Planning for The Optimal Hybrid Power Plants (Case Study Grid 3 Nusa in Nusa Penida, Bali)

1st I Gede Putu Oka Indra Wijaya
Electrical Engineering Faculty
Telkom University
Bandung, Indonesia
igedeputuokaindra@student.telkomuniversity.ac.id

2nd Sudarmono Sasmono
Electrical Engineering Faculty
Telkom University
Bandung, Indonesia
ssasmono@telkomuniversity.ac.id

3rd Wahmisari Priharti
Electrical Engineering Faculty
Telkom University
Bandung, Indonesia
wpriharti@telkomuniversity.ac.id

4th Bandiyah Sri Aprillia
Electrical Engineering Faculty
Telkom University
Bandung, Indonesia
bandiyah@telkomuniversity.ac.id

5th Yasarah Labibah
Electrical Engineering Faculty
Telkom University
Bandung, Indonesia
yasarahlabibah@student.telkomuniversity.ac.id

***Abstract*—Currently on the island of Nusa Penida only electricity is supplied from the diesel electric power plant Kutampi. The plan is that in 2022 there will be an additional source of electricity that comes from PV solar energy. In addition to the two power plants already mentioned, this study will examine the option of adding wind power plant. The characteristics of renewable energy generators are intermittent and non-dispatchable, so a BESS (battery energy storage system) is also used as power smoothing and frequency control. The planning for the optimal hybrid power plant in Nusa Penida aims to increase the contribution of renewable energy and reduce the COE (Cost of Electricity) lower than the existing COE of Diesel Power Plant in 2018, that is 19 cent$/kWh. As well as testing the stability of the system frequency with the allowable range according to the Java, Madura, and Bali Grid Code, which ranges from 49.0 Hz – 51.0 Hz.**

Keywords*—Nusa Penida, diesel electric power plant, PV solar energy, wind power plant, BESS, hybrid power plant, renewable energy, optimal

I. INTRODUCTION

There are more than 17,000 islands in Indonesia, one of which is Nusa Penida Island which is part of the Province of Bali. Many tourists from all over the world have traveled to this island, but unfortunately the supporting factors such as electricity supply are still not optimal. Until now, the electricity supply in Nusa Penida is sourced from the existing Kutampi Diesel Power Plant which has a power capacity of 11.9 MW, which is fueled by Marine Fuel Oil [1]. Diesel Power Plant itself is a generator whose basic cost of generation is expensive and not environmentally friendly. Because Solar Power Plants and Wind Power Plants are able to operate without using fuel so that it can eliminate the third component in the LCOE (Levelized Cost of Energy), that is fuel cost. In previous studies, many have discussed the problem of planning hybrid power plants that combine solar energy, wind energy, and storage. But the case is on a different island and only focuses on COE (Cost of Electricity) results without system frequency stability.

The reason for using the Solar Power Plant and the Wind Power Plant as the main source of electricity generation in Nusa Penida is to realize the plan of the Governor of Bali. Regional action plan towards “Bali Mandiri Energi Bersih” which means Bali is Clean Energy Independent which is also in line with the national policy targeting a 23% New Renewable Energy mix by 2025 [2][3]. The Solar Power Plant and the Wind Power Plant itself are non-dispatchable generators and are prone to intermittent [4]. Therefore, the solution is to use a fast response generator which will be backed up by the existing Diesel Power Plant. And so that the hybrid generator is optimal in terms of frequency stability, a BESS or battery energy storage system is also installed as power smoothing and frequency control. With the existence of BESS, it is hoped that it will reduce the use of Diesel Power Plants.

In this study, the optimal hybrid power plant planning modeling was carried out using the HOMER (Hybrid Optimization Model for Electric Renewables) and DIgSILENT (Digital Simulation and Electrical Network Calculation Program) applications. HOMER is an application developed by “The National Renewable Energy Laboratory” which is used to design hybrid generation systems and budgets [5]. It is expected that the resulting COE is lower than the COE in the existing system configuration of the Diesel Power Plant in 2018, that is 19 cent$/kWh. To analyze the frequency stability of the hybrid generating system, the DIgSILENT application is used [6]. This hybrid power system is stable, characterized by the frequency of the system remaining within the permissible range according to the Grid Code of the Java, Madura, and Bali, that is range between 49.0 Hz – 51.0 Hz [7].

