Evaluation of Hybrid System Solar-Wind-Diesel In Nusa Penida Bali-Indonesia

Charla Triselda Manik, F. Danang Wijaya, Tedy Juliandhy

Abstract— Nusa Penida is one of the outest island in Indonesia located around Bali island. Electricity system of this area is apart from Bali's electricity system that supply by 20 kV interconnection of hybrid solar-wind-diesel power station and connected to Nusa Penida island, Nusa Lembongan island and Nusa Ceningan island. This system is called three nusa system. Solar radiation average is 5,34 kWh/m2/day with 4,4 m/s wind speed average. This condition can be use to develope a renewable energy power station in this area. However, environmental conditions greatly affect the performance of the system in meeting the electricity supply. In this paper discussed the extent of the feasibility of hybrid plants were built with natural conditions and specifications of the equipment used in hybrid system in Nusa Penida. The influence of the natural conditions for the production of electrical energy associated with the specifications of the equipment used is known by measuring the daily conditions where hybrid system installed. This information is used to analyze the performance of hybrid systems and development the operations models of hybrid generation at Nusa Penida so electrical energy in this area is fulfilled.

Index Terms— nusa penida, renewable energy, solar, wind, hybrid, interconnection, grid

1 INTRODUCTION

BALI is one of the provinces in Indonesia with land area of 5636.66 km2 or 0.29% of total area of Indonesia. Economic activity of the Balinese are driven by the tourism industry and it must be supported by adequate electrical power system.

Bali's electricity system is served by three main diesel generators with a total capacity of 696 MW consisting of 14 substasion and interconnected to Java's network supplied be Java Paiton plant in East Java via submarine cable [1].

Taking into account the national energy policy blueprint 2005-2025 regarding the utilization of renewable energy which should be increased to 5%, it is necessary to diversify energy in electricity generation by prioritizing optimal utilization of renewable energy [2].

Beside of Bali island, Province of Bali also has smaller islands in arround, one of them is Nusa Penida. Nusa Penida is an island separated from the mainland Bali, but administratively entered the district of Klungkung. Electricity of this region served by interconnection network system that connected to three islands in the sub-district of Nusa Penida namely Nusa Penida, Nusa Lembongan and Nusa Centingan. This system is also called three nusa system. Map location of three nusa's system shown in Figure 1.

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The three nusa's system is a 20 kV distribution network system which is separated from Bali electricity.

In order to reduce the dependence of fossil fuels on climate change due to carbon emissions and by utilizing the existing natural potential, then hybrid solar and wind power stations were built in Nusa Penida [3].

The results of observation of the existing power stations in Bali showed that most renewable plant sites are far away from the distribution network so it required to develop a new distribution network. Solar and wind power station in Nusa Penida describe of a renewable energy generation that has been interconnected to the 20 kV distribution system of PLN.

This paper discusses the technical evaluation of hybrid system generation in Nusa Penida based on the natural conditions and equipment specifications that used.

2 CONDITIONS OF THE HYBRID SYSTEM LOCATION

2.1 Natural Condition of Nusa Penida

Nusa Penida is the name of a sub-district in Klungkung, Bali-Indonesia. Astronomically Nusa Penida is located at 8° 44'43" south latitude and 115° 32'21" east longitude. This area gets light intensity average of 5.34 kWh/m2/day with an average wind speed at 4.4 m/s, the average air temperature of 27.2° C and average humidity of 79.5% as shown in Table 1 [4]. Thus the potential of wind and solar energy in this region deserve to be categorized as a source of renewable energy power stations [5].

Utilization of solar and wind hybrid system will be more efficient than when used apart. Both of these energy sources will be complementary, where the dry season the solar system will dominate, and while in the rainy season wind power more involved [6].

Implementation of solar and wind power generation is carried out in line with the Bali government project to achieve the 'Bali go green, go clean' which is one of the projects submitted by Indonesia on the United Nations Framework Convention on Climate Change held in 2007 at Nusa Dua, Bali [7].

2.2 Hybrid Generating System in Nusa Penida

The hybrid power system consist of Nusa Penida diesel generators, solar power station (SPS) and wind power station (WPS). This system has 11 diesel generating units (8 units Kutampi's diesel engine and 3 unit Jungut Batu's diesel engine), wind power station consisting of 9 units of wind and 2 units of solar. The interconnection of hybrid generation system in Nusa Penida is shown in Figure 2.

