Techno-economic analysis of an optimized hybrid energy system implementation using PV-wind turbine-diesel generator at Indonesia’s remote telecommunication base

M M M Dinata*, V A Mardiana, A Mitayani, G N Nurkahfi

Research Center for Electronics and Telecommunication, Indonesian Institute of Science, Sangkuriang Street, LIPI Campus 20th Building, Bandung, 40135, Indonesia

*E-mail: moch035@lipi.go.id

Abstract. Nowadays, the implementation of the telecommunications industry in Indonesia should be encouraged to be more environmentally friendly, especially the source of electrification for base stations whose numbers are increasing every year. The purpose is not only to reduce CO$_2$ emissions, but also how these efforts are made to reduce cost of electricity (CoE) so that it can improve operator's operational cost efficiency. On this paper, author analyzed the implementation of a hybrid energy system plus (HES+) in Indonesia, which in addition to using solar panels is also optimized by adding wind turbines to areas that have proper wind speeds. Design, identifying the potential geographical location, calculation and sizing for optimized hybrid energy system is the major part of this study. Therefore, the calculation result for the CoE of base station could be as accurate as possible. It is also found that with HES+ installed, telecommunication operator has improved energy efficiency, reduced OPEX and minimized greenhouse gases with reducing 50 Ton of CO$_2$ emission per site per year.

Keywords: hybrid energy system; techno-economic analysis; cost of electricity

1. Introduction

As stated in the article from previous work [1], the implementation of Hybrid Energy System (HES) in Indonesia is done only by using solar panels as an alternative energy source. The study showed that the efficiency of fuel use and maintenance costs significantly increase if we compared between using a charge discharge (CDC) system and HES. Calculation model of Hybrid Energy System (HES) using a solar panel that developed by [1] proved that it provides cheaper Cost of Electricity (CoE) up to 67% than the CDC system. Average CoE from 12 sample sites, for CDC system around IDR 10,969/KWh meanwhile solar cell HES only around IDR 3,543/KWh. The importance of this research to be continued is because according to [2] global annual electricity consumption for the telecommunication sector has increased from 219 TWh in 2007 to 354 TWh in 2012, which corresponds to an annual growth rate of 10%. This projection of global electricity consumption is expected to escalate at an annual additional rate of 10% between 2013 and 2018. Accordingly, report from well-known SMART (Standards, Monitoring, Accounting, Rethink, Transform) 2020 also said the Greenhouse Gas (GHG) emissions produced by the telecommunication networks in 2020 will increase by a factor of three when compared to 2007, which means an increase from about 86 Mt CO$_2$e to 235 Mt CO$_2$. 

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The growth of telecommunications towers in Indonesia is growing rapidly every year, as the market analysis report issued by GSMA, in 2015, it was predicted that the number of telecommunication towers in Indonesia would be as many as 134,426 sites. From 134,426 sites, around 5,722 sites (4.25%) were off Grid (without electricity connection), and around 9,132 sites (6.79%) were connected to an unreliable grid. Moreover, from annual report of Indonesia’s ministry of communications and informatics in 2017 [3], based on Operations Performance Report and confirmation with mobile cellular telecommunication operators in October 2017, out of 83,218 villages, 22,521 villages are located in 3T region (foremost, outermost and lagging) and 60,697 villages are located in non 3T region. From the 22,521 villages located in the 3T regions, 7,314 villages still have no telecommunication access; 518 villages receive with signal strength <50%, and the remaining 6,796 villages receive no signal at all. Of the 60,697 non-3T villages, 1,261 villages still have no telecommunication access.

As already mentioned, this research is a development of research that has been done previously by the author himself. The HES system that has been implemented is optimized by adding wind turbine, the author then calls it Hybrid Energy System Plus (HES+). Take into consideration the trend of outdoor site implementation which is more environmentally friendly by telecommunication operators in Indonesia, every site mostly consists of 2G, 3G, and 4G BTS, each of which requires power between 1-1.5 kW, so that the author limits the load profile that will be calculated in this paper per site around 6kW. The capacity of wind turbine used in this paper is 10kW, and with the assumption as in [1], each of these sites has a minimum battery capacity of 1,000 Ah and a Diesel Generator minimum of 20 kVA. To add the analysis that has been done in [4], Techno-economic analysis that will be covered at this study includes advantages and disadvantages of HES+, energy produced, investment cost, operational and maintenance cost, CoE, Present Worth (PW), Future Worth (FW) and Annual Worth (AW).

