Power Capacity Assessment of Hybrid Diesel-Solar Photovoltaic Microgrid in Tablas Island, Romblon

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Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 10 May 2021

Abstract: The energy profile of Tablas Island has been demanding in the past years due to the emerging commercialization and even industrialization. Power capacity assessment was conducted in order to verify the sufficiency of power for supply in the coming years considering the increasing demand of energy. A forecast for annual power peak demand was considered in this study in comparison to the dependable capacity of the hybrid microgrid. It shows that the power peak demand from 2018 to 2030 is significantly increasing from 7.19MW to 13.02MW. The 8.8Mega-Watt (MW) diesel-fired power plant has dependable capacity of 6.16MW to 7.04MW from its 70% to 80% plant utilization respectively. The 7.5MW peak solar PV power plant has the maximum AC power capacity of 5.77MW. These power plants were the composition of the hybrid microgrid delivering power from 6.80MW to 8.89MW. Based on the forecast data for annual power peak demand towards 2030, it only met the demand of 8.65MW in the year 2021 but this power did not meet the peak demand in the succeeding years. Several methods to augment the power capacity of the hybrid microgrid were suggested in this study considering the mixed application of conventional and the application of more renewable energy sources as power key-players for generation and distribution.

Keywords: Capacity Assessment, Dependable Capacity, Hybrid Microgrid, Solar Photovoltaic.

1. Introduction

The nation's demand of energy shows a bigger picture of how promising its roadmap towards development. Economic development greatly rely on how much power is used for transportation, communication, facility operation and the like (Ashkar, Samra, Auwerswald, & Holverson, 2017). The energy security roadmap of the Philippines is a combined effort of all energy industry in the exploration of new available energy sources. Both renewable and conventional energy resources are critical roles that will continue to reinforce and mitigate the increasing demand of energy.

Tablas as the largest of the islands that comprise the province of Romblon has a land area of 135,590 hectares for an estimated 43,400 households (Singh, 2019). Tablas Island Electric Cooperative (TIELCO) and National Power Corporation-Small Power Utility's Group (Napocor-SPUG) had been operating in Odiongan Town in Tablas since 1988. In 2014, Napocor-SPUG generates 4.8MW against the island's demand of 5.9MW resulting to frequent power outage to Tielco's franchise areas (Cinco, 2005).In June 28, 2015, Sunwest Water & Electric Company (SUWECO) replaced the role of power generation in the island. The plant has eight units of 1.1MW Cummins modular diesel engine that generates efficient power for Tablas's microgrid. It has the capability to supply power to more than 200,000 residents (The Manila Times, 2015).

The power generation privatization was intended to unravel the worsening power outage in the island. Power outage records show how demanding the energy profile of Tablas Island, Romblon.

Figure 1 shows the unscheduled power outage of Tielco from year 2013 to 2017 and the highest was recorded in 2015.

Power outage was minimized in 2016 but in 2017, it re-emerged again. Figure 2 shows the power generation outage from year 2013 to 2017 and the highest outage were recorded in 2014 under Napocor-SPUG generation. After privatization, the outage was minimized in 2016. However, power outage re-emerged in 2017 and reached a mean loss of 19.05 MWHr. This shows that even privatization took the role in power generation; outages were not avoided due to the increasing demand of power in the microgrid.

