# Potential of Small Size Hybrid Diesel-Photovoltaic to Improve Sub-District Supply Duration in East Sumba, Indonesia

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**Abstract-** This paper presents a preliminary techno-economic assessment of isolated mini off-grid power generation which involve locally available renewable energy resources in Ngadu Ngala sub-district, East Sumba, Indonesia. Currently, only 6 hours of supply available from diesel generator is available for the area, started from 6 PM until 12 PM. In this study, 10 year projection on domestic load is provided as the demand. The study is performed to prolong the supply duration from 6 hours to 24 hours daily. The analysis is mainly intended to find long-term optimum sizing of power generation system, which involve significant renewable energy penetration, with the least cost of energy. Based on the simulation performed by HOMER software for the case of 24 hours supply, the most optimum sizing is revealed for a hybrid system consists of 200 kWp Photovoltaics (PV) and a 72 kW diesel generator, with energy cost of only US$ 0.281/kWh, which is quite cheap. Moreover, PV penetration rate is reached 51%.

**Keywords** Renewable energy, hybrid, diesel, photovoltaics, supply duration.

## 1. Introduction

Renewable energy is seen as one promising alternative energy resources not only because it is clean but also due to decreasing unit costs as well as lower operational and maintenance costs [1]. In the case of developing countries, for example in Indonesia, opportunity to provision electricity based on renewable energy is growing up due to simplicity in the implementation, technology readiness, and decreasing in technology price. In few places of the Sumba Island, Indonesia, for example, renewable energy technology in terms of small hybrid wind turbine-PV has been installed in places with sufficient wind energy potential. Other villages in the island have 32 kW micro hydro system [2] and 500 kW photovoltaics system [3]. Although the cost of energy and other relevant costs by installing renewable energy based system are sometimes higher than that achieved by conventional fossil fuel system, still the renewable based system have shown their comparative benefits over the conventional one, especially for islands like Sumba. Very low utilization, disperse load, difficult terrain, and irregular fuel availability are barriers for installing the fossil fuel system.

Many papers have discussed techno-economic assessment either on off-grid renewable energy power system or hybrid renewable energy-diesel generators in specific cases and applications, such as for offices and laboratories, and also mainly for communities in remote areas [4-8]. Nevertheless, lack of reports found on the integration of renewable energy into the centralized hybrid small power generation system with the aim to improve supply duration over long-term projected demand period. This paper presents a preliminary techno-economic assessment of an isolated mini off-grid power generation which involve renewable energy resources for Sumba Island, Indonesia. In the analysis, 10 year projection on domestic load demand within a sub-district level is provided as the energy demand. The research purpose is mainly intended to find optimum sizing of centralized hybrid small power generation system which involve significant renewable energy penetration, cosidering the lowest cost of energy.

Furthermore, the proposed system is examined in terms of its potential to increase the supply duration and the penetration rate of the renewable energy side so that the electricity supply could meet the projected demand over 10 year time frame, up to year 2024.

This paper is organized as follows: research methodology comprises electricity supply-demand overview, relevant data and renewable energy potential of the observed area are presented in the following section. Small hybrid power generation systems including supply duration scenarios and key parameters is discussed subsequently followed with results and discussion. Finally, conclusion is provided.

## 2. Research Methodology

### *2.1. Electricity Condition and Supporting Data*

Ngadu Ngala is a sub-district of East Sumba, East Nusa Tenggara province. It is located in the southern part of Sumba Island. The topography is characterized with hills and sloping mountains. Consisting of five villages, only very few parts of land are occupied with households and other small, simple construction. Number of population of the Ngadu Ngala sub-district in 2014 was 5,056 people with 1,346 households [9]. Areas which are covered by existing grid is depicted in Figure 1.