2. Identifying Potential Location, Designing, and Sizing HES+
Indonesia as an archipelago country located right on the equator has an advantage because almost all regions of Indonesia get a good sunlight intensity. Sun peak hour determined for 5 hours, based on fluctuations of sun radiation. In contrast to the almost equal potential of solar radiation in each area, the choice of location to install wind turbines in Indonesia requires further consideration. Various wind speed profile in Indonesia ranges between 3 and 10 m/s depending on geographical location. Some areas that meet the minimum wind turbine speed requirement can be seen in the Table 1 below.

Those wind speed profile was based on data from www.globalwindatlas.info, by selecting a certain area on the map, then the calculation of wind speed and power density appears in Figure. Based on the average data, in this study, the authors determine the wind speed used is 8 m/s. If we want to calculate it manually, we can use the power coefficient curve formula from [5].

As introduced before, HES+ implemented on this research was the integration between solar panel and wind turbine to produce alternative energy needed to activate BTS that has not been reached by electricity in remote area. The use of these 2 alternative energy sources is expected to generate better efficiency than previous research [1], hence lower cost of electricity. From Figure 1 below, diesel generator will only be activated if the energy produced by solar panel, wind turbine and energy stored in the battery is insufficient to supply the load.

Authors use 205Wp polycrystalline solar panel [1] and 10kW Fiberglass-Reinforced Plastic blades wind turbine capacity with parameters that are used in calculation such as blade length radius (r)=4 m [6]; Air Density (ρ)=1.23 kg/m³; Power Coefficient (Cp)=0.4; Wind Speed (v)=8 m/s. 1). As in [7], there are calculations and equations involved in understanding and constructing wind turbine generators. However, the laymen need not worry about most of these complications and should instead ensure that they remember the following vital information:
1. The power output of a wind generator is proportional to the area swept by the rotor - i.e. double the swept area and the power output will also double.
2. The power output of a wind generator is proportional to the cube of the wind speed.
Table 1. Speed profile of wind in some location in Indonesia.

| Area                  | Wind Speed (m/s) | Power Density (W/m²) | Area                  | Wind Speed (m/s) | Power Density (W/m²) |
|-----------------------|------------------|----------------------|-----------------------|------------------|----------------------|
| Sabang, NAD           | 6.35             | 322                  | Pulau Gindang, NTT    | 6.89             | 412                  |
| Pulau Beureh, NAD     | 6.06             | 269                  | Kupang, NTT           | 6.91             | 414                  |
| Lhoknga, NAD          | 7.22             | 463                  | Sumba Timur           | 6.73             | 343                  |
| Leupeung, NAD         | 8.24             | 685                  | Wesiri, Tupi-tupi, Maluku | 8.42         | 676                  |
| Kluang Jaya, NAD      | 9.11             | 1204                 | Pulau Romang, Maluku  | 6.4              | 285                  |
| Jaya, NAD             | 9.38             | 1287                 | Pulau Babar, Maluku   | 6.52             | 302                  |
| Tangse Pidie, NAD     | 6.8              | 582                  | Pesisir Merauke       | 6.37             | 269                  |
| Langkat, Sumut        | 6.64             | 500                  | Kota Gorontalo        | 6.53             | 380                  |
| Karo, Sumut           | 6.16             | 332                  | Litomas, Gorontalo    | 7.28             | 677                  |
| Padang Lawas, Sumut   | 6.21             | 389                  | Banggai, Sulteng      | 6.96             | 447                  |
| Tapanuli Selatan, Sumut | 6.11        | 404                  | Soladik, Sulteng      | 7.45             | 485                  |
| Lubuk Sikaping, Sumbar | 6.52         | 516                  | Majene, Sulbar        | 6.15             | 313                  |
| Kota Agung, Lampung   | 6.07             | 270                  | Simbuang, Sulung      | 6.3              | 345                  |
| Kota Bandar Lampung   | 6.14             | 286                  | Pinrang, Sulsel       | 6.34             | 337                  |
| Sukabumi, Jawa Barat  | 6.01             | 243                  | Pare-pare, Sulsel     | 7.77             | 531                  |
| Brebes, Jawa Tengah   | 6.36             | 386                  | Soppeng, Sulsel       | 8.37             | 674                  |
| Slahung, Ponorogo     | 6.55             | 377                  | Barru, Sulsel         | 8.77             | 869                  |
| Bima, NTB             | 6.4              | 312                  | Pangkajene, Sulsel    | 7.37             | 585                  |
| Pulang Sangerang, NTB | 7.46             | 419                  | Maros                 | 8.18             | 626                  |
| Pulau Komodo, NTT     | 6.34             | 342                  | Janepono              | 7.41             | 467                  |

Figure 1. Schematic diagram HES+.