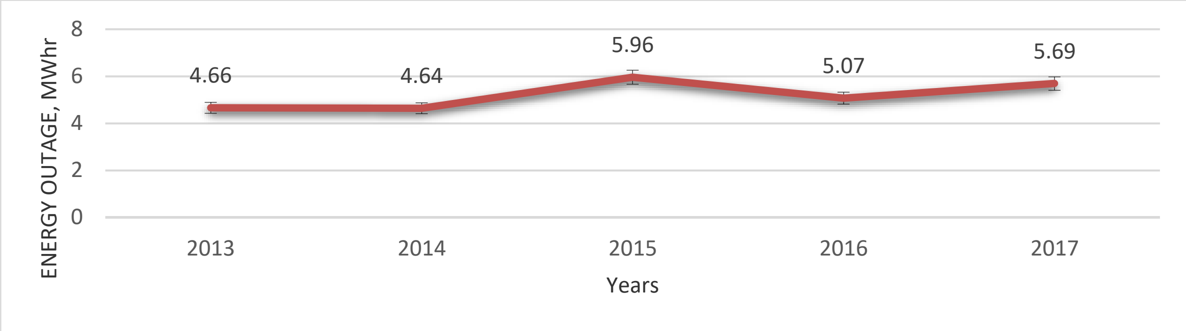

Figure 1.TIELCO's Unscheduled Power Outages from 2013–2017

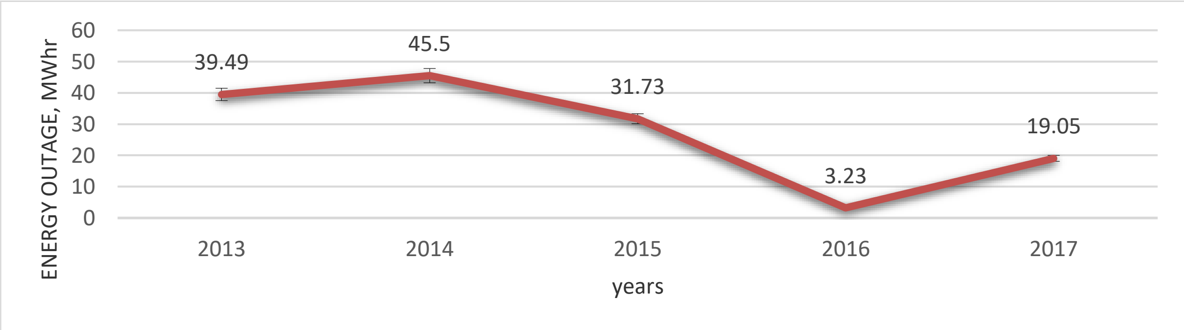

Figure 2. Diesel-Fired Power Plant Outages from 2013–2017

The roadmap towards the year 2030 for the required annual energy supply is significantly inclining which means the demand of power in the coming years will test the limit of the power plant capacity. In Figure 3, the year 2018 consumed about 40,243.16 MWhr of energy and this will be doubled by the year 2030. This expected higher demand of energy in the coming years will necessitate much reliable power supply.

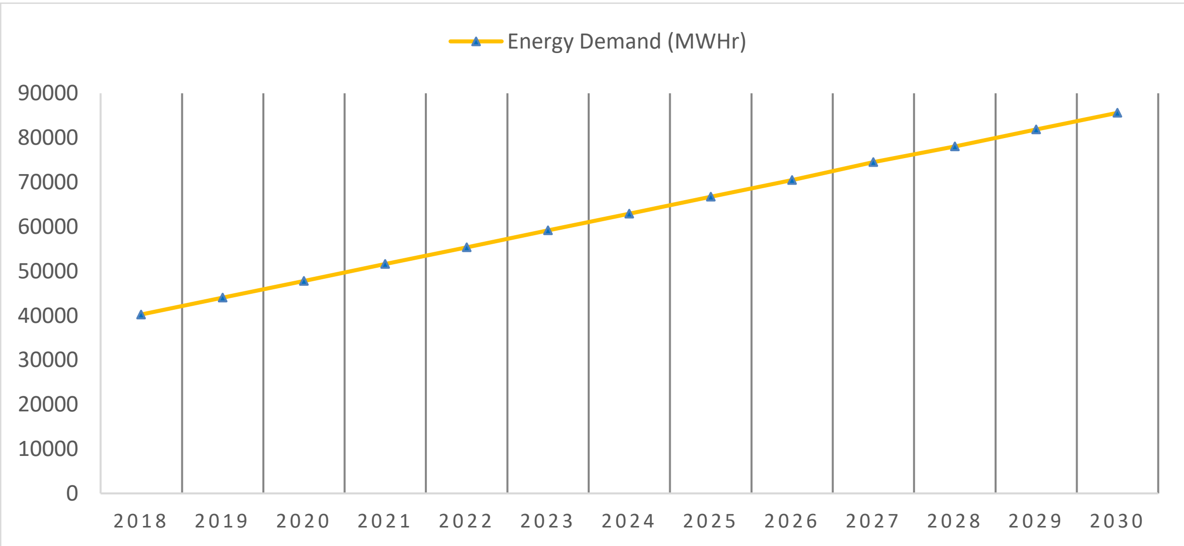

Figure 3: TIELCO's Annual Energy Demand Forecast 2018-2030

The province is looking for sufficient and reliable power supply. Tapping the island's renewable energy resources is one of the options to solve the power outage problem in Tablas. Solar power is one of the most feasible renewable energy resources in the island having enough irradiance of 5.5 kWh per square meter per day (Fajardo, et al., 2014).