At the beginning of the operation, this hybrid system is running well. Until September 2007 the total energy generated by two units of wind power station reached 164.7 MWh, with details of unit 1 in operation since April 2006 and unit 2 in operation since December 2006. The energy produced is equivalent to 49.429 liters of diesel. Taking into account the price of diesel fuel 6500 Rupiah/ liter at the time, the savings cost is about 321 million Rupiah [9]. On this basis then WPS construction were developed, 7 units of wind turbines built during 2007 and the total turbine operated to 9 units with a total installed capacity of 735 kW. Similarly, both of solar were built, unit 1 operated since September 2008 and unit 2 since January 2009 with a total installed capacity of 62 kW.

3 Technical Specification Of Solar And Wind Power

Implementation of renewable energy is strongly influenced by the nature and environment factors, such as solar radiation, temperature, rainy days, air pressure, humidity, wind speed and so on. In order to make the contribution of the hybrid plants can be maximum, then the environmental factors need to be considered, especially wind speed and solar radiation which the main factor to generate electrical energy for power generation.

3.1 Solar Power Station

Solar power station constructed by using a number of PV modules. PV modules made from semiconductor material that captures the electromagnetic radiation from the sun then converted to DC current [10]. Beside of solar radiation, solar production is also affected by PV technology and topology that used.

There are 2 units of SPS built in Nusa Penida, with 216 modules for unit 1 and 198 modules for unit 2. Each unit connected to 6 units converter. Modules specifications that used are given in Table 2.

Figure 1. Map location system Nusa

TABLE 1.
WEATHER CONDITION IN NUSA PENIDA

Month	Air temperature (°C)	Daily Solar Radiation (kwh/m²/d)	Wind speed (m/s)	Relative Humidity (%)
January	26.7	4.93	4.3	82.9
February	26.7	5.04	4.5	82.4
March	26.6	5.43	3.2	83.5
April	26.9	5.39	3.6	81.7
May	26.8	5.19	4.9	78.3
June	26.4	4.84	5.6	76.3
July	25.8	4.79	5.7	75.1
August	25.4	5.33	5.5	75.5
September	25.5	5.95	4.8	78.5
October	26	6.19	3.8	80.4
November	26.4	5.67	3.2	82.8
December	26.6	5.28	3.2	82.5
Average	26.3	5.34	4.4	80

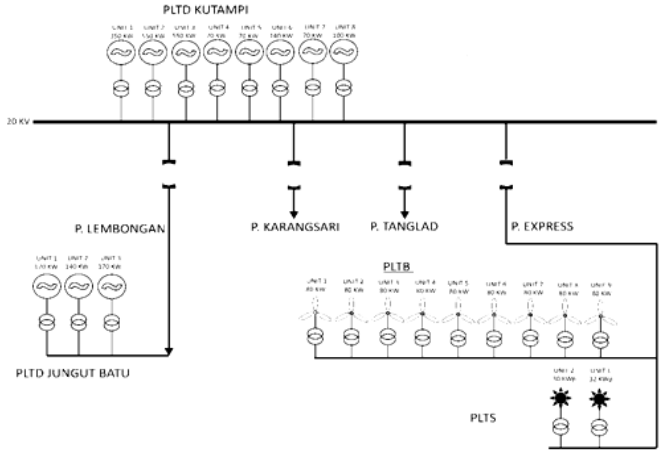

Figure 2. Interconection of Hybrid Generation System in Nusa Penida [8]

TABLE 2.
PV MODULE SPECIFICATION BP3150N

Peak power (Pmax)	150 W
Warranted minimum Pmax	145.5 W
Voltage (Vmp)	34.5 V
Current (Imp)	4.35 A
Open Circuit Voltage (Voc)	43.5 V
Short Circuit Current (Isc)	4.75 A
Minimum Bypass Diode	8.0 A
Maximum Series Fuse	15 A

3.2 Wind Power Station

Wind power station built by using wind turbine towers to convert wind speed to be electrical energy. Wind turbines can produce electricity when the wind gusts can rotate the blade. There are 9 units of wind turbine in Nusa Penida. Similarly to SPS, beside of wind speed, the WPS is also influenced by climate and environment, WPS production is also determined by configuration system that used.

The WPS system works with wind speed range of 3 m/s - 25 m/s. When the wind speed is less than 3 m/s, then the system will automatically disengage from the grid (cut-in wind speed). Conversely, if the wind speed exceeds 25 m/s, the system will distort the turbines of the wind direction so that the blade will stop (cut-out wind speed). The specification of wind turbines used in WPS Nusa Penida are given in Table 4.

3.3 Inverter

Inverter is used to convert the DC current and voltage generated by PV array into AC current and voltage. Capacity of the inverter is depends on the capacity of solar modules that used. Type of inverter that used is the Sunny Mini Central, the specifications is shown in Table 3.

