Presented at the 6th DLSU Innovation and Technology Fair 2018
De La Salle University, Manila, Philippines
November 22 & 23, 2018

Design, Analysis, and Simulation of 3MWp Grid-Tied Solar Photovoltaic System for Tablas Island, Romblon

Junrey Dumaya Garcia[1]
[1] *Graduate Program – Master of Engineering*
[2] *Technological Institute of the Philippines*
junrey2026@gmail.com

Abstract: Design of a 3MWp Grid-Tied Solar Photovoltaic System was created in order to augment the current power supply needs of Tablas Island in Romblon. The technical specifications of the selected equipment and materials were analyzed in compliance to the standards stated in Philippine Electrical Code and simulated using PVsyst photovoltaic simulation software for solar PV applications. The designed PV system could generate 4401MWh of energy every year from an AC generated power of 2.3MW. Voltage drop and short-circuit fault calculations made shown a safe and reliable operation of the PV system. In addition, the PV system would eliminate 3,362.364 tons of CO_2 potential emission in the atmosphere and would save 330,527.292 gallons of diesel consumption per year. Also, the design if made into a hybrid PV-Genset system will reduce the cost of electricity by 6.36% compared to the current generating system alone.

Key Words: Grid-Tied PV System; PVSyst Simulation; CO_2 Avoidance

1. INTRODUCTION

Power consumption is the barometer of any nation's development. Economic and development greatly rely on how much power is used for transportation, communication, facility operation and the like. At present, the country's power requirement is primarily met by burning conventional fossil fuels such as coal, oil and natural gas. Unfortunately, these sources will not meet the increasing demand. In harnessing the energy from these fuels, issues and concerns in environmental protection and preservation arise. Burned coal, oil and natural gas will lead to growing greenhouse gas pollution (Cusick, 2013). The depletion of these fossil fuels comes at an alarming rate. In order to bring down the dependence on these fuels, the Philippine government is looking into the possibility of generating power through more renewable energy sources.

Tablas is the largest of the islands that comprise the province of Romblon. It has a land area equivalent to 839.156 km² for a population of 164, 012 (NSO, 2018). Tablas Island Electric Cooperative (Tielco), a rural electric utility company, manages the Tablas grid that supplies power to the island.

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 generated 4.8 MW against the demand (with 35, 000 households) of 5.9 MW (Cinco, 2015). Power consumption normally rises during the summer season that could not be met by Napocor's power generation capacity. Even after privatization took the role of power generation in the island in 2015, the power contractor Sunwest Water and Electric Co. (SUWECO), still could not cope up with the demand thus rotating brownouts to nine municipalities still occur. These scenarios signicantly affect the lives of the people on the island.

At present, SUWECO's diesel power plant has a dependable capacity of 6.75 MW from an installed capacity of 12.7 MW diesel power source. However, generator sets are operated from 70 to 80% utilization. This is to prevent the fast wearing down of generator sets caused by the continuous operation. Due to this, Tielco and its franchise area suffers from unexpected outages due to the insufficiency of power supply. It also resulted to rotational power supply and outage which affects the operation of government offices, schools, hospitals, and commercial establishments.

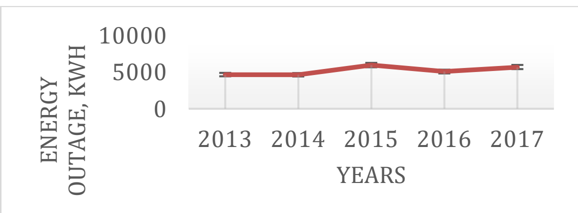

Figure 1: TIELCO's Unscheduled Power Outage 2013-2017
Source: *Tablas Island Electric Cooperative*

Figure 1 shows the unscheduled power outage from the year 2013 to 2017. The year 2015 had the highest power outage record as shown in the graph. This was during the transition of power generation from Napocor to SUWECO due to privatization. The power outage was lessened in the next years but in the year 2017, power outage reemerged. This shows that even privatization took the role in the generation of electricity; power outage could not be avoided.

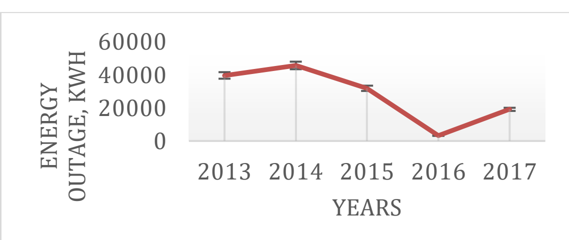

Figure 2: Power Generation Outage 2013-2017
Source: *Tablas Island Electric Cooperative*

Figure 2 shows the power generation outage from the year 2013 to 2017. The year 2014 had the highest record of outage under Napocor's generation of electricity. After privatization, the outage was lessened until the year 2016. However, in the year 2017, the power outage reemerged and reached a mean loss of 19, 051.063 kWh. Maintenance shutdown and repair was the reason of outage due to machine wore out caused by continous operation of the power plant.

