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Initial Research of Renewable Energy Resources for Hybrid Microgrid Implementation, Using Solar and Wind; Transforming the Diesel Dependence: Study Case of Mamburit Island - Indonesia

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***Abstract*— Electrical demands are growing rapidly in the world, especially in larger cities, and Indonesia is not the exception. Indonesia's average peak demand is projected to increase by 142% (reaching 61.2 gW) in 2025, and by 205% (reaching 77.3 gW) in 2030, compared with 25.3 gW in 2010.**

However, the challenge of completing the growing demand in big cities reveals another huge problem, which are those small villages and islands without any electricity facility until now.

The design for Mamburit Island in Sumenep-Indonesia as a real case will integrate different generation sources such as, solar panel system PV considering the daily average irradiation DNI of 5.78 kwh/m^2 in the area, vertical axis wind turbine VAWT, taking advantage of the annual wind speed average of 8.82 m/s and energy storage system ESS as a real, feasible and friendly options to supply electricity facility. All this, integrated with engine diesel generator EDG present as the actual main sources, minimizing the fossil dependence, through micro grid MG principle integration.

This paper describes the measurement process, mathematical considerations, and principles description for the application of the MG hybrid integration model to Mamburit Island as real study case for provide electricity to small island.

Keywords*— *Micro Grid, Micro Grid Integration, Renewable Energy.

I. Introduction

Every year the electrical demand in the big cities around the world is increasing. Therefore, the countries have the responsibility to find new electrical generation sources and it's mandatory to consider multiple factors such as: How that new generation will impact the environment? Are the new generation sources adapting to the climate change challenge? Renewable energy sources could be the answer of those questions.

In 2019 the total electricity generated in Indonesia was of 35 gW according to the Indonesian ministry of energy and mineral source ESDM. In the same year, the percentage generated through renewable energy was only of 12.4 % [1]. It shows the highest dependence of fossil oil derived as Electrical generation sources.

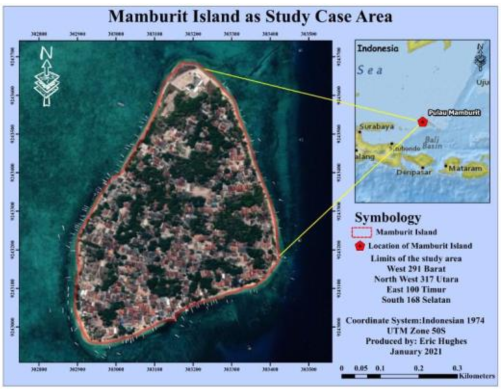
One example in Indonesia is the case of Rote Island where the electric demand increases almost 5% every year, and all the energy is generated using EDG. In order to complete the demand, 155 ton/year of diesel are used. This system becomes unsustainable to complete the increasing demand for the population and leads to constant blackouts [2].

In order to contribute and minimize the challenge of providing electricity for small island and remote areas nowadays, MG principle has been applied in some countries as an excellent option.

The United Nations (UN) through the plan 2030 develop 17 statement development goals SDG focusing in providing equality for all the world. Many countries conclude that one strategic way to minimize the poverty, protect the planet and fight again the inequality is providing clean electricity [3].

For example, Germany transforms its electrical matrix generation, projecting to reduce 80% of their emissions through renewable energy source application [3].

MG is an independent, a sustainable and an efficient grid where the final costumers need to be responsible and committed to the grid. There are several micro grid models which normally adapt to every specific need [4].



. Fig. 1. The Map of Mamburit Island [5]

An on-site analysis about the electrical situation in the Mamburit island (Figure 1) concludes that around four hundred houses depend on 10 EDG from around 1.5 kW/each, just working during the night (7 pm-5 am) and around 90 private Solar Home Systems SHS of around 60 W/each in some houses. Those two systems generate around 20 kW/day in a different day time and distribute minimal amount during the day from the SHS owner. The rest of it is distributed during the night when the EDG starts operating.

