energy sources. As shown in Fig. 2 and Fig. 3 about the potential of solar and wind speed in Labuan Bajo in the last 3 years.

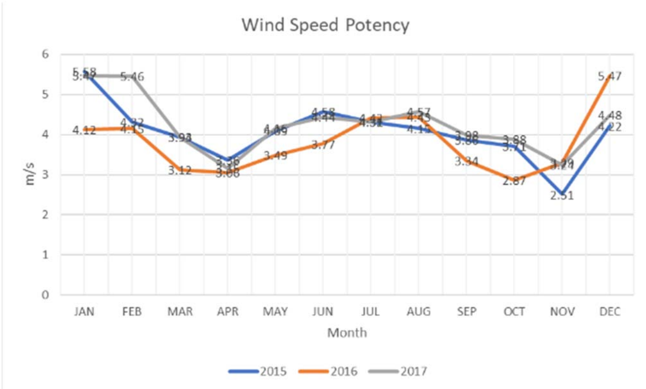

Fig. 2. Wind Speed Potency in Labuan Bajo

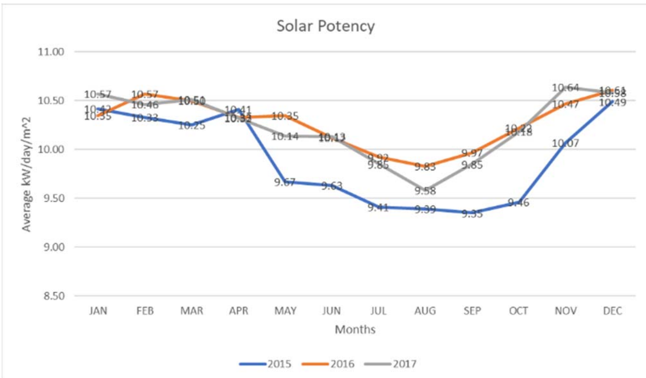

Fig. 3. Solar Potency in Labuan Bajo

B. System Schematic

System consists of two major parts of the bus, namely the AC bus supplied by DER (using a diesel power plant), and the DC bus supplied and connected with Wind Turbine, PV, and Battery.

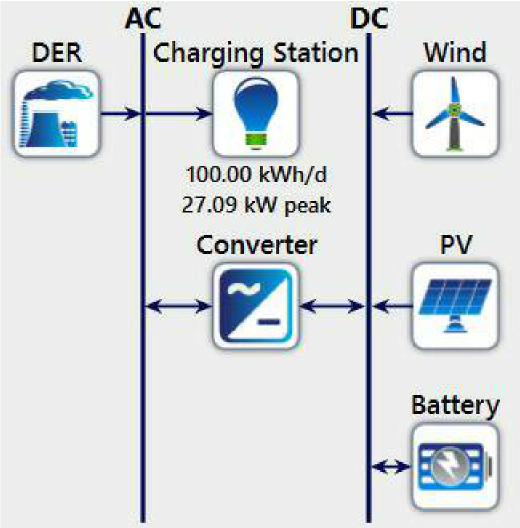

Fig. 4. Proposed System Schematic

The DER used is a small-scale diesel power plant with a generator output of 10kW. Wind Turbine is used with a DC 1kW generator capacity. The PV used is solar panels with an output per panel of 1kW. The system also consists of a battery with a capacity that is tested according to the methodology and converter.

C. Charging Station

The charging station load is modeled into the HOMER assuming 50 vehicles per day and the capacity of each vehicle is 2 kWh per vehicle. Refers to [4], charging station load can be shown in Fig. 5 and Fig. 6.

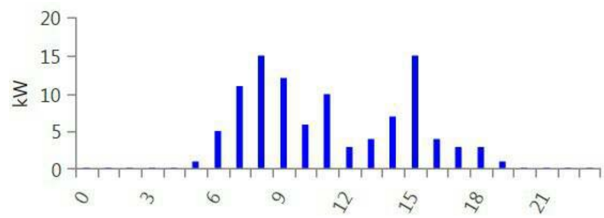

Fig. 5. Load Profile in Labuan Bajo

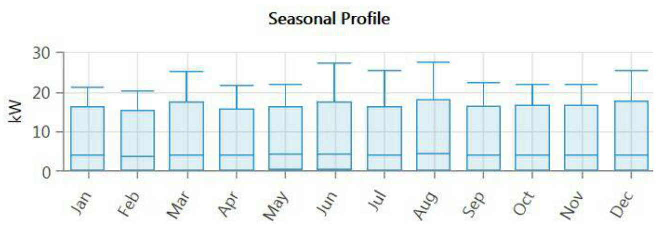

Fig. 6. Load Seasonal Profile in Labuan Bajo

V. Result and Discussion

Through step 1, results are obtained as shown in TABLE IV. From these results it can be noted that the most optimal composition of the generator is Solar + DER (scenario 3), which is equipped with a converter and battery. In this situation, gives the lowest NPC and operating cost. From this results it can be seen that the potency of Solar energy in Labuan bajo is bigger than other resources. The bigger PV capacity the bigger land area cover need. To reduce that implication DER was needed. The big initial capital was coming from battery. The results showed the battery at that scenario is the lowest.