Figure 2. Turbine blade sweep area.
Using a formula to find energy generated by wind turbine as stated on [8] we must first look for the sweep area as shown at Figure 2. Inserting blade length radius value from parameters stated above to the equation (1).

\[
\begin{align*}
    r &= 4m \\
    A &= \pi r^2 \\
    &= \pi \times 4^2 \\
    &= 50.3m^2
\end{align*}
\]

\[
P_{\text{wind turbine}} = \frac{1}{2} \rho A v^3 C_p
\]

\[
= \frac{1}{2} \times 1.23 \times 50.3 \times 4^3 \times 0.4
= 6.33kW
\]

And then we can calculate the power converted from the wind into rotational energy in the turbine using equation (2). The HES+ capacity sizing must be suitable with the load profile that will be supplied. As mentioned before, load profile used on this paper is around 6kW with reason accordingly above. On [1], it is shown that the load profile that is around 6kW was Krui site, and that is what we will use as load profile at this paper. From below parameters in Table 3, Table 4 and reference from [9], we can calculate remaining energy needed to supply Krui sites load. This remaining energy calculation does not include the energy that is already supplied by wind turbine (2).

### Table 2. Load profile at Krui, Lampung site.

| Qty | Appliance | Total Load (Watt) | Duration used/day (hour) | Total load/hour (Watt Hour) |
|-----|-----------|-------------------|--------------------------|----------------------------|
| 1   | Load DC   | 3780              | 24                       | 90.720                     |
| 2   | Load AC   | 3000              | 8                        | 24.000                     |
|     | Total     | 6780              |                          | 114.720                    |

### Table 3. Parameters for HES+.

| Parameters                              | Value | Unit  | Parameters                              | Value | Unit  |
|-----------------------------------------|-------|-------|-----------------------------------------|-------|-------|
| Capacity battery will used              | 1,000 | Ah    | Vmax Solar Controller (MPPT)            | 150   | Volt  |
| Nominal voltage                         | 48    | V     | Square of PV                            | 1.6   | m²    |
| Efficiency battery/ battery loss        | 85    | %     | Days of autonomy                        | 1.0   | Days  |
| DoD Battery                             | 80    | %     | Wind turbine radius (r) - 10 kW         | 4     | meter |
| Cable loss                              | 2     | %     | Wind speed (v)                          | 8     | m/s   |
| PV module will used                     | 205   | Wp    | Air density (p)                         | 1.2   | kg/m³ |
| Generation factor (sun peak hour) in Indonesia | 5     | Efficiency Factor | Wind Turbine (Cp) | 40 | %     |
The remaining power needed, number of PV needed, square of area needed, battery capacity, battery cell and total MPPT used can be calculated using equation (3) until (8) respectively as below.

\[ P_{solar} = \frac{\text{total load per hour (Wh)}}{\text{sun Peak hour (h)}} \times \text{energy losses} - P_{turbine} \]
\[ = \frac{114,720Wh}{5h} \times 1.3 - 6.33kW \]
\[ = 23.5kWp \]  
\[ PV_{amount} = \frac{\text{total solar load (Wp)}}{\text{PV capacity used (Wp)}} \]
\[ = \frac{23,500Wp}{205Wp} \]
\[ = 115 \text{ pcs module} \]  
\[ Area = \text{PV amount} \times \text{space area per module} \]
\[ = 115 \times 1.6m^2 \]
\[ = 184m^2 \]  
\[ Battery = \frac{\text{load per hour (Wh) \times autonomy (day)}}{\text{voltage (v) \times batt eff (%) \times depht of Chrg (%)}} \]
\[ = \frac{114,720Wh \times 1day}{48v \times 85\% \times 80\%} \]
\[ = 3,514Ah \]  
\[ Batt_{string} = \frac{\text{total battery capacity}}{\text{batt capacity used per unit}} \]
\[ = \frac{3,514Ah}{1000Ah} \]
\[ = 4 \]
\[ = 96 cell \]  
\[ Total MPPT = \frac{P_{solar}}{\text{MPPT capacity per module}} \]
\[ = \frac{23,500Ah}{3,200Ah} \]
\[ = 7 \text{ MPPT module} \]