On August 21, 2019, a 7.5MW peak solar photovoltaic (PV) power plant was inaugurated in an intention to supply clean energy in addition to the 8.8MW diesel-fired power plant capacity. This is the hybrid diesel-solar PV microgrid which is considered the largest in the Philippines. Despite the existence of the solar PV power plant, the diesel power plant was still operating in its full potential due to the varying and penetrating supply of solar energy.

Hence, power interruption occurs especially during seasons of high demand. With this foreseen problem, power capacity assessment was indeed an important thing to conduct in order to verify the sufficiency of power for supply in the coming years considering the increasing demand of energy for Tablas Island.

2. Objectives

The main objective of the study is to conduct power capacity assessment of hybrid diesel-solar photovoltaic microgrid of Tablas Island, Romblon. Specifically, this study aims to:

1. Forecast annual power peak demand towards year 2030;
2. Determine the dependable AC capacity of the Solar PV power plant at;
   a. 50% nominal power rating;
   b. 100% nominal power rating;
   c. 150% nominal power rating;
   d. 200% nominal power rating.
3. Determine the power capacity of the hybrid microgrid based on the dependable capacity of both diesel-fired and solar PV power plants;
4. Determine the overall theoretical DC peak power of the solar PV power plant based on degradation rate of the PV module.

3. Materials And Methods

A. Materials

Data. Data collected are power outages record, machine count and its current workability, and the solar PV installed capacity. These data are the backbone or the primary supporting information in order to sufficiently conduct the necessary calculation and assessment needed for this study.

B. Methods

Data gathering, preliminary assessment, calculation and analysis, drawing conclusion and recommendation were the steps made in conducting this study.

Data gathering. Energy purchase records for Tablas's grid were collected. The current grid capacity was based on the amount of power generated both by the diesel power plant and the solar power plant facility. Data gathered also included machine count and utilization rate of each, which was conducted during plant visitation and plant personnel interviews. Power outage data on both power plant and distribution facility were also gathered. The record covers monthly outage rate for the year 2013-2017. Knowing all these data, the assessment for the current grid capacity was made for the next stage.

Preliminary assessment. Gathered data were then evaluated. A forecast of the power demand towards the year 2030 was made. By evaluating the current grid capacity and the power outage record, information on how much power supply will suffice the demand was determined.

Calculation and analysis. The variables herein were all collected from the mathematical simulation using the analysis of regression.

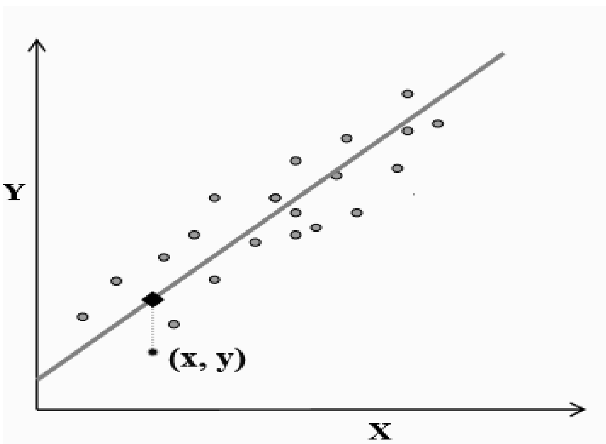

Figure 4. The Ordinary Least Square Method

This method minimizes the difference between the observed and estimated value. Requires that the sum of the squares of the errors for the best fit function be at the minimum as calculated using this equation;

$$Y_i = a + bX_{1_i} + \varepsilon_i \quad (1)$$

$$\varepsilon_t = Y_t - \hat{Y}_t \quad (2)$$

In order to find the best fit, errors are squared then minimized with respects to the coefficients a and b which can be solved using this equation;

$$b = \frac{n\sum X_i Y_i - n\sum X_i \sum Y_i}{n\sum X_i^{\,2} - \left(\sum X_i\right)^2} \quad (3)$$

$$a = \frac{\sum Y_i - b\sum X_i}{n} \quad (4)$$

The annual power peak demand forecast was determined using the equation derived from load distribution forecasting.

$$\boldsymbol{Demand_{Peak}} = \frac{\boldsymbol{Demand_{Average}}}{\boldsymbol{Load\ Factor}} \quad (5)$$

$$\boldsymbol{Demand_{Average}} = \frac{\boldsymbol{Energy\ (kW - hr/year)}}{\boldsymbol{Time\ (8760\ hrs/year)}} \quad (6)$$

This is the baseline data for the capacity evaluation and expansion estimation. The dependable capacity of the 8.8MW diesel-fired power plant and the 7.5MWp solar PV power plant are needed to be analyzed whether the generated power of this hybrid facility met the power demand given by the forecast data.