II. METHOD

The determination of optimal installed capacity of the combination of variable renewable energy power plant will carry out into 3 state as following:

A. *The Economic State*

Determination of optimal installed capacity based on the economic approach. The criteria of optimal installed capacity are COE, where the objective function is minimum COE as following:

$$COE = \frac{\sum_{t=1}^{n} I_t + M_t + F_t}{\sum_{t=1}^{n} E_t} \qquad (1)$$

Where, I_t is investment in year t, M_t is operation and maintenance costs in year t, F_t is Fuel cost in year t, E_t is electrical energy generated in year t, and n is system age.

B. The Static State

In the static state, load flow simulation will be carried out to determine busses voltage, losses after penetration of variable renewable power plant to the grid. While the short circuit simulation will be carried out to determine breaking capacity (Ib) in the substations (GH) after penetration of variable renewable power plant to the grid. *Ib* can be defined as the breaking current rating where the circuit breaker is able to interrupt the short circuit current, without being destroyed or causing an electric arc with unacceptable duration. Thus, the objective function for simulations in the static condition is following:

$$0.9\ p.u \leq V_{bus} \leq 1.05\ p.u \qquad (2)$$

$$Min\ (l) \qquad (3)$$

$$Ib \leq 14\ kA \qquad (4)$$

Where, V_{bus} is busses voltage, l is losses after penetration of variable renewable power plant to grid. *Ib* is breaking capacity of equipment related to integration of renewable energy power plant. 14 kA is maximum breaking capacity of 20 kV electrical system.

C. The Dynamic State

In the dynamic state, the frequency stability simulation is carried out to determine the frequency nadir and new frequency stability during disturbances and intermittency condition. The objective function for frequency stability simulations is following:

$$0.98\ p.u \leq fn \leq 1.02\ p.u \qquad (5)$$

Where, *fn* is nadir frequency during disturbances and intermittency condition.

III. RESULTS AND DISCUSSION

A. The 3 Nusa Grid

The 3 Nusa Grid is 20 kV grid in Nusa Penida Islands. Whilst the Nusa Penida Islands is small island located on the offshore of Bali Island, Indonesia as shown in Fig. 1. The Nusa Penida Islands is containing of 3 small islands following The Nusa Lembongan Island, The Nusa Ceningan Island and The Nusa Penida Island. Since the 20 kV grid connect the 3 islands then the 20 kV grid in Nusa Penida Islands is named the “3 Nusa Grid” or 3 islands connected grid.

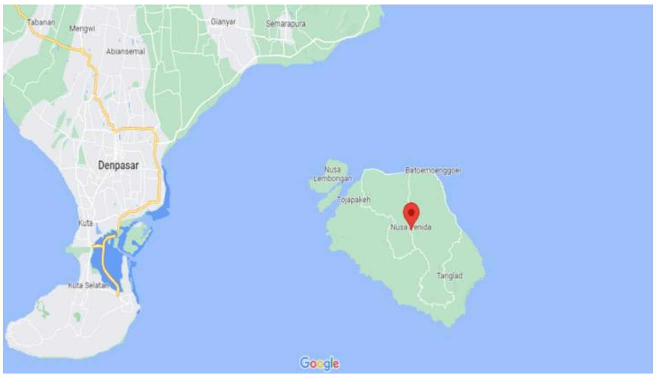

FIG. 1. Site Location

B. The Load Profile

The peak load forecasting of the grid in 2022 will be 10.84 MW. Whilst the off-peak load will be 8.67 MW. The main electricity supply was 7 x 1.7 MW Diesel Power Plant (PLTD). Reserve for reliability and emergency was 3 x 1 MW Diesel Power Plant. The single line diagram of 3 Nusa Grid is shown in Fig. 2. On the related of variable renewable energy resources, the global horizontal irradiation in Nusa Penida Islands is about 1990.27 kWh/m, while the mean wind speed is about 4.77 m/s.