Due to the size of the Island ($3.46\ \text{km}^2$), there are not any hydric sources. The only available natural resources are solar radiation and wind (considered low-middle speed). It is not possible to consider PV farm station [4] because of the island space. Therefore, PV will be installed on the roof of some houses as an alternative option.

This paper describes the measurement methodology to evaluate the natural resources as renewable energy sources and the integration of the generation sources in a MG model as an effective option to supply electricity for the small island of Mamburit as study case. The measurement methodology can minimize fossil dependence and become a model for small island or remote areas.

Information data of irradiation for PV and wind for VAWT as natural resources are collected and processed using mathematical equations. The data is analyzed to determine the MG integration model combine with EDG and simulate the integration.

II. LITERATURE REVIEW

A. General Description

The electric grid is the intricate system designed to provide electricity all the way from its generation to the customers that use it for their daily needs. These systems have grown from small local designs, to stretching thousands of kilometers and connecting millions of homes and businesses today [6].

Nevertheless, when we talk about MG it is refer to the independent network where each generator source and costumer take part in the management of the grid system and his efficiency [7]. Each MG is combined with different generation sources, normally called smart park and controlled by a smart system or automatic switch [8].

This research will describe the MG hybrid integration process starting from the natural resource measurement, actual generation analysis, consumption data collect and the evaluation of VAWT, PV and ESS integrated with EDG as hybrid generation mode. Propose to transform the community of Mamburit island. The idea is to keep the EDG generation value and provide the rest through clean energy sources.

B. MG Integration Models

Previous research developed using MG as an integration model to supply energy for a remote touristic place, shows some similar elements in comparison to the model propose. In the research, where is present high-speed wind conditions the electric vehicle EV is propose as ESS and most of the 70% of the electricity was generated through horizontal axis wind turbine HAWT. Due the low peak demand during the day and even in the night, it make the system efficient [4].

Another Research developed by the Madura Islam University in Jawa Timur, related to the wind speed behavior analysis in Sumenep Regency, determine that the wind speed average in Sumenep Regency is between 2.5 to 8.0 m/s, that is under the range of VAWT applications. Because the research was focus in the implementation of HAWT, the result was dismissed as power of generation source [9].

A journal paper related to electrical generation based on renewable energy, explain about the strength and weakness of using VAWT in MG, concluding that for low and medium constant wind under 2.5 m/s and up, VAWT shows good efficiency according to the selected model for remote areas [10].

Another paper related to the different models of VAWT developed by student of the Brazilian Technological Institut and published by IEEE shows several conclusions of each VAWT model. The advantages and relevant information according to the wind behavior and output details were also described in [11]. The turbine rotation speed ω, is calculated using (1), where J_{rot} is the turbine inertia, P_{mech} the mechanical power and T_{gen} the torque applied by the generator. A rotor inertia of 2.25 × 108 kg $m^2$was used, which was estimated in a previous VAWT study. Trough the (1) equation the result confirms that two blades VAWT have good torque passing rapidly the inertia point, but with low output power generation. Otherwise, the three blades show high output, but need help to increase the torque and broke the inertia point.

$$\omega = \frac{1}{\mathrm{J_{rot}}} \int \frac{\mathrm{P_{mech}}}{\omega} - \mathrm{T_{gen}}\ \mathrm{dt} \tag{1}$$

Therefore, the implementation of MG integrating using different renewable sources requires an on-site evaluation with the objective to determine the consumption projection and Community behaviour related to their daily activities. On the other side, the natural resources available in the research area has to be measured to determine the best integration model.

Hence, before the field evaluation is carried on, the period of one year was selected to determine the feasibility of the natural resources in the area, wind speed, solar irradiation and actual consumption/demand behavior. Thus, the MG hybrid integration can be developed. Figure 2 shows the grid direct current DC block considering the integration of PV, VAWT and ESS.