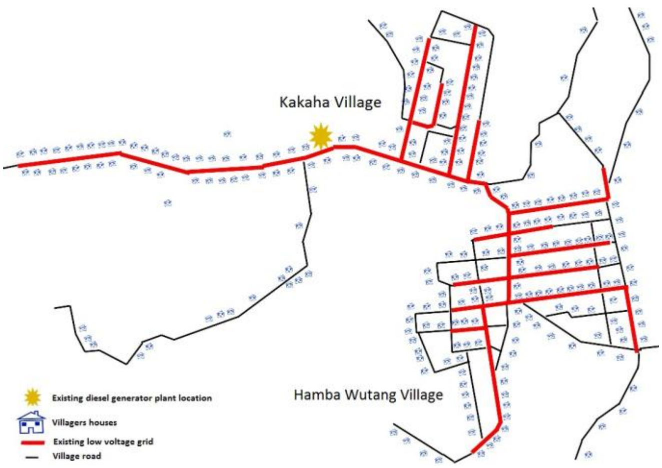


**Fig. 1.** The villages area which are covered by an existing low voltage electricity grid

In 2014, there were 295 customers, mainly households, who had access to electricity which are provided by a state electricity company, “Perusahaan Listrik Negara”, hereafter called “PLN”. It can be concluded that the electrification ratio of the sub-district was only 22%. Historical total number of customer which have access to PLN, their energy consumption, and annual peak load during 2010 – 2014 is presented in Table 1. Up to now, the electricity is provided by two diesel generators, each with 20 kW power output. The main problem in the Ngadu Ngala is the limited duration of electricity supply. Diesel generators were operated only from 6 PM – 12 PM due to fuel supply limitation. Difficult terrain condition was one of barriers in transporting the fuel. Daily energy consumption for 6 hours loading in 2014 [10] is presented in Table 2.

**Table 1.** Historical number of PLN customer, electricity consumption and peak load during 2010 – 2014 [2]

| Year | Number of PLN customer (Household) | Electricity consumption (kWh) | Peak load (kW) |
|---|---|---|---|
| 2010 | 135 | 19,987 | 6.9 |
| 2011 | 180 | 21,645 | 8.1 |
| 2012 | 201 | 26,001 | 8.8 |
| 2013 | 250 | 27,014 | 15.5 |
| 2014 | 295 | 27,278 | 18.46 |

**Table 2.** Daily energy consumption for 6 hours supply in 2014

| Hour | Electricity consumption (kWh/day) |
|---|---|
| 6.00 PM – 7.00 PM | 13.69 |
| 7.00 PM – 8.00 PM | 18.46 |
| 8.00 PM – 9.00 PM | 14.44 |
| 9.00 PM – 10.00 PM | 10.28 |
| 10.00 PM – 11.00 PM | 9.02 |
| 11.00 PM – 12.00 PM | 8.84 |
| Total | 74.73 |

### *2.2. Renewable Energy Potentials*

The observed area of Ngadu Ngala sub-district is located in 10°14’ South Latitude and 120°22’ East Longitude. As characterized by its nature, solar radiation is available abundantly. On the other hand, unlike other few parts in the island, wind energy is less available and it is considered not viable for the purpose of electricity generation. Solar daily radiation and the clearness index of the observed area is presented in Table 3.

**Table 3.** Solar daily radiation and clearness index

| Month | Clearness Index | Daily Radiation (kWh/m2/day) |
|---|---|---|
| January | 0.548 | 6.02 |
| February | 0.530 | 5.79 |
| March | 0.603 | 6.31 |
| April | 0.662 | 6.34 |
| May | 0.689 | 5.93 |
| June | 0.681 | 5.50 |
| July | 0.688 | 5.70 |
| August | 0.710 | 6.47 |
| September | 0.713 | 7.18 |
| October | 0.704 | 7.53 |
| November | 0.658 | 7.19 |
| December | 0.599 | 6.56 |
| Average | 0.645 | 6.38 |

### 2.3. Energy Supply-Demand Planning

To find the least cost - long term - optimum sizing of centralized hybrid system which involve significant renewable energy penetration, 3 system configurations are considered as supply. The first configuration is diesel generator system only, the second configuration is hybrid diesel generator and photovoltaics, and the last configuration is photovoltaics system only. Meanwhile, 24 hours demand duration up to year 2024 is taken into account. In order to predict electricity demand of the entire Ngadu Ngala sub-district in year 2024 based on the customer point of view, a survey was initially conducted to find daily electricity consumption in year 2015 if electricity is supplied for 24 hours in Ngadu Ngala sub-district. The daily load curve that is resulted from the survey is shown in Figure 2. Meanwhile, the projection of the 2024 daily load profile based on the 2015 survey result up to year 2024, is presented in Figure 3.