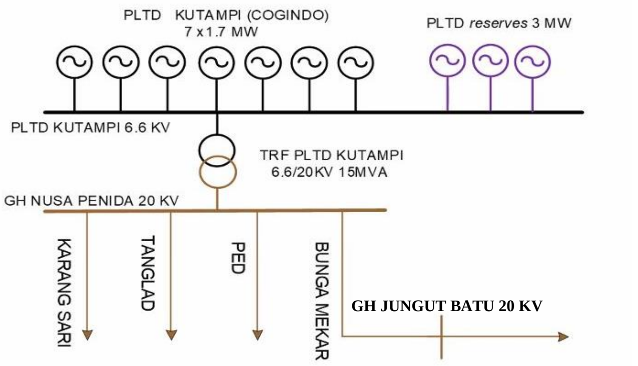

FIG. 2. The 3 Nusa Grid

C. Optimal Installed Capacity

The power plant system design to serve the load is shown in Fig. 3. The diesel power plant and wind turbine is connected to AC bus, while Solar PV and battery energy storage system is connected to DC bus. Since the load is connected to AC bus the converter should adding to change DC to AC.

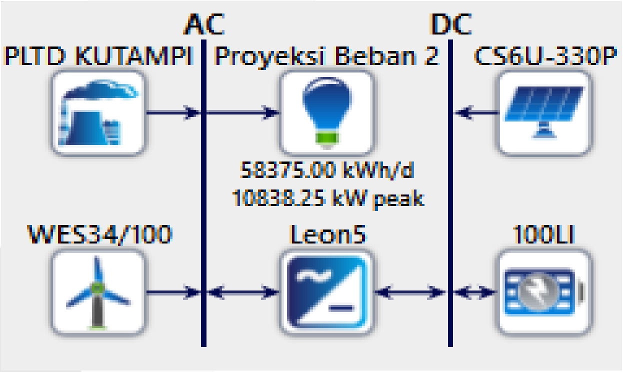

FIG. 3. Hybrid design

The simulation is running in HOMER. The simulation is following the criteria of equation (1) and minimum COE. The optimal composition is Diesel Power Plant 11.9 MW, Solar PV 3.5 MW, Wind Turbine 4 MW and battery energy storage system 3 MW. The COE of the composition is 9.68 cent$/kWh. It is lowest COE, since the existing COE of Diesel Power Plant in 2018, that is 19 cent$/kWh. Capacity of Diesel Power Plant was 11.9 MW with reserves for reliability and emergency was 3 MW Diesel Power Plant.

D. Stability Installed Capacity

Since all the sources is variable renewable energy, then the optimal installed capacity doesn’t enough yet to fixed hybrid composition. The stability analysis should be carrying out to making it fixed. The stability simulation is using

Digsilent Power Factory. The stability analysis contains load flow analysis and frequency stability analysis. The load flow analysis is needed to make sure during the static condition, all the grid parameter is meet the grid code rules according to equation (2), equation (3), and equation (4). Once the parameter is in the range of allowable values then the dynamic analysis can be carrying out. The following results from the load flow simulation are shown in Table I. and Table II. With The Wind Power Plant (PLTB) scenario with a capacity of 4.0 MW connected directly to GH Nusa Penida:

TABLE I. Percentage of Losses Each Feeder

No	**Feeder**	**Losses**		**Standard**
		LWBP	***WBP***	
1	Ped	0.78	0.98	Minimum possible
2	Tanglad	0.11	0.09	
3	Karang Sari	0.11	0.09	
4	Bunga Mekar	1.34	1.16	