To get the dependable capacity of the diesel power plant, the installed capacity of the plant must be multiplied to the machine utilization factor (U_f). Machine utilization factor is the operational capacity of the diesel generators in percentage to maintain its reliable and efficient operation. Hence, we use the equation to get the dependable capacity of the diesel power plant:

$$MW_{dependable} = MW_{installed}\ x\ U_f \quad (7)$$

For the solar PV dependable capacity determination, an equation was used to calculate the amount of AC power for distribution relating to the peak DC installed capacity and the inverter's performance factor. It was called inverter loading ratio (ILR) and was calculated as:

$$\boldsymbol{AC\ Output\ (W)} = \frac{\boldsymbol{Installed\ Capacity\ (Wp)}}{\boldsymbol{ILR}} \quad (8)$$

A conservative ILR of 1.3 is used in this calculation. This is also based on the variable penetration of solar energy on the PV array.

Considering the mean and median degradation rating of the PV modules of any type at 0.8% and 0.5% annually, we use geometric progression to determine the maximum DC peak capacity of the solar PV until year 2030.

$$\boldsymbol{a_n = a_1 r^{n-1}} \quad (9)$$

Where: a_n is the plant capacity in the year 2030;

a_1 is the installed capacity;

r is the common ratio;

n is the nth year of the solar PV power plant.

Also, the uncertain conditions which affect the performance of the PV modules, percent nominal power rating was included in the calculation such as when the nominal power rating was at 50%, 100%, 150% or 200% respectively.

Drawing conclusion and recommendation. Based on the conducted calculation and analysis, the hybrid diesel-solar PV microgrid capacity can now be concluded whether its generated power met the pre-determined demand until year 2030. It offers possible power security scheme if the supply does not satisfy the demand criterion of the island. It exhibits methods from conventional to non-conventional schemes in order to meet the ever-increasing demand of the island. Moreover, it demonstrates environmental awareness on CO2 emission reduction because of the renewable energy power generation application as one of the power key-player for distribution.

4. Results And Discussion

A. Results

Power demand forecast. Based on the forecast data, Tablas Island pushes its way towards rapid development as its power demand increases annually as shown in figure 5.

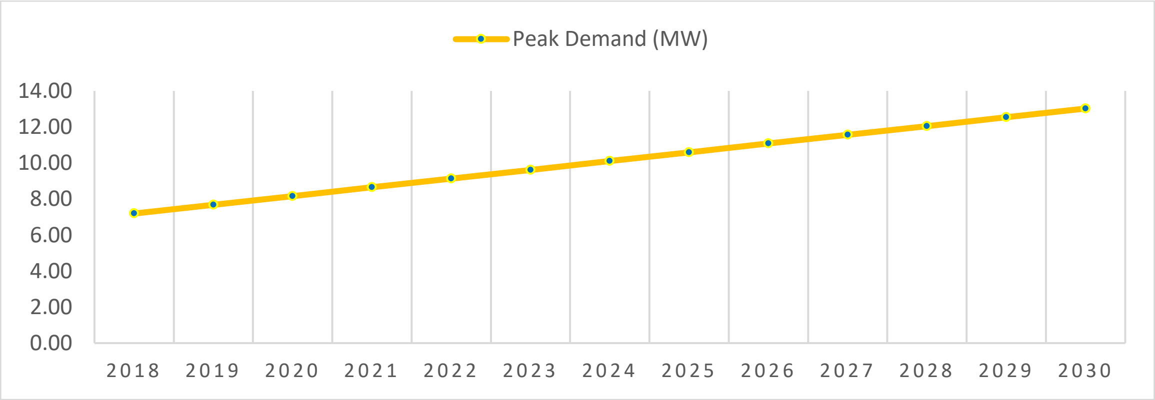

Figure 5. Yearly Peak Demand Forecast 2018-2030

Microgrid dependable capacity. The dependable capacity of the hybrid diesel-solar PV microgrid considering percent utilization of the diesel power plant, and nominal power rating are shown below.