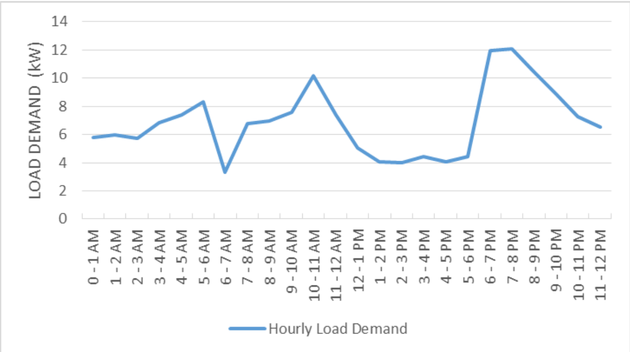


**Fig. 2.** Survey result on daily load curve of Ngadu Ngala's PLN customers if electricity is supplied for 24 hours

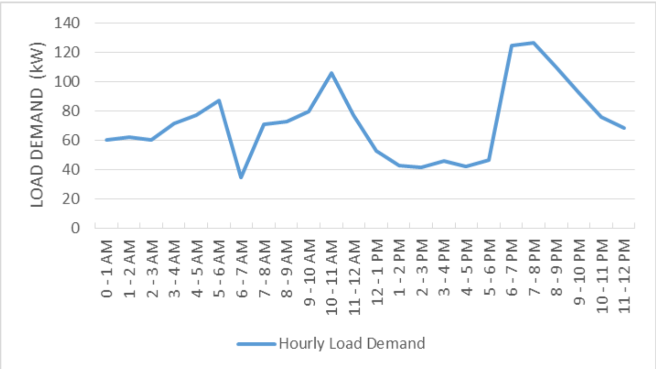


**Fig. 3.** Projection of the 2024 daily load curve of Ngadu Ngala's PLN customers for 24 hours electricity supply

In this study, the load pattern is assumed to be identical between what is projected with that is obtained from the survey, as can be seen in the two figures above. This is to recognize the fact that the society dwell in the observed areas has simple daily routine, taken into account the household sector as the dominant consumer of the electricity and their main occupation as farmer or fisherman. However, a slight variability in terms of hourly load fluctuation has been taken into account in the sizing analysis.

### 2.4. Technical and Cost Parameter

Existing three phase 20 kW power output diesel generator is included in this study as part of hybrid system. The capital cost of of 20 kW diesel generator is priced at US$ 9,000. The price of 100 Wp PV panel is US$ 96 [10]. The solar cell is considered having 20 years lifetime. In the simulation, the PV system is installed using the simplest way without any tracking capability. This condition is likely the most appropriate construction due to easiness in maintenance and to avoid technical problems which could potentially be occurred during its service period.

The storage system consists of 12 Volt batteries with 200 Ah nominal capacity. The price of each battery is taken US$ 365. Meanwhile, to convert DC to AC voltage, array of inverters is added into the system. Inverter with 1 kW nominal output capacity is taken at US$ 420. All major components of the hybrid system have the same replacement cost plus the inflation rate which is accounted in the particular year.

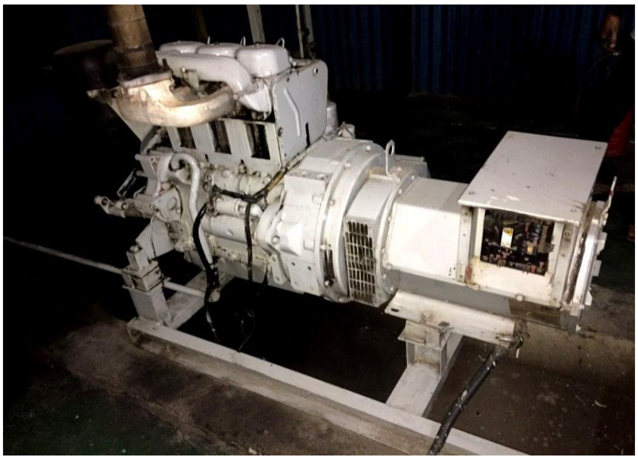

**Fig. 4.** Existing diesel generator in the Ngadu Ngala grid

Other important costs parameter are also taken into account. The inflation rate is considered 5.75% based on the 5 year average inflation of Indonesia [11]. The fixed capital cost consists of land allocation cost, is rated at very low rate of US$ 0.2/m$^2$ [9]. System fixed operation and maintenance cost is comprising maintenance and labor costs for PV and diesel generators. As listed in the PLN statistical report [12], the cost of maintenance and labor are rated at US$ 0.04/kWh and 0.07 cent $/kWh for PV, also US$ 0.03/kWh and 0.9 cent $/kWh for diesel generator. In addition, the fuel cost for diesel generator in the observed area is rated at US$ 0.75/liter.