TABLE II. Voltage of Each Busbar

No	**Busbar**	**Voltage (LWBP)**		**Voltage (WBP)**		**Standard**
		kV	***p.u.***	***kV***	***p.u.***	
1	GH Nusa Penida	20	1	19.9	1	(+5% and -10%)
2	PLTD Kutampi COGINDO	20	1	19.9	1	
3	Unit PLTD Kutampi	6.6	1	6.6	1	
4	Feeder Karang Sari	20	1	19.9	1	
5	Feeder Ped	20	1	19.9	1	
6	Feeder Bunga Mekar	20	1	19.9	1	
7	Feeder Tanglad	20	1	19.9	1	
8	GH Jungut Batu	19.6	0.98	19.4	0.97	
9	Hotel Mahagiri	19.6	0.98	19.4	0.97	
10	Site PV Suana	19.9	1	19.8	0.99	
11	Site PV Pejukutan	19.8	0.99	19.8	0.99	
12	Site PV Ped	19.8	0.99	19.8	0.99	
13	Site PV Sakti	19.6	0.98	19.4	0.97	
14	Site PV Manta Point	19.8	0.99	19.7	0.99	
15	Site PV Tanglad	19.8	0.99	19.7	0.99	
16	PV Site 6 Suana	20.2	1.01	-	-	
17	PLTB Nusa Penida	20.2	1.01	20.1	1.01	

After the load flow simulation, then a short circuit simulation is carried out to determine the value of breaking capacity in each busbar as shown in Table III.

TABLE III. Breaking Capacity Value of Each Busbar

No	**Busbar**	**Ib (kA)**		**Maximum Standard (kA)**
		LWBP	***WBP***	
1	GH Nusa Penida	0.62	0.46	14
2	PLTD Kutampi COGINDO	0.62	0.46	
3	GH Jungut Batu	0.52	0.45	
4	Hotel Mahagiri	0.52	0.45	
5	Site PV Suana	0.58	0.44	
6	Site PV Pejukutan	0.5	0.39	
7	Site PV Ped	0.59	0.45	
8	Site PV Sakti	0.56	0.46	
9	Site PV Manta Point	0.46	0.38	
10	Site PV Tanglad	0.4	0.34	
11	PV Site 6 Suana	0.62	-	
12	PLTB Nusa Penida	0.61	0.46	

Validated criteria, if the similarity between the simulated and calculated data is at least 90%.

TABLE IV. Model Validation With Voltage Value Parameters

No	**Location (Feeder)**	**Simulation (kV)**	**Calculation (kV)**	**Similarity (%)**
1	Feeder Ped	19.9	19.22	96.46
2	Feeder Bunga Mekar	19.9	18.95	94.99

Based on Table IV. It can be said that the system model is valid based on the value of the voltage.

Since the off-grid system is stable during static condition, then the stability of the off-grid system during dynamic condition should be checked in the next stage. The dynamic analysis simulation is following the criteria of equation (5). The worst condition in grid stability will occur in peak load time. Since the peak load time will occur in the night when the Solar PV is not in operation mode then only fluctuation of wind velocity scenarios defined in the simulation.

Analysis of frequency stability during intermittent wind power generation is carried out to estimate the reliability of the electricity system when the wind speed fluctuates to an extreme within a certain period of time. According to the data, the extreme fluctuation of wind speed in Nusa Penida is 2.850 m/s to 1.372 m/s in 600 seconds. While the fluctuations in wind speed that often occur are a decrease of 0.008 m/s. In Table V. Shows data on the power curve of the wind turbines used in the Nusa Penida sub-district.

TABLE V. Wind Turbine Power Curve

Name	WES 34/100
Rated Capacity	100 kW
V Cut-in	2 m/s
V Rated	8 m/s
V cut-off	16 m/s

Below is a simulation result of frequency stability with intermittent disturbances of the Wind Power Plant or wind speed fluctuations.