Table 1: Dependable Capacity Matrix of 7.5MWp Solar PV Power Plant

Nominal Power (%)	Multiplier	Megawatt Peak (DC)	MW Generated (AC)
50	0.1105	0.829	0.638
100	0.2011	1.508	1.160
150	0.2779	2.084	1.603
200	0.3211	2.408	1.853

Table 2: Power Capacity of the Hybrid Diesel – Solar PV Microgrid at 70% Utilization Rate of the Diesel Power Plant

Rated Nominal Power (%)	Total Power Generated (MW)
50	6.798
100	7.320
150	7.763
200	8.013

Table 3: Power Capacity of the Hybrid Diesel – Solar PV Microgrid at 80% Utilization Rate of the Diesel Power Plant

Rated Nominal Power (%)	Total Power Generated (MW)
50	7.678
100	8.200
150	8.643
200	8.893

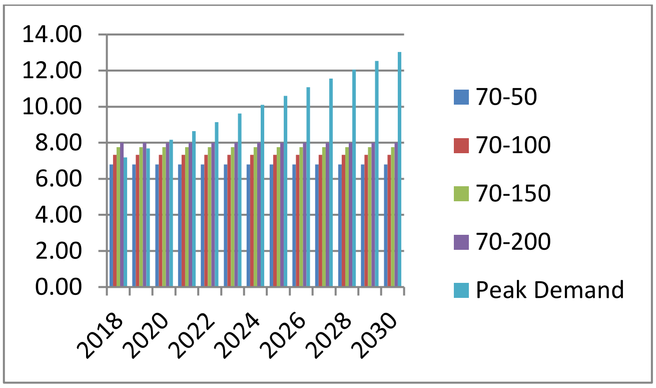

Figure 6: Power Capacity of the Hybrid Diesel – Solar PV Microgrid at 70% Utilization Rate of the Diesel Power Plant

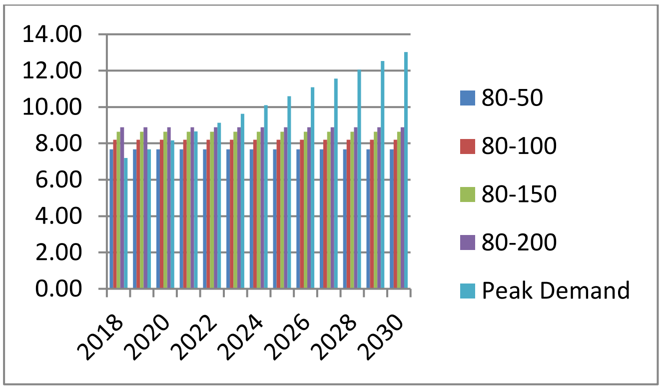

Figure 7: Power Capacity of the Hybrid Diesel – Solar PV Microgrid at 80% Utilization Rate of the Diesel Power Plant

Peak capacity degradation. The installed peak capacity of the solar PV drops within the rate of 0.5% and 0.8% annually. The graph below shows significant declination of installed DC peak power of the 7.5MWp solar PV power plant.