The simulation is performed using HOMER software [13]. Some key parameters and constraints are imposed into the simulation to obtain the most optimum sizing of the hybrid system with the least cost of energy. The maximum annual capacity shortage is set to be zero [14]. The analysis is also intended to find the impact of renewable energy fraction towards the optimum sizing. Hence, the minimum renewable energy fraction, which is the amount of energy generated by the PV towards the total energy supplied, is also imposed.

## 3. Results and Discussion

Existing 6 hours load profile with 75 kWh/day energy consumption and 18 kW peak load is analyzed in order to get relevant initial information regarding the existing system costs, i.e. diesel generator. Using HOMER software, PV system and hybrid PV-diesel generator system are simulated to obtain their optimum sizing and relevant costs, which represent technical and economic aspect, respectively. Later on, results obtained in PV and hybrid diesel generator-PV, including the potential of the PV penetration rate is compared with that achieved by diesel-only system. Simulations are performed for existing 6 hours load profile as to capture initial condition and for long-term 24 hours supply duration with enhancing load profile.

In this study, the optimum sizing is defined as the size of each source that meet the energy required by the load throughout the year without resulting in a energy shortage. Still, the least cost of energy is considered as one of important constraint. Hence, the combination in terms of sizing of PV and diesel generator in the hybrid system is also selected based on this criteria.

The optimum sizing from the simulation results of diesel generator, PV, and hybrid diesel-PV system configuration are shown in Figure 5, Figure 6, and Figure 7, respectively. The costs structure summary of the three alternatives system, which consists of total net present cost, operating cost, and levelized cost of energy is presented in Table 4. Meanwhile, electricity production and the penetration rate of PV in the hybrid system is presented in Table 5. From Table 4, we can see that the cost of energy of system with diesel generator and system with hybrid diesel generator-PV is relatively similar. In fact, lower net present cost hybrid diesel generator-PV system is offered by the hybrid system over the rest alternatives.

**Table 4.** Cost summary of system configuration for existing 6 hours supply

| Cost structure | System configuration | | |
|---|---|---|---|
| | Diesel Generator | Hybrid Diesel-PV | PV |
| Total net present cost, US$ | 80,726 | 79,399 | 161,472 |
| Operating cost, US$/year | 8,398 | 8,637 | 6,900 |
| Levelized cost of energy, US$/kWh | 0,398 | 0,391 | 0,795 |

**Table 5.** Electricity production share for existing 6 hours supply

| Hybrid system component | kWh/year | Share (%) |
|---|---|---|
| PV Array | 7,581 | 23 |
| Generator 1 | 26,005 | 77 |
| Total | 33,586 | 100 |

Other benefit of having the hybrid system in this case is a reduction in terms of the unit of diesel generator, from 2 units become 1 unit only, corresponds to a potential saving in terms of fuel, in addition to a lower $CO_2$ emission.

For the case of 10 years demand forecasting, as seen in Figure 3, the projection on long-term daily load demand, i.e. at year 2024, could be 127 kW peak and this would give 1,733 kWh per day energy consumption for 24 hours supply scenario. The simulation results of diesel generator, PV, and hybrid diesel generator-PV system configuration in terms of their optimum sizing are shown in Figure 8, Figure 9, and Figure 10, respectively. Meanwhile, the costs structure summary of the three alternatives system is presented in Table 6.

| | | gen 1 (kW) | gen 2 (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | gen 1 (hrs) | gen 2 (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20 | 20 | $ 18,178 | 8,398 | $ 80,726 | 0.398 | 0.00 | 10,320 | 2,190 | 0 |

**Fig. 5.** HOMER screenshot on optimum sizing of diesel generator system for existing 6 hours supply

| | | | PV (kW) | 6FM200D | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 30.0 | 200 | 19 | $ 110,084 | 6,900 | $ 161,472 | 0.795 | 1.00 |