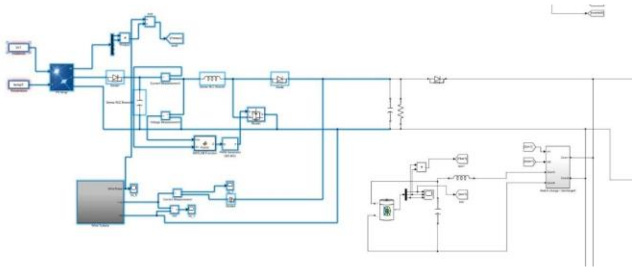


Fig. 2. Micro Grid Block DC Design Using Simulink

III. METHODOLOGY

In this section: methods, analysis and resources applied to obtain the natural resources values and the electricity consumption/demand are describes. The process consists of two steps which are:

a) Determining the characteristics power of the natural resources available in the area (wind and sun) at least 1 year by monthly period.

b) Performing the electrical consumption behaviour (demand, demographical and geographical characteristics) and the actual electrical generation average, through EDG and private SHS.

A. *Natural Resources Measurement Process*

Natural resources present in the area are two, wind and solar radiation which are presented into two section:

1) *Wind Speed Data*

The wind speed measurement process was conducted in 3 days every month, 3 times every day in a period of one year (June 2020-june 2021), which is considered to be a limited data. But it was valuable for VAWT implementation process due that the focus is determine the constant wind blow over 2.5 m/s.

Considering that some geographic factors impact the wind behavior, the research area was divided into four selected points, those are north, south, east, and west to correctly manage the wind speed behavior.

Using a Uni-T digital anemometer model UT363 BT (Figure 3), the wind measurement process was carried out. The device is placed at the upper end of a 10-meter bamboo which is the minimum height to approach the wind speed for VAWT application and connected to the digital receptor device through Bluetooth protocol, the information was collected in a real time and stored in a database.

Fig. 3. Digital Anemometer Uni-T Model UT363BT

In order to determine the wind speed daily average, the data collected 3 times in the same day. First, the wind speed average is determined as constant. For this research, the VAWT average wind speed will be 2.5 m/s which is the lowest wind speed value to VAWT application.

$$V_m = \left(\frac{1}{n}\sum_{i=1}^{n} Vi^3\right)^{1/3} \tag{2}$$

where V_m = approximate wind speed, T_i = time, V_i = speed of time, n = number of measurements.

To obtain the daily and monthly wind speed average is determine using a Weibull distribution theorem (3) and considering v as the wind speed average as constant of 2.5 m/s.

$$f(v) = [\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}]e^{-\frac{v^k}{c}} \tag{3}$$

where $f(v)$ means the effective average daily and monthly value; v is 2.5 m/s which is the minimum speed generation value for the VAWT application (as constant) k the speed data and c is directly related with k $(1{,}5 < k < 4)$, which means c Impact directly the wind speed average [5]

However, since the wind speed data is limited and it can generate uncertainties, Bayesian approach [12] is implemented considering the projection based in the air density as is show in (4).

$$AEP = \sum_{ji=1}^{t} Pwt(Vj)`\rho \tag{4}$$

where $`\rho$ is the normalized air density, Since the power performance curve (speed) is provided with respect to the standard air density of 1.225 kg/m^3. Considering the time, monthly value and duration test time, the annual energy projection AEP is obtained.

Considering two possible scenarios (low wind speed and high wind speed) the formulation (5) shows the contribution average of VAWT combination, based in 8 turbines of 2 kW max output. Then,

$$vawt = \left(w \times \frac{1}{2} t \times ef\right) \tag{5}$$

where w, means the monthly average wind speed, t is the hours in a month and ef is the system efficiency 90%. For the specific case of low wind blow season $\frac{1}{3}t$ should be considered and the final value have to be multiplied by 8 which is the VAWT quantity projected.

2) *Solar Irradiation Data:*

Because of the solar irradiation variation is not too high in all the Republic of Indonesia, this is obtained through the Indonesian meteorological, climatological and geophysical agency BMKG and compared with Hommer software system. In radiation behavior the raining and summer season were also considered. According to the "figure 4" the power daily irradiation average is around 5.78 kW/m^2.