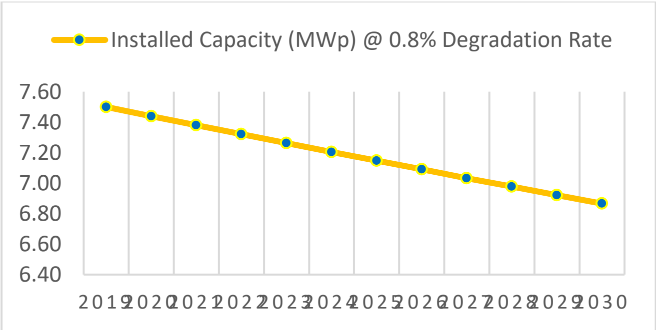

Figure 8: Solar PV capacity degradation 2019-2030 at 0.8% degradation rate

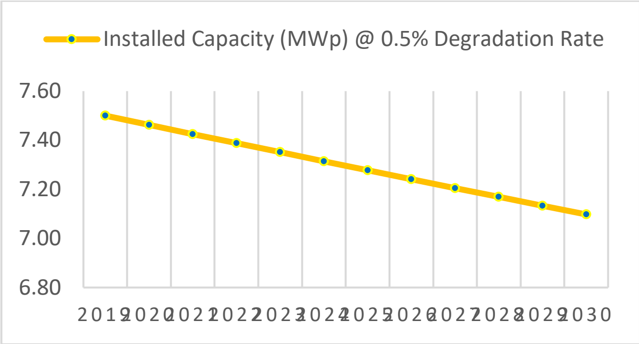

Figure 9: Solar PV capacity degradation 2019-2030 at 0.5% degradation rate

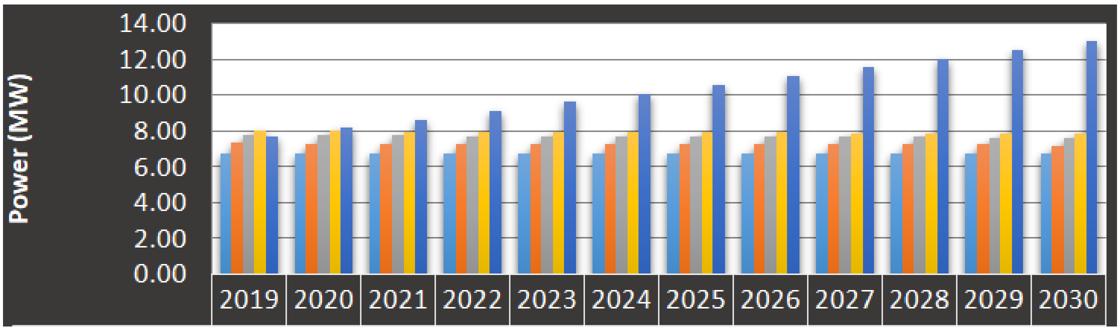

Figure 10: Power Capacity of the Hybrid Diesel-Solar PV Microgrid at 70% Diesel Plant Utilization and 0.8% PV Module Degradation Rate

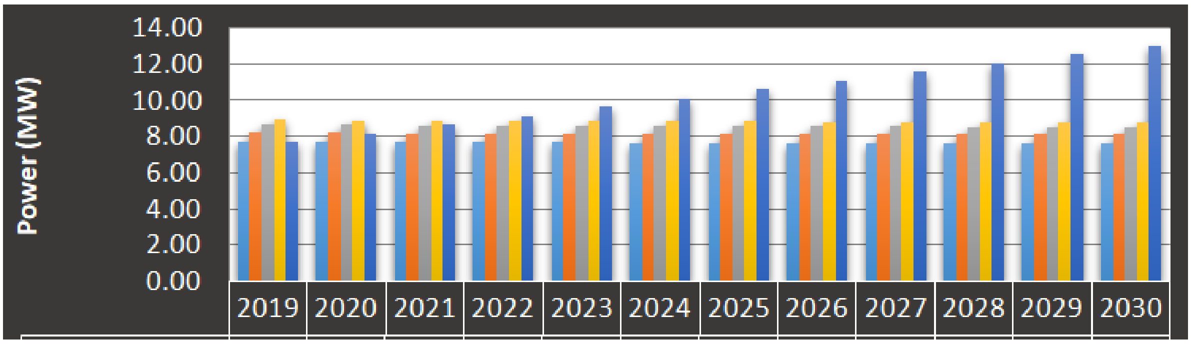

Figure 11: Power Capacity of the Hybrid Diesel-Solar PV Microgrid at 80% Diesel Plant Utilization and 0.8% PV Module Degradation Rate

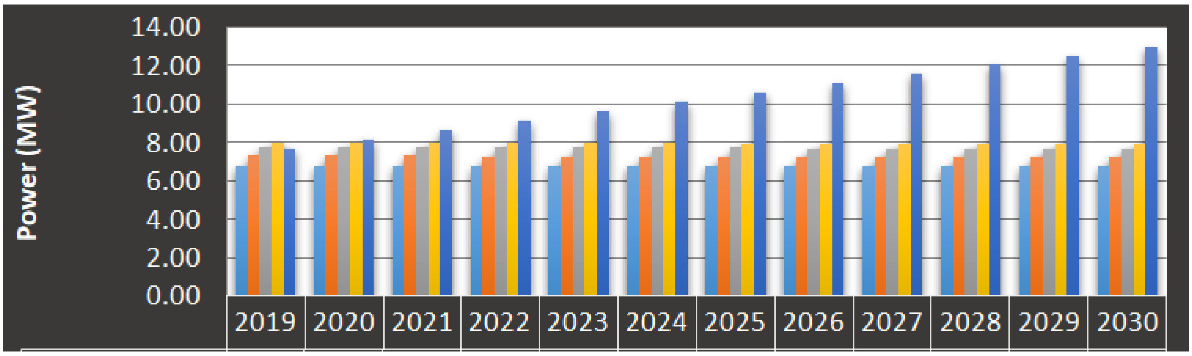

Figure 12: Power Capacity of the Hybrid Diesel-Solar PV Microgrid at 70% Diesel Plant Utilization and 0.5% PV Module Degradation Rate