3.4 Hybrid Interconnection to the Grid

Diesel is still the major generator of electricity in Nusa Penida backbone. With the interconnection of solar and wind power station to the grid, is expected to meet the electricity needs of the island. This hybrid system is a 3-phase system that was built without use of energy storage systems (batteries) and solar power station is use a single inverter.

The pattern of the hybrid plant operations during the daytime is served the load by the 350 kW diesel with wind and solar power station. At night solar power station doesn't work, so only use diesel and wind power station. At evening WPP power generated is also used to supply lighting of 'power house', so as to determine their own energy consumption and sent to the distribution system, the export-import kWh meter is used [9]. Hybrid system configuration in Nusa Penida is shown in Figure 3.

TABLE 3.
INVERTER SPECIFICATION SMC 5000A

V_{DC} max	600 V
$V_{DC\ MPP}$	246-600 V
I_{DC} max	26 A
V_{AC} nom	230 V
f_{AC} nom	50/60 Hz
P_{AC} nom	5000 W
I_{AC} nom	21.7 A
Cos φ	1

TABLE 4.
WIND TURBINE SPECIFICATIONS AT NUSA PENIDA

Wind speed min	3 m/s
Wind seed nom	12 m/s
Wind speed max	25 m/s
Wind speed peak	60 m/s
P_{AC} nom	80 kW
Voltage	400 V± 10%
Frequency	50 Hz
Type	Variable speed

4 MEASUREMENT REAL CONDITIONS

To determine how much the influence of the weather changes to the production of solar and wind power station, it's necessary to measure the daily solar radiation intensity and wind speed.

4.1 Measurement of Solar Radiation Intensity

Measurements were taken in 24 hours of 00.00-24.00 o'clock pm. Weather conditions when the measurement is bright with a little cloudy. Based on the measuring instrument datalogging solar power meter, solar radiation when measuring ranges 200-1000W/m2. Measurements results of solar radiation intensity is shown in Figure 4.

Figure 5 describe the intensity of the sun's influence on the level of production of SPS. From this graph it appears that the higher the radiation intensity obtained PV modules, the greater the capacity of electricity that can be generated. Total capacity for 1 day is raised to 154.3 kW, with details of unit 1 of 52.9 kW and 2 units of 101.4 kW. This value is not maximized category related specifications of equipment used where STC (standard test condition) solar cell is 1000 W/m2.

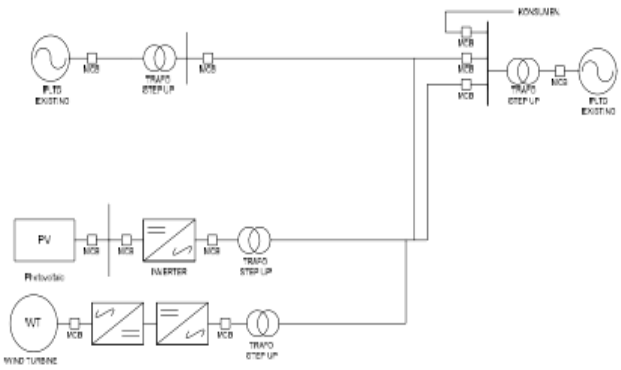

Figure 3. Configuration of hybrid systems in Nusa Penida [11]

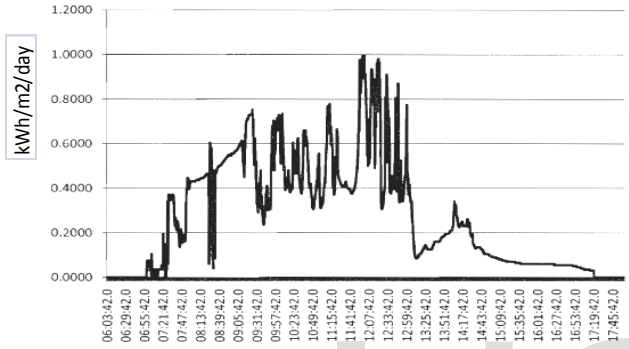

Figure 4. Data of Daily Solar Radiation [12]