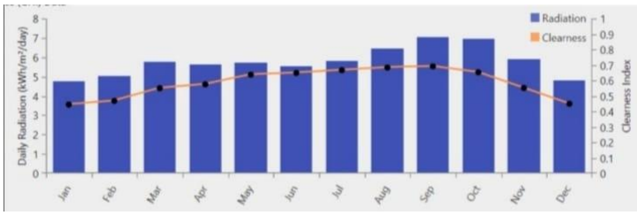


Figure 4. Radiation data. Source BMKG

After determining the daily irradiation average by km^2, it is important to determine the monthly average. The formulation (6) shows the monthly output generation average projected for a scenario of 90%.

$$Pout = (ir * PVpeak * 31 * 0.9) \tag{6}$$

where the daily irradiation is represented by ir, PV peak considered in 140, monthly days are presents with 31days and considering a system with 90% of efficiency by 0.9.

B. *Electrical Generation and Consumption Average*

After of an exhaustive technical evaluation in the island, two main system were observed and measured which together complete the actual generation amount.

1) *Engine Diesel Generation source:*

Actually, is the main power generation available just during the night (7 pm-5 am), with a very low output generation (60 watts/householder) and around 15 kW as max EDG output. The community does not have any organization or special electrical distribution structure. All the EDGs are from personal owners, willing to extend a basic line to all the around houses as a business opportunity selling electricity. Those who want to be part of their distribution line should pay between 5 and 10 thousand IDR/day.

This situation causes constant blackout, EDG damage and sometimes burn in the EDG welding because of the basic system installed without any electrical protection. Furthermore, it causes users to move to other EDG causing the same problem of blackout or burning.

2) Solar Home Systems Source

The other system used during the day is SH. The system of 30 or 60 watts is combined with batteries of 30/40 Ah 12 Volts. In some householders, the SHS is 100 watts with small battery of 30 ah or less. It affects the system efficiency.

On the other hand, some houses with SHS of 60 watts, integrate batteries of 60 and 80 ah, making the system inefficient.

The energy generated through the EDG and SHS system was measured at the operational time of each one. From EDG´s (between 7 until 5 am) and for SHS system average during the day (between 8 and 4 Pm) integrated with batteries at night.

All the AC value were obtained using a Greenlee Textron ampere clamp model cm-600 (Figure 5). The SHS, batteries, and DC values were measured with a multimeter extech model 410 Figure 6.

Fig.5. Ampere Clamp

Fig 6. Multimeter extech 410

3) *Consumption* Projection:

Based on the actual generation/consumption system in the island, there are several challenges at the moment to create an efficient and sustainable electrical power system model to complete the demand.

One of those challenges is the island space, a place of 3.46 km^2 with a density of 400 houses and 4000 habitants, public building and limited social/sports areas.

The implementation for PV or VAWT park generation in a single place will affect the dynamic of the community because of the afforded mentioned limitations. Therefore, the roof of houses can be an alternative option to be used as a base of PV.

On the other side, taking into account that the consumption peak occurs at night when PV solar energy is not available. ESS integration will be essential to keep saving the exceeding PV and VAWT generation during the low peak demand and provide it during the night.

The graph in Figure 7 shows the actual electric generation distribution. Basically, the area has 3 electrical generation sources which are SHS, EDG and ESS (batteries). It provides more than 50% through EDG generation which have to change.

Figure 7 also shows the challenge to minimize the EDG dependence as main present source in an unsustainable system.

After determining the availability of each generation sources in the area, the structure combination should be determined as central generation sources.

$$Q_1 + Q_2 + Q_3 = Q_{total} \quad (7)$$

where Q_1 means EDG, Q_2 mean SHS and Q_3 ESS (small batteries. Therefore, the value of the kw/h is determined by fossil generators, and it has to change.