**Fig. 6.** HOMER screenshot on optimum sizing of PV system for existing 6 hours supply

| | | | | PV (kW) | gen 1 (kW) | 6FM200D | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | gen 1 (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 4.0 | 15 | 4 | 4 | $ 15,070 | 8,637 | $ 79,399 | 0.391 | 0.23 | 9,129 | 2,190 |

**Fig. 7.** HOMER screenshot on optimum sizing of hybrid diesel-PV system for existing 6 hours supply

| gen 1 (kW) | gen 2 (kW) | gen 3 (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | gen 1 (hrs) | gen 2 (hrs) | gen 3 (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 20 | 87 | $ 37,512 | 197,728 | $ 1,510,204 | 0.321 | 0.00 | 222,988 | 2,555 | 1,460 | 8,395 |

**Fig. 8.** HOMER screenshot on optimum sizing of diesel system for long-term demand projection covering 24 hours supply

| PV (kW) | 6FM200D | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. |
|---|---|---|---|---|---|---|---|
| 600 | 3000 | 200 | $ 1,760,082 | 95,153 | $ 2,468,785 | 0.524 | 1.00 |

**Fig. 9.** HOMER screenshot on optimum sizing of PV system for long-term demand projection covering 24 hours supply

| PV (kW) | gen 1 (kW) | gen 2 (kW) | gen 3 (kW) | 6FM200D | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | gen 1 (hrs) | gen 2 (hrs) | gen 3 (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 20 | 20 | 44 | 250 | 110 | $ 361,804 | 128,918 | $ 1,321,991 | 0.281 | 0.51 | 123,030 | 5,234 | 2,949 | 5,175 |

**Fig. 10.** HOMER screenshot on optimum sizing of hybrid diesel – PV system for long-term demand projection covering 24 hours supply

**Table 6.** Cost summary of system configuration for 24 hours supply projection

| Cost structure | System configuration | | |
|---|---|---|---|
| | Diesel Generator | Hybrid Diesel-PV | PV |
| Total net present cost, US$ | 1,510,204 | 1,321,991 | 2,468,785 |
| Operating cost, US$/year | 197,728 | 128,918 | 95,153 |
| Levelized cost of energy, US$/kWh | 0.321 | 0.281 | 0.524 |

From Table 6, we can see that significant reduction in terms of the levelized cost of energy over the ten years supply-demand planning could be potentialy achieved by selecting hybrid diesel generator-PV system. In terms of the total net present cost, there will be a potential saving around US$ 188,000 due to selection of hybrid system compared to that resulted by diesel-ony system. Moreover, according to the simulation result, the hybrid diesel generator-PV has shown lower cost of energy compared to that resulted by diesel generator configuration and the lowest over all configuration alternatives. From Figure 10, renewable energy fraction obtained by hybrid diesel generator-PV system is 51%, which is relatively high to cover a 24 hours electricity demand. In addition, potential significant fuel saving up to 100,000 liter would contribute towards a reduction in cost of energy, from US$ 0.321/kWh in the case of diesel system to US$ 0.281/kWh in hybrid system. The share of electricity production in the hybrid system at the year 2024 for 24 hours supply projection is presented in Table 7. Based on the simulation result, there would be around 71,750 kWh or 9.6% excess electricity within the total 746,926 kWh annual electricity production. Here, the excess electricity is taken into account as the last year excess during the ten years demand projection.

**Table 7.** Electricity production at year 2024: 24 hours supply projection

| Hybrid system component | kWh/year | Share (%) |
|---|---|---|
| PV Array | 379,033 | 51 |
| Generator 1 | 101,440 | 14 |
| Generator 2 | 58,980 | 8 |
| Generator 3 | 206,473 | 28 |
| Total | 745,926 | 100 |

From the analyses, we can see that the hybrid diesel generator-PV configuration would be the most suitable system for long-term requirement since it has the ability to cover 24 hours demand in the Ngadu Ngala sub-district. The PV installation could significantly reduce high expense of diesel fuel over 10 year supply-demand planning. The hybrid system also offers lower costs compared to diesel generator only system, with significant amount in total net present cost and operating cost without acknowledging the further reduction in PV capital cost.