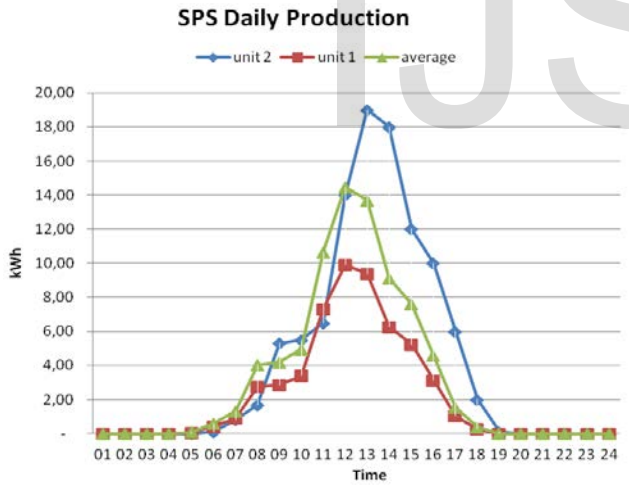

Figure 5. Relation of solar irradiation intensity with solar production

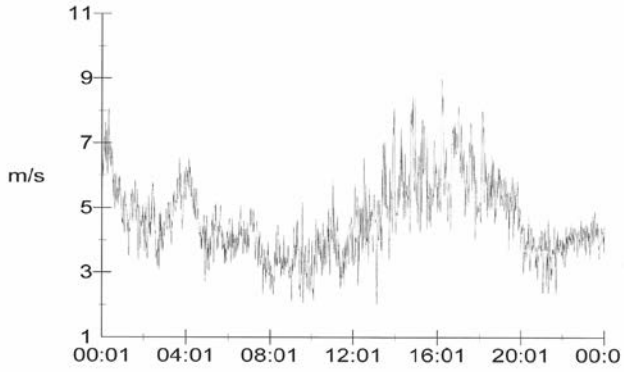

Figure 6. Variation of wind speed for 1 day [13]

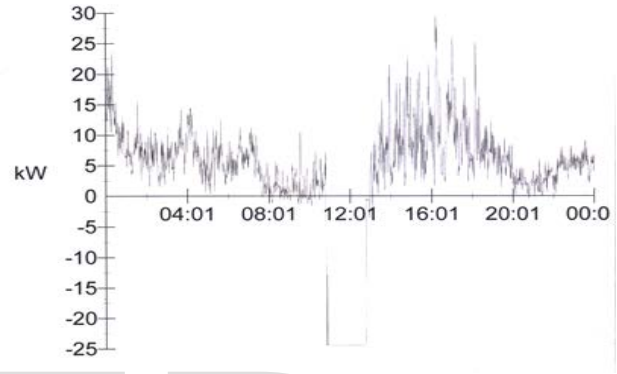

Figure 7. Variation in the power production of WPS [13]

4.2 Input and Output Power of PV Module

Power input is the power gets from solar irradiation that can be expressed by :

$$P_{in} = Ir \times A \quad (1)$$

When:
Pin= input power (Watt)
Ir= solar irradiation (W/m2)
A= module surface area (m2)

Power output is the power generated by PV modules that can be expressed by :

$$P_{out} = V_{oc} \times I_{sc} \times FF \quad (2)$$

When :
Pout= output power
Voc= open circuit voltage
I= short circuit current
FF= fill factor

Fill factor can be obtained from :

$$FF = V_{oc} - \ln (V_{oc} + 0.72) / V_{oc} + 1 \quad (3)$$

4.3 Measurement of Wind Speed

The wind speed at Nusa Penida fluctuate times to time. Figure 6 shows the variation of wind speed for 1 day. Although the wind speed can be very high, but the average speed is only about 4 m / s [13]. Figure 7 shows the amount of power generated by a wind power station units with varying wind speed fluctuations.

5 Discussion

The presence of generating renewable energy (solar and wind power station) is intended to reduce dependence on oil-fired power stations (diesel). In addition to meet the electricity needs in the area of Nusa Penida, reducing fuel usage, hybrid system is also intended to reduce CO2 emissions related to global climate change.

Hybrid system device performance is greatly influenced by natural conditions. Unpredictability in weather and climate changes causes changes in working patterns and output of the system.

Related to irradiation conditions that is not always constant, the level production of SPS produced is also follow to radiation pattern, as shown in Figure 4 and 5. When the maximum production rate of 100%, the total power generated up to 28.91 kWh, but this value is not reached the expected capacity 62 kW. This occurs because although the rate of conversion of 100%, the level intensity of solar received by PV modules is a major determining factor whether kWh generated will be maximum or not.

The increase of solar radiation intensity causes temperature of PV modules rise up. The increase of temperature will decrease the output voltage but increase its output current. However, if the surface temperature of the PV modules continously rise, the current will be constant, but the voltage is still down so the output power will decrease. If the output power decrease then the efficiency of solar modul will also go down. Therefore, the condition of the surrounding area and hygiene of PV modules related to shadding is also noteworthy because of its existence. Shadding can be caused by conditions around the installation of PV or the architecture of PV building itself. The number of rainy days, rainfall throughout the year, will also reduce the acceptance of sunlight by PV modules.