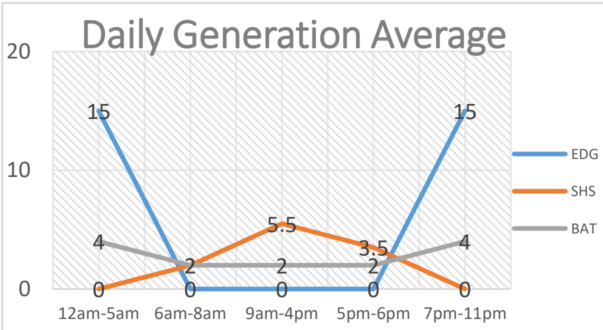


Fig. 7. Average Actual Generated Data

On other hand, a short interview was carried out to understand the electrical consumption behaviour in the research area using a sample of 10% of the houses (40). The householders connected to the EDG have between 3 and 5 light bulbs of 4 Watts and a water pump (Sanyo). While those who have SHS/ESS have television.

The interview consists in three questions which are:

1. Which home electric devices do you have?
2. How are the use behaviour of your home devices?
3. Do you have any electric generation sources?

The result helps us determine the consumption rate amount and usage behaviour, and confirm the previous values of 60 Watts from the EDG or 130 Watts for those who have SHS.

IV. RESULTS

The Indonesian electric company PLN has divided the electrical consumption according to the status of every family, including the Islands under the range of 450 to 900 VA. The company also determines the minimum consumption amount is 40% of the load value. Considering that the island population is under the basic economy capacity (poor class), every kW/h has the regular cost of IDR 1,352. However, the government applies a subsidy of IDR 415 for every kW/h offering an accessible cost [13].

Based on the minimum generation amount of 450 VA for each householder in the research area, it’s possible to determine the load in the MG and the electrical generation.

The reality afforded considered in the research area, leads us to consider different possible combinations using efficiently the solar radiation and wind speed in integration with ESS as is show in Figure 8.

Based on the information obtained by the local government with an estimation of 400 houses, with consumption average oscillating between 400 and 450 VA, looking to provide the minimum consumption amount of 40%, then through (8) it is possible to obtain the approximate generation target to complete the load.

Even though the load amount is already reached, it is important to consider the distribution time to complete the night demand without increase the EDG generation.

$$DP = (Ps*Nh*Ef*T) \tag{8}$$

$$(450*400*0.40*744) = \quad 53{,}568\text{kW/h each month} \tag{9}$$

Where, DP means distribution power, Ps is the section 450, Nh is the number of houses, and T is the hours by month.

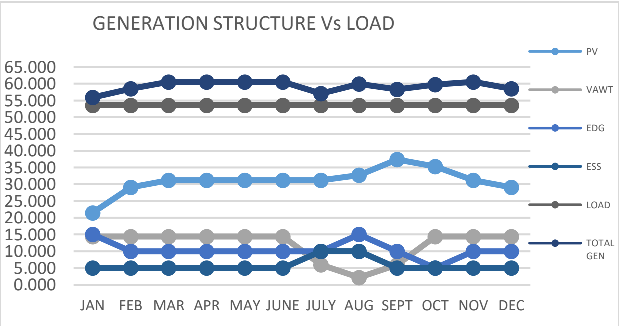


Fig. 8. MG Projection generation KW

A. Integration Model Evaluation

After wind speed value are obtained, the daily value is integrated and distributed to obtain the wind speed average. This information is divided by time, place and plotted to be better analyzed as shows in Figure 9.