Other important benefit for the environment is the reduction of $CO_2$ emission which resulted from around 50% reduction in electricity produced by diesel generators. If we increase the daily energy consumption up to 10% for every hour during 24 hours supply, or 1,906 kWh/day and 139 kW peak load, the cost of energy would be slightly increase at US$ 0.286/kWh. Other affected costs would be total net present cost and operating cost, which are US$ 1,478,859 and US$ 136,164/year, respectively. However, these values are still lower than the costs exhibit by the utilization of diesel generator only as presented in Table 5. In addition, the renewable energy fraction can be still maintained at around 50%.

From the analyses of existing 6 hours supply and 24 hours supply based on long-term demand projection as the first and second case, respectively, we can see that the cost of energy is lower for the second case. It is particularly referred to the comparison between hybrid system in the first and second case. In addition, the penetration rate of PV is doubled for the same configuration, for which apparently would reduce the $CO_2$ emission. These two cases also give indication of the comparative benefits revealed from integrating renewable technologies. The PV integration into the system would result more benefits in terms of costs saving if the demand are seen significant.

## 4. Conclusion

The potential of renewable energy to improve the electricity supply duration in the Ngadu Ngala sub-district, Sumba Island, Indonesia, is presented in this paper. Using 3 alternatives of system configuration, no supply shortage is found based on the simulation performed by HOMER software. According to the analyses, the hybrid diesel generator-PV system would likely be the most suitable for the observed area considering technical as well as economic point of view, for the long run. The analyses results also reveal the comparative benefits of hybrid diesel generator-PV system over the existing system in terms of the cost of energy and the penetration rate. Other advantages include diesel fuel saving and $CO_2$ emission reduction.

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## References

[1] Tanoto, Y., Handoyo, E.A., "Renewable Energy potential for sustainable long-term electricity energy planning: A bottom-up model application", International Journal of Renewable Energy Research, vol. 5, no. 3, pp. 919-925, September 2015.

[2] PT. PLN (Persero), Mutu, keandalan serta efisiensi pembangkit, Waingapu, NTT (in Bahasa Indonesia), PLN NTT, Waingapu: Indonesia, 2015.

[3] http://www.pln.co.id/ntt/?p=428

[4] Srivastava, R., Giri, V.K., "Optimization of Hybrid Renewable Resources using HOMER", International Journal of Renewable Energy Research, vol. 6, no. 1, pp. 157-163, March 2016.

[5] Rahman, Md.M., Islam, S.A.K.M., Salehin, S., Al-Matin, Md.A., "Development of a Model for Techno-economic Assessment of a Stand-alone Off-grid Solar Photovoltaic System in Bangladesh," International Journal of Renewable Energy Research, vol. 6, no. 1, pp. 140-149, March 2016.

[6] Salahi, S., Adabi, F., Mozafari, S.B., "Design and simulation of a hybrid micro-grid for Bisheh village," International Journal of Renewable Energy Research, vol. 6, no. 1, pp. 199-211, March 2016.

[7] Pradhan, A.K., Kar, S.K., Mohanty, M.K., "Off-Grid Renewable Hybrid Power Generation System for a Public Health Centre in Rural Village," International Journal of Renewable Energy Research, vol. 6, no. 1, pp. 282-288, March 2016.

[8] Salehin, S., Rahman, Md.M., Islam, S.A.K.M., "Techno-economic Feasibility Study of a Solar PV-Diesel System for Applications in Northern Part of Bangladesh," International Journal of Renewable Energy Research, vol. 5, no. 4, pp. 1220-1229, December 2015.

[9] BPS Kabupaten Waingapu, Waingapu dalam angka 2014 (in Bahasa Indonesia), Waingapu: BPS, 2014

[10] http://sunelec.com/solar-panels/12v-solar-panels/sonali-100w-solar-panel.html

[11] http://www.bi.go.id/id/moneter/informasi-kurs/transaksi-bi/Default.aspx

[12] PT. PLN (Persero), 2014 PLN Annual Statistical, Jakarta: PLN, 2014

[13] http://www.pspb.org/e21/media/HOMERModelingInformation.pdf

[14] Tanoto, Y., Santoso, M., Massay, C., "Off-grid fully renewable energy with free capacity shortage for remote electrification", 2013 IEEE 7th International Power Engineering and Optimization Conference, Malaysia, 3-4 June 2013.