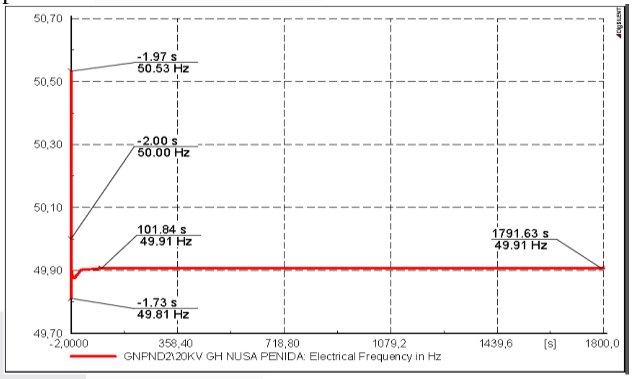

FIG. 4. Simulation Results of Intermittent Frequency Stability of Wind Power Plants at Off-Peak Load

From the graph during the day in Fig. 4. We can analyze that the initial frequency of 50 Hz increased to 50.53 Hz and decreased to 49.81 Hz due to fluctuations in wind speed. And it starts to stabilize again at 101.84 seconds with a frequency value of 49.91 Hz.

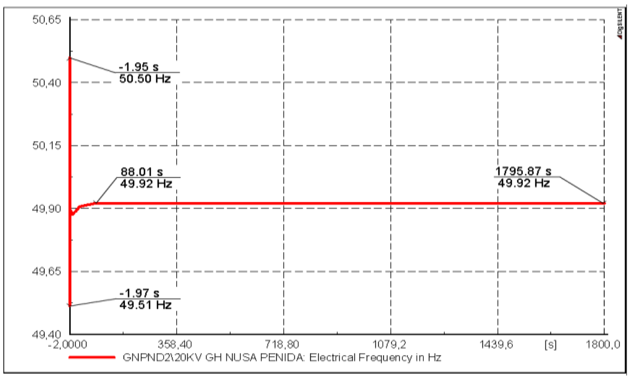

FIG. 5. Simulation Results of Intermittent Frequency Stability of Wind Power Plants at Peak Load

From the graph at night in Fig. 5. We can analyze that the frequency has increased to 50.50 Hz and decreased to 49.51 Hz due to fluctuations in wind speed. And it starts to stabilize again at 88.01 seconds with a frequency value of 49.92 Hz. From the decrease in the lowest frequency which is only up to 49.51 Hz, it can be seen that this system is safe to use continuously in accordance with the Java, Madura, and Bali Grid Codes. In Table VI. Are the frequency rules on the Java, Madura, and Bali grid according to the Minister of Energy and Mineral Resources Regulation No. 20/2020.

TABLE VI. Frequency Grid Code According to the Minister of Energy and Mineral Resources Regulation No. 20/2020

Frequency Range	Operation Time Range
51,50 Hz < f ≤ 52,00 Hz	Operates for a minimum of 15 minutes
51,00 Hz < f ≤ 51,50 Hz	Operates for a minimum of 90 minutes
49,00 Hz ≤ f ≤ 51,00 Hz	Operate continuously
47,50 Hz < f < 49,00 Hz	Operates for a minimum of 90 minutes
47,00 Hz < f ≤ 47,50 Hz	Operates for at least 6 seconds

Below is a graph of the results of the active power of the Wind Power Plant when there is an intermittent disturbance of the Wind Power Plant or fluctuations in wind speed.