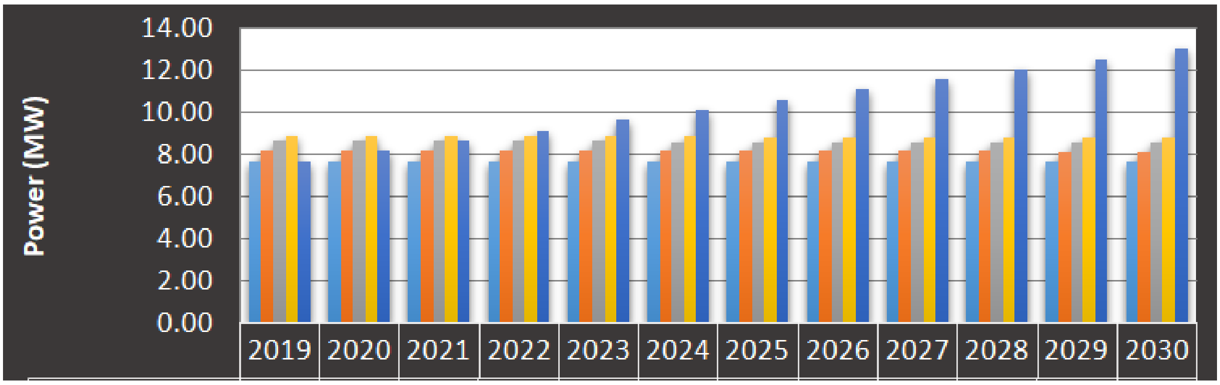

Figure 13: Power Capacity of the Hybrid Diesel-Solar PV Microgrid at 80% Diesel Plant Utilization and 0.5% PV Module Degradation Rate

B. Discussion

Figure 5 shows that there is a steady rise in demand on the roadmap towards the year 2030. Significantly, it shows that there is already power insufficiency in the year 2022 given that the operational plant utilization of the diesel-fired power plant remains at 80% maximum.

Given the installed capacity of diesel power plant at 8.8MW, the dependable capacity at 70% to 80% plant utilization was 6.16MW to 7.04MW. In the case of 7.5MW peak solar PV power plant, the theoretical maximum AC generated is 5.77MW considering the inverter loading ratio (ILR) of 1.3.While the theoretical AC generated of solar PV power plant considering the degradation rate of solar modules at 0.5% and 0.8% was 5.46MW and 5.28MW respectively towards the year 2030. The amount of dependable power capacity of solar PV power plant ranges between 0.638MW at 50% nominal power rating to 1.853MW at 200% nominal power rating as shown in Table 1. The range of dependable capacity of solar PV power plant depends upon any certain condition during its operation. It involves cloud shading, changes in ambient temperature and the varying solar irradiance at a certain time of the day. The power generated by the solar PV power plant is mixed with the output generated power of the diesel power plant, resulting to hybrid diesel-solar PV power generation.

At 70% plant utilization of the diesel power plant, when combined with the varying output of solar PV power plant, the total generated power ranges from 6.798MW to 8.013MW as shown in Table 2 while at 80% plant utilization, when combined with the varying output of solar PV power plant, the total generated power ranges from 7.678MW to 8.893MW as shown in Table 3. This shows that the allowable plant capacity of the hybrid microgrid ranges within 6.798MW to 8.893MW AC power.

Based on Figure 6, when the utilization rate of 8.8MW diesel power plant is 70% and the nominal power rating of solar PV power plant reaches 200% maximum, the total generated power is 8.013MW. It met the demand of 7.679MW for the year 2019. But this power did not meet the peak demand of 8.164MW for the year 2020. When the utilization rate of the diesel-fired power plant was increased to 80% and the nominal power rating of solar PV power plant reaches 200% maximum, the total generated power is 8.893MW as shown in Figure 7. It met the demand of 8.65MW for the year 2021. But this power did not meet the peak demand of 9.136MW for the year 2022 and onwards.

In Figure 8 and 9, the amount of DC peak power (installed capacity) drops from 7.10MWp to 6.87MWp towards the year 2030 due to the annual degradation rate of 0.5% to 0.8% respectively. Although the rate of degradation is too small to consider, it still contributed to the overall grid performance of the hybrid microgrid considering the demand of power is increasing.

Figure 10 shows the power capacity mix of the hybrid microgrid having 70% diesel-fired plant utilization rate, 50% - 200% solar PV nominal power rating, and 0.8% degradation rate. It shows that the capacity of the grid at varying nominal power rating was decreasing annually while the demand is significantly increasing. Same through with the other power mix as shown in Figure 11, 12 and 13 which means that the microgrid needs more reliable power generation scheme to meet the demand in the upcoming years.

5. Conclusion and Recommendation

A. Conclusion

Based on results of the study, the following conclusions are made:

1. Power peak demand of Tablas Island is significantly inclining from 7.19MW to 13.02MW from 2018 to 2030 based on the annual peak demand forecast.