3. Techno-Economic Analysis of HES+ Implementation
On this analysis, author will compare not only from economical, but also from technological and environmental point of view between traditional electrification system of rural telecom site (CDC), HES (solar panel) and HES+ (solar panel and wind turbine). From economical point of view, there are 4 components in comparison. Taking into consideration are the age of PV, Diesel Generator, Battery as well as the exchange rate, fuel price and inflation, so the calculation was projected only for 10 years ahead.
3.1. Investment cost
Calculated based on actual BoQ (Bill of Quantity) from operator [1] and currency of IDR 14,500 per US dollar, investment cost for site with 6.8kW load profile with CDC electrification is around IDR 559,035,753, for HES is around IDR 1,036,211,553, and for HES+ is around IDR 820,748,227.

3.2. Operational and maintenance cost
Diesel generator is a device that needs regular maintenance (periodic maintenance), and the maintenance period depends on the activated duration of the generator. For example, changing oil and filter should be done every 200 hours of activation, change fuel hoses every 1000 hours and others maintenance which can be found on the manual book. Within 10 years projected period, we can find out how often maintenance must be done for each item. That number then multiplied by unit price for each maintenance and also added with service cost, of course the exchange rate also considered if using imported goods. Using traditional CDC electrification system where DG will be active for around 20 hours/day, the telecom operators have to pay IDR 4,002,755,800 for 10 years DG maintenance cost. If using HES, where DG will only be active for 6 hours/day, telecom operators only need to pay IDR 1,226,398,700, and if using HES+ it costs only around IDR 1,003,223,725 with active duration of 5 hours/day. The cost savings for using HES+ are approximately around IDR 2,999,532,700 that can be done by the operator compared to CDC, shown in Figure 3. If we compare operational cost for running diesel generator with price for industry fuel IDR 12,500 per litre, at CDC system, it will cost IDR 2,737,500,000 for fuel, HES will cost around IDR 821,250,000 and HES+ will cost only around IDR 684,375,000 There is a cost saving potential around IDR 2,053,125,000 that can be done by the telecom operator if using HES+ on their sites in remote area, shown in Figure 4.

![Figure 3](image1.png)
**Figure 3.** Diesel generator maintenance cost comparison.

![Figure 4](image2.png)
**Figure 4.** Diesel generator operational cost comparison.
3.3. Cost of Electricity (CoE) comparison

Cost of electricity (CoE) is the nominal amount of the price paid by the customer for each unit energy used (kWh). By the article Kaldellis J. K. et al. [10], cost of electricity for HES+ is the division between the cost energy (until n years) and the total energy produced (until n years) can be formulated as equation (9):

\[
\text{Cost of electricity (CoE)} = \frac{C_n}{\text{Total Energy Produced (n year)}}
\]

\[
= \frac{IC_0(1-\gamma) + FC_n + VC_n - Y_n}{\text{Total Energy Produced (n year)}}
\]

where \(C_n\) is the cost of energy (n year), is calculated from first investment/initial cost \((IC_0)\) multiplied with 1 minus percentage of government subsidy \((\gamma)\), then added with fixed maintenance/operational cost \((FC_n)\) and variable maintenance/operational cost \((VC_n)\), and next deducted with residual value of investment \((Y_n)\) which is 4% per year. The result then divided with total energy produced (n year) by the electrification system. From calculation above, CoE of HES+ is the lowest among other electrification systems, suitable with fixed maintenance cost and variable maintenance cost. As shown in Figure 5 and Table 5.

3.4. Worth value comparison

The last component to determine the economic value of implementation HES+ is calculation of the present worth, future worth and annual worth. As we can see on Figure 6, PW, FW and AW of HES and HES+ have positive values, but CDC has a negative value because there are no savings from fuel and maintenance efficiency, we only calculate investment cost and battery replacement cost for every 4-year. Meanwhile, after the HES and HES+ are installed, it result a significant savings, despite the necessary of a huge investment earlier and the cost of replacement batteries every 4-years, so that the value was positive.