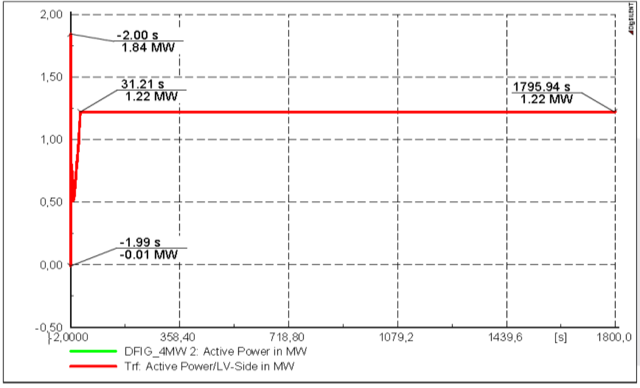

FIG. 6. Simulation Results of Wind Active Power Intermittent at Off-Peak Load

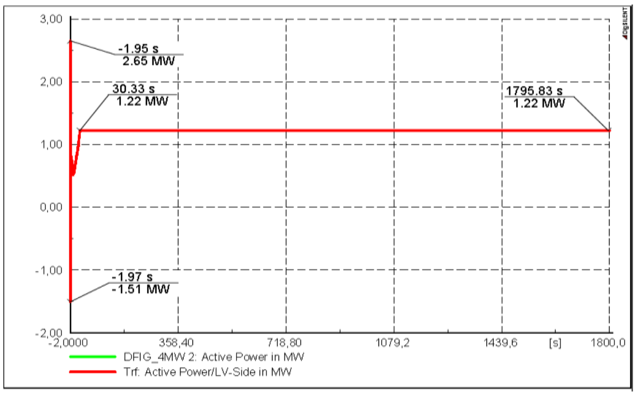

FIG. 7. Simulation Results of Wind Active Power Intermittent at Peak Load

Based on the graph in Fig. 6. and Fig. 7. Indicates that after experiencing fluctuations, the wind active power is stable at 1.22 MW. The wind active power starts to stabilize at the 31.21 second during the daytime intermittent and stabilizes at the 30.33 second during the night intermittent. The wind active power is strongly influenced by the power curve of the wind turbine.

Since during worst scenario in intermittency, the off grid is stable then the composition of the hybrid power plant containing variable renewable energy source is meet both economic criteria and stability criteria.

IV. CONCLUSION

From the results of the research, it was concluded that the option of adding a Wind Power Plant to the existing hybrid system consisting of a Diesel Power Plant, a Solar Power Plant, and BESS was the best option after being optimized for the HOMER application. In the planning of the Hybrid Power Plant system, the results of the optimization of the capacity of 11.9 MW for Diesel Power Plants, 3.5 MW for Solar Power Plants, 3 MW for BESS, 4 MW for Wind Power Plants, and 15 MW for converters. Cost of Electricity decreased after the entry of the optimal Hybrid Power Plant to 9.68 cent$/kWh. Meanwhile, the Cost of Electricity in the configuration of the existing Diesel Power Plant system in 2018 was 19 cent$/kWh.

This optimal Hybrid Power Plant system planning option can be applied because it has been tested for frequency stability when an intermittent disturbance occurs in a new power plant, that is the Wind Power Plant. With the highest frequency increase during intermittent is 50.53 Hz during the day and the lowest decrease during intermittent is 49.51 Hz at night. So that the result of frequency in the DIgSILENT simulation does not exceed the applicable reference limit according to the Grid Code of the Java, Madura, and Bali (The Minister of Energy and Mineral Resources Regulation No. 20/2020).

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REFERENCES

[1] M. F. Fikri, R. A. A. R, and C. Hudaya, “Study on Optimization of Renewable Energy-Based Power Plants on The Electricity System of Nusa Penida Island, Bali,” Sent. 2018 Semin. Nas. Tek. Elektro 2018, pp. 265–275, 2018.

[2] Bali Province, Bali Governor Regulation Number 45/2019 Concerning Bali Clean Energy. 2019, p. 20.

[3] Republic of Indonesia, Presidential Decree No. 22/2017 Concerning The General National Energy Plan. 2017.

[4] Nurmela, S. Sasmono, N. Hariyanto, D. Hamdani, and K. M. Banjarnahor, “Optimal and Reliable Variable Renewable Energy Power Plant for Isolated Area,” pp. 1–4, 2021.

[5] Kunaifi, “HOMER Program for Feasibility Study of Hybrid Power Plants in Riau Province,” Semin. Nas. Inform., vol. 1, 2010.

[6] K. UGM, “Press Release – DIgSILENT Software Training,” 2018. https://kmteti.ft.ugm.ac.id/press-release-pelatihan-software-digsilent/ (accessed Sep. 04, 2021).

[7] Ministry of Energy and Mineral Resources, Regulation of The Minister of Energy and Mineral Resources Number 20 of 2020 Concerning The Grid Code of The Java, Madura, and Bali, no. 3. 2020, pp. 417–607.