2. The dependable AC capacity of the 7.5MWp solar PV power plant was determined to be:

a. 0.638MW at 50% nominal power rating;

b. 1.160MW at 100% nominal power rating;

c. 1.603MW at 150% nominal power rating;

d. 1.853MW at 200% nominal power rating.

3. The power capacity of the hybrid microgrid was determined to be:

a. 6.80MW at 70% utilization rate of diesel-fired power plant and 50% nominal power rating of solar PV power plant;

b. 7.32MW at 70% utilization rate of diesel-fired power plant and 100% nominal power rating of solar PV power plant;

c. 7.76MW at 70% utilization rate of diesel-fired power plant and 150% nominal power rating of solar PV power plant;

d. 8.01MW at 70% utilization rate of diesel-fired power plant and 200% nominal power rating of solar PV power plant;

e. 7.68MW at 80% utilization rate of diesel-fired power plant and 50% nominal power rating of solar PV power plant;

f. 8.20MW at 80% utilization rate of diesel-fired power plant and 100% nominal power rating of solar PV power plant;

g. 8.64MW at 80% utilization rate of diesel-fired power plant and 150% nominal power rating of solar PV power plant;

h. 8.89MW at 80% utilization rate of diesel-fired power plant and 200% nominal power rating of solar PV power plant.

4. The overall theoretical DC peak power of the solar PV power plant was:

a. 7.46MWp at 0.5% degradation rate and 7.44MWp at 0.8% degradation rate by the year 2020;
b. 7.43MWp at 0.5% degradation rate and 7.38MWp at 0.8% degradation rate by the year 2021;
c. 7.39MWp at 0.5% degradation rate and 7.32MWp at 0.8% degradation rate by the year 2022;
d. 7.35MWp at 0.5% degradation rate and 7.26MWp at 0.8% degradation rate by the year 2023;
e. 7.31MWp at 0.5% degradation rate and 7.20MWp at 0.8% degradation rate by the year 2024;
f. 7.28MWp at 0.5% degradation rate and 7.15MWp at 0.8% degradation rate by the year 2025;
g. 7.24MWp at 0.5% degradation rate and 7.09MWp at 0.8% degradation rate by the year 2026;
h. 7.21MWp at 0.5% degradation rate and 7.03MWp at 0.8% degradation rate by the year 2027;
i. 7.17MWp at 0.5% degradation rate and 6.98MWp at 0.8% degradation rate by the year 2028;
j. 7.13MWp at 0.5% degradation rate and 6.92MWp at 0.8% degradation rate by the year 2029;
k. 7.10MWp at 0.5% degradation rate and 6.87MWp at 0.8% degradation rate by the year 2030.

The power capacity of the hybrid diesel-solar PV microgrid will suffice the power demand of Tablas Island until 2021only based on forecast data considering the attainment of maximum 80% diesel-fired power plant utilization. Forecast data is just an estimate of power demand's varying movement. However, it is important for us to be well informed on the current situation to act ahead of time in order to solve these foreseen problems in the future.

B. Recommendation

There are several methods to augment the power capacity of the hybrid diesel-solar PV microgrid in Tablas Island. One of which is by increasing the utilization rate of the 8.8MW diesel power plant from 90% to 100% resulting to 9.773MW to 10.653MW which will suffice the demand until 2025 only based on forecast data. This will result to a more operational activity of the power generators, reducing its resting pace, and machine life expectancy will be shortened.

Another method is by adding five more 1.1MW generator sets in the microgrid resulting to a total of 13.293MW power capacity of the hybrid diesel-solar PV microgrid able to meet the peak demand of 13.023MW in the year 2030. But it gives huge amount of carbon emission in the atmosphere by 87,158 tons of carbon dioxide and 8.57 million gallons of diesel consumption in 2030.

Another method is by expanding the solar PV power plant by adding 17MWp solar PV expansion. It was almost 2.3 times the size of the existing solar PV power plant. In this rate, the diesel power plant operates at 80% plant utilization with the assumption of 200% nominal power rating dependable capacity of the whole solar PV power plant. When combined, the total AC power generated is 13.09MW able to suffice the peak demand in the year 2030 as projected by the forecast data. The amount of CO2 emission reduction was 40,500 tons and saved 3.98 million gallons of diesel fuel.

In consideration to the power capacity augmentation, it is highly recommended to conduct power capacity optimization for the hybrid power mix in Tablas Island, Romblon. It is for the purpose of finding suitable amount of conventional and renewable energy resources application as power key-players for generation and distribution

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