TABLE IV. Result For Best Scenario

Scenario	PV (kW)	Wind (kW)	DER (kW)	Lead Acid (kWh)
1	108	0	0	45
2	0	0	10	65
3	36.4	0	10	45
4	104	1	0	83
5	0	1	10	64
6	24	1	10	48
Scenario	**NPC (US$)**	**Operating Cost (US$/year)**	**Initial Capital (US$)**	
1	$ 776,145.00	$ 26,427.00	$ 353,503.00	
2	$ 604,506.00	$ 36,213.00	$ 29,470.00	
3	$ 423,625.00	$ 18,264.00	$ 133,614.00	
4	$ 777,075.00	$ 26,605.00	$ 354,614.00	
5	$ 603,893.00	$ 35,769.00	$ 35,907.00	
6	$ 431,570.00	$ 20,688.00	$ 103,063.00	

Next, the best scenario from TABLE I is then comparing with vary of battery types. Battery Li-ion (NCA) and LFP were used in this research were made by UNS Manufactures Battery. The spec of this battery cell for NCA and LFP are 3,7V with 2700 mAH and 3,2V with 1400 mAH respectively. The Lead Acid, NCA and LFP life cycles are 400, 400 and 2500 respectively. LFP Price is more expensive than NCA and Lead Acid. The result of this step can be shown in TABLE V.

TABLE V. Comparison Results By Installing Battery

	PV (kW)	DER (kW)	Batt. Capacity (kWh)	Converter (kW)
Lead Acid	36.4	10	45	19.8
Li Ion (NCA)	26.1	10	19	15.9
LFP	31.5	10	18	18.1
	Battery Type	**NPC (US$)**	**Operating Cost (US$/year)**	**Initial Capital (US$)**
	Lead Acid	$ 423,625.00	$ 18,264.00	$ 133,614.00
	Li Ion (NCA)	$ 363,093.00	$ 16,662.00	$ 98,507.00
	LFP	$ 223,350.00	$ 5,763.00	$ 131,839.00

TABLE V showed, the best result obtained by installing LFP battery. It is indicated by the lowest operation cost and NPC. But since LFP has longer life cycles, the initial Capital also very high. NCA even though has the lowest Initial capital, since the life cycles is shorter than LFP, the operation cost and NPC is also high.

Next, the best result from comparing performing of battery is than comparing to defined capacity of battery. This step is to determine which one is better. A defined energy storage size 20 kWH has taken as an comparison for free optimization battery. The result showed in TABLE VI.

TABLE VI. OPTIMIZE COMPARISON FOR THE BATTERY CAPACITY

Battery Capacity	**PV (kW)**	**DER (kW)**	**Batt. Capacity (kWh)**
Derivative Optimization	31.5	10	18
Defined - 20kWh	22.6	10	20
Battery Capacity	NPC (US$)	Operating Cost (US$/year)	Initial Capital (US$)
Derivative-Optimization	$ 223,350.00	$ 5,763.00	$ 131,839.00
Defined - 20kWh	$ 225,298.00	$ 7,410.00	$ 107,634.00

From TABLE VI can be observed that by using Derivative optimization still provides better than defined battery. It can be shown from the lowest NPC and operating cost. TABLE VI also showed even the initial capital in the defined battery is lower than derivative optimization, the operation cost is still high due to higher maintenance of the defined Battery.

VI. CONCLUSION

Potential for renewable energy in rural areas, in this paper is exemplified in Labuhan bajo, East Nusa Tenggara, Indonesia, apparently having a very high abundance to provide energy sources in rural areas. For charging station infrastructures for supporting Electric Vehicles, the best solution achieved with implementing hybrid systems from PV and DER, equipped with LFP batteries, the most optimal battery off-grid system in Labuan Bajo can be realized.

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REFERENCES

[1] R. Beula and S. Sashan, "Implementation of Solar and Wind Hybrid System for Rural Electrification," *IJAREEIE*, vol. 3, no. 1, 2007.

[2] P. Kumar, R. Pukale, N. Kumabhar, and U. Patil, "Optimal Design Configuration Using HOMER," *Procedia Technol.*, vol. 24, pp. 499–504, Jan. 2016.

[3] M. Ranjevaa and A. K. Kulkarnia, "Design Optimization of a Hybrid, Small, Decentralized Power Plant for Remote/Rural Areas," *Energy Procedia*, vol. 20, pp. 258–270, Jan. 2012.

[4] S. Cheon, S.-J. Kang, S. Cheon, and S.-J. Kang, "An Electric Power Consumption Analysis System for the Installation of Electric Vehicle Charging Stations," *Energies*, vol. 10, no. 10, p. 1534, Oct. 2017.