From technological point of view, HES+ has monitoring and automation features that will give the user flexibility to control and monitor remotely [1]. To complete techno-economic analysis on this paper, author will study from the environmental point of view. The 20kVA diesel generator that is used at Indonesia’s remote telecommunication base station with 1500 rpm [11], release many hazardous air contaminants and greenhouse gases (GHG) including particulate matters (diesel soot and aerosols), carbon monoxides, carbon dioxides and oxides of nitrogen. Particulate matter is largely elemental and organic carbon soot, coated by gaseous organic substances such as formaldehyde and polycyclic aromatic hydrocarbons (PAHs) which are highly toxic [12]. It is difficult to get all required data for every particular greenhouse gas emission due to technical and monitoring problems. Therefore, for simplicity, it is often expressed in terms of the amount of carbon dioxide (CO\(_2\)) emitted. The best way is to calculate the carbon dioxide emissions based on the amount of fuel consumption by diesel generator. However, the number of kg of CO\(_2\) produced per litre of fuel consumed by the diesel generator depends on the characteristics of the diesel generator and of the characteristics of the fuel. The reported ranges of emission factor from diesel generators were found in literature from 2.4 to 3.5 kgCO\(_2\)/litre of diesel fuel consumption. Therefore, the emission factor of 3.0 kgCO\(_2\)/litre is considered for this study [12]. Based on calculation using data from [1], CDC electrification system with 20 hours DG operation and 60 litre fuel consumption per day will emit 66 TonCO\(_2\)/year. HES Electrification will emit 20 TonCO\(_2\)/year and HES+ will emit about 16 TonCO\(_2\)/year. That means, the use of HES+ will avoid 50 Ton of CO\(_2\) emission per year per site to the atmosphere, if there are 14,854 telecommunication sites in Indonesia that have not been connected to electricity and/or have poor quality and reliable grid [13], and if 30% of those was installed with HES+, telecommunication operator will participate to reduce greenhouse gas (GHG) emission of 222.81 Kilo Ton of CO\(_2\) per year.
Table 4. Summary electrification cost calculation

| Site Electrification system | CDC (IDR) | HES (IDR) | HES+ (IDR) |
|-----------------------------|-----------|-----------|------------|
| Capex (ICo)                 | 559,035,753 | 1,036,211,553 | 820,748,227 |
| Fixed Maintenance Cost (FCn) | 2,737,500,000 | 821,250,000 | 684,375,000 |
| Variable Maintenance Cost (VCn) | 4,002,755,800 | 1,226,398,700 | 1,003,223,725 |
| Residual Value (Yn) 10 year (IDR) | 371,665,213 | 688,907,258 | 545,660,207 |
| Total Energy Produced 10 year (kWh) | 1,147,200 | 1,147,200 | 1,147,200 |
| Subsidy Percentage (γ) | 0% | 0% | 0% |
| CoE (IDR)                  | 6,039 | 2,088 | 1,711 |

Figure 5. Cost of electricity comparison.

Figure 6. 6.8 kW load profile worth analysis.

4. Conclusion and future work
The HES+ that has been analysed in this paper is the best choice for electrification of telecommunications sites in remote areas, when compared to CDC and HES. This statement is proven with the techno-economic analysis that we already conduct. From economical point of view, HES+ will reduce cost of electricity from IDR 6,039 per kWh to IDR 1,711 per kWh or by 71.7% if
compared to CDC system and down about 18% if compared to HES at IDR 2,088. The decrease of the cost of electricity was influenced by the decrease in operational costs (OPEX) from fuel consumption and maintenance of the diesel generator due to operational hour of diesel generator that was also declining. PW, FW and AW of HES+ also have positive values; indicate that HES+ is very feasible for implementation in Indonesia. The use of remote monitoring technology also greatly supports the implementation of HES+ to reduce site guard wages and transportation costs that have been issued by operators. Lastly, from environmental point of view, the use of HES+ will avoid 50 Ton of CO₂ emission per year per site to the atmosphere and from the calculation above, telecommunication operator will participate to reduce greenhouse gas (GHG) emission of 222.81 Kilo Ton of CO₂ per year. It is clear that HES+ implementation is one way to boost the green telecommunication industry because it will improve energy efficiency, reduce OPEX and minimize greenhouse gases.

For further research, it is suggested to make a study of the implementation of HES or HES+ in all Indonesia telecommunications sites, both those in urban and rural areas. The challenge is how to make a business model that is still profitable for telecommunications operators even though they have to spend a substantial initial investment cost. Incentives and subsidies must be given by the government to encourage more operators to use renewable energy as a source of electrification, in order to support government efforts to reduce industrial carbon emissions.

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