Wind speed for the initial conservation WPS is already qualified minimal associated turbine propulsion equipment specifications used. Fluctuations in wind speed at Nusa Penida is quite large, often soaring high wind speed for a few moments and then disappeared. This greatly affects the production of electricity generated by WPS. If it connected to the grid, wind speed fluctuations will adversely affect the working frequency of the system changes, especially because the system does not use the storage system. Production of WPS is relatively small, it causes the load-sharing does not occur between plants so it makes the protection system between diesel generator works. To overcome this, each of diesel generators installed by using load-sharing controller.

Table 5 shows the total kWh production of solar and wind power station at Nusa Penida in 2009. Based on these data it can be seen that the average injection per month of hybrid system onto the grid is only about 3.23% and this value has not reached the expected value which is 6.28%.

6 Conclusion

In this paper discussed how the influence of local area's weather and climate changes where hybrid system installed related to specifications of the equipment used and also for the electricity production.

Based on the nameplate of each engine, the total capacity of hybrid system solar-wind in Nusa Penida can produce maximum power of 792 kWh. However, the capable power is not same to power generated in the fact. Since the presence of environmental factors such as temperature, rainfall, rainy day, wind conditions, and others, caused electricity production of hybrid system not optimal. In addition, other conditions such as shadding, hygiene solar modules, and various non-technical aspects also affect the output of the system.

Changes in environmental conditions causes change in work patterns and output of the system. If the power station is often to not operating due more natural conditions allow, the power station components will be damage faster, reduced work efficiency and the possibility to not be operated is greater. It is necessary for further studies such as forecasting daily environmental conditions to be used as an initial estimate to the operation of renewable generation.

In addition, the use of energy storage systems need to be taken into account related hybrid system output fluctuations varied so that the system output can be maintained its stability and decrease the lifetime of equipment in the system can be reduced. In addition, the technical aspects of the operating system also needs to be noted to ensure the continued operation of the hybrid system so that the electrical energy needs of the region can remain to fulfilled.

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TABLE 5.

PRODUCTION OF SOLAR AND WIND POWER STATION AT NUSA PENIDA IN 2009 (KWH)

NO	Month	PRODUCTION (kWh)											TOTAL OF PRODUCTION
		WPS 1	WPS 2	WPS 3	WPS 4	WPS 5	WPS 6	WPS 7	WPS 8	WPS 9	SPS 1	SPS 2	(kWh)
1	January	0	2.865,60	1.104,40	0	0	0	0	0	7.969,80	2.434,20	1.980,10	16.354,10
2	February	0	1.575,30	544,4	0	0	0	0	5.099,10	2.153,40	4.221,00	2.692,10	16.285,30
3	March	0	1.249,50	-94,8	-191	-116,8	0	0	1.622,10	1.436,10	3.290,80	3.287,50	10.483,40
4	April	0	3.752,10	330,4	975	0	0	0	2.508,60	1.968,30	3.344,00	4.083,00	16.961,40
5	May	0	3.843,00	781	1.064,00	2.102,00	0	0	2.965,20	1.924,80	3.116,00	3.517,00	19.313,00
6	June	0	4.190,10	-332	575	0	0	0	4.566,00	3.504,60	3.062,00	3.777,50	19.343,20
7	July	0	9.306,90	3.482,60	3.998,00	1.332,00	0	0	10.065,00	9.836,10	3.400,50	4.078,10	45.499,20
8	August	0	9.565,80	2.520,40	4.227,00	0	0	0	10.007,10	6.371,40	2.389,50	3.339,90	38.421,10
9	September	0	7.258,20	2.032,00	3.234,00	461,2	39.109,50	10.929,90	8.910,90	3.945,00	1.375,00	695,9	77.951,60
10	October	53,7	4.365,60	576	933	202,8	0	3.924,90	6.076,50	0	1.836,80	17	17.986,30
11	November	3.225,60	3.278,40	716	1.145,00	377,2	0	0	0	0	3.206,70	880,9	12.829,80
12	December	2.300,70	2.347,20	440,2	814	560	0	0	0	0	1.283,50	1.491,50	9.237,10
	TOTAL	**5.580,00**	**53.597,70**	**12.100,60**	**16.774,00**	**4.918,40**	**39.109,50**	**14.854,80**	**51.820,50**	**39.109,50**	**32.960,00**	**29.840,50**	**300.665,50**