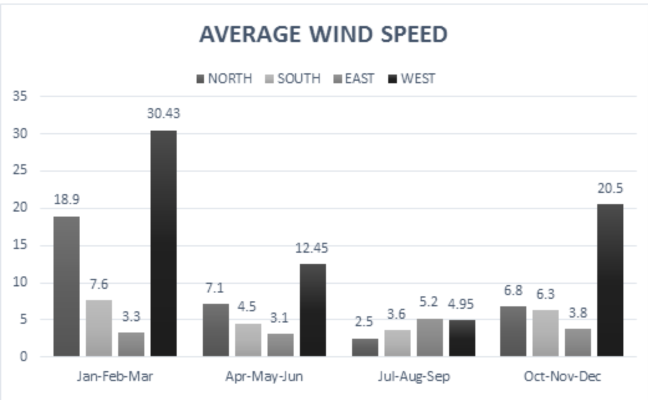


Fig. 9 wind Speed Average

1) Wind Turbine Model Characteristics.

VAWT is divided in two main groups, VAWT of two blades and VAWT with three or more blades. Each group is classified by their different models, according to the wind behavior Figure 10.

The VAWT of two-blades turbine has a greater torque fluctuation with rotor angle, producing two peaks per revolution as the upwind and downwind blades, both produce torque peaks at the same azimuth.

By contrast, the three-blades turbine has a smoother torque, with the peaks from the downwind blades occurring in between those of the upwind ones.

In both turbines groups, the torque fluctuation increases at low tip speed ratios, when the blades start to stall for greater proportions of the rotor revolution, and each peak starts to split into two separate peaks. This is a problem when the turbine is operating above the rated wind speed, and stall control is used to limit the turbine power [10].

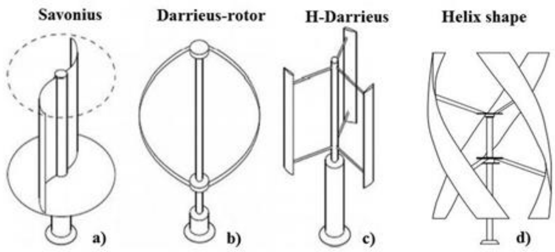


Fig. 10. VAWT Models [11]

According to the wind speed result in the four evaluation points, it shows values under the standard for VAWT. Hence, two points shows steady and good wind speed average, which are the south and west point. However, the wind speed average has different values in both points, In the west point for example, apply the two blades Savonius VAWT due the torque will not increase turning at same wind speed or less, because have two positions, also adapting to the fluctuations. Otherwise, the VAWT three blades Darrieus will adapt to the constant wind speed, showing low starting torque, but after few minutes will start generating a significant output value.

2) Final Considerations.

Understanding that the peak demand behavior happens at the night and committed to minimize the dependance of EDG. ESS is propose to integrate the MG with the idea to store the remaining PV and VAWT generation output during the morning [14].

On the other hand, maximizing the efficient of the VAWT and PV generation during the low peak demand during the evening, will be possible to store a large part of that energy generated in an ESS device.

For the night in a constant scenario (excepting the low wind speed month, Fig 8) the wind is still available, when the consumption peak demand occurs.

Therefore, EDG will only work at their maximum output power if the wind is not available during the night, as it is projected during the month of July, August and September transforming the EDG dependence.

The MG integration is combined by PV which is projected to generate 53% of the total demand (30 kW), the

VAWT with the 25% (around 12 kW) [15] and the rest managing the EDG output and ESS. The details about sizing are not described here.

V. Conclusion

This paper offers an electrical integration model solution for remote areas and small island applying the concept and principle of MG using the island of Mamburit as real case. Measurement process for natural resources available in the island using a basic method and tools was arranged. Through various ways as interview, measurement generation, supported by basic mathematical equations the load projection demand was obtained. Wind speed limited data dan Weibull and Bayesian approach are used to minimize uncertainties. It was applied as novelty in MG using VAWT. The result confirms the integration of VAWT, PV and ESS in the MG, transforming the previous EDG dependence in the process to provide electricity for remote island. VAWT for MG applications as an important generation source is also confirmed in this paper [16]. The ESS size, and the generation for a scenario of 100% load have to be analyze in a future step. As a tropical region, every area has different renewable sources. The correct evaluation using MG integration can generate a correct model, provide electricity, create opportunities for remote areas, and minimize the fossil dependence.

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