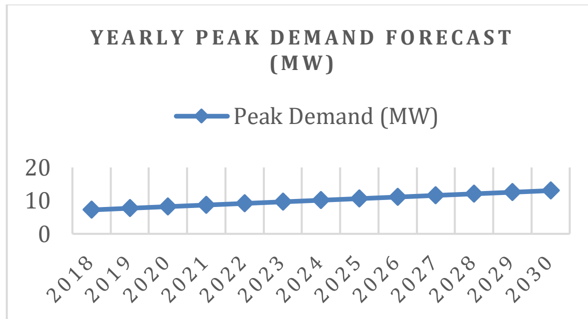

Figure 3: TIELCO's Yearly Peak Demand Forecast 2018-2030
Source: *Tablas Island Electric Cooperative*

As Romblon pushes its way towards commercial and industrial development, the demand for power industry also increases. Figure 3 is the graph of yearly peak demand forecast from the year 2018 to 2030. It shows that there is a steady rise in demand on the roadmap towards the year 2030. Significantly, this also shows that there is already a power insufficiency in the year 2018 that is significantly rising towards the year 2030.

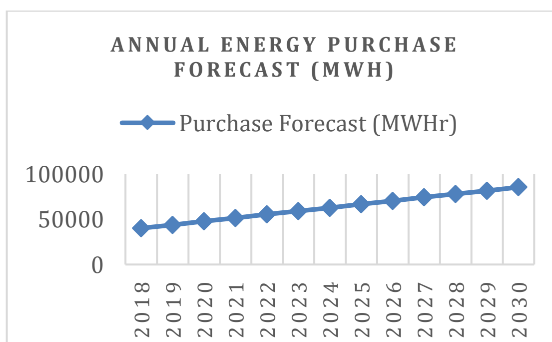

Figure 4: TIELCO's Annual Energy Purchase Forecast 2018-2030
Source: *Tablas Island Electric Cooperative*

The roadmap towards the year 2030 for the required annual energy supply is also significantly rising. In the forecast, the year 2018 will need

40,243.16 MWh of energy that will be doubled by the year 2030. This expected higher demand of power in the coming years will necessitate much reliable power supply. The province is looking for sufficient and reliable power supply and may tap the island's renewable energy resources. Solar is far most economically feasible power among other renewables in the island. Solar power is hereby selected because there is already available data unlike other resources like wind, there is a need to conduct years of study before using this wind resource or not. With solar power, only the irradiance in the location of the proposed PV plant is needed before the project can be proposed concerning design and cost.

The Tablas Island can take advantage of its abundant sunlight. The average solar radiation ranges from 128 – 203 W/m^2 depending upon the sunlight duration, which is equivalent to 4.5 – 5.5 kWh/m^2/day (Fajardo, et al. 2014). The northern part of the country has enough sunlight to generate an average of 4.5-5 kWh per square meter per day and that is where Tablas Island, Romblon lies geographically.

Diesel fuel combustion is the main power generation in Tablas Island. According to Anayochukwu et. al, burning diesel fuel in power generation means serious impacts to the environment with direct health concerns for human. It releases harmful substances including directly emitted organic and elemental carbons, toxic metals, carbon monoxide, carbon dioxide and variety of toxic gases such as formaldehyde, acrolein, and polycyclic aromatic hydrocarbons (Anayochukwu et. al, 2013). According to US Energy Information Administration, the amount of CO_2 production is a function of carbon content on the fuel. Diesel fuel can emit 161.3 pounds (lbs) of CO_2 per million British Thermal units (Btu) of energy when burned and a total of 22.38 pounds (lbs) of CO_2 can be emitted in one gallon of diesel fuel. For PV system, there can be CO_2 avoidance factor of 0.764 kg per kilowatt-hour of PV plant operation. It can be calculated as follows:

$$Annual\ Avoidance\ of\ CO_2 = Annual\ Energy\ Output\ (kWh) * 0.764\ kg/kWh$$

To augment the current power supply needs of the island without much effect to the environment, a design of 3MWp solar PV system was made and analyzed using the standards stated in the Philippine Electrical Code. It uses PVsyst photovoltaic simulation software to be able to determine the solar potential of the proposed PV plant based on its geographical location considering the parameters involved in the area. It also aimed to calculate the CO_2 emission avoidance in the atmosphere upon establishment of the PV facility.

2. METHODOLOGY

Data gathering, preliminary assessment of the location, pre-design and simulation of PV system, design of the PV power system, and the conduct of technical & financial analysis of the system, were the steps made in conducting this study.

2.1 Gathering of Data

Power records for Tablas's grid were collected. The current grid capacity that was based on the amount of power generated by the power plant facility was noted. Data gathered also included maintenance, machine count and utilization rate of each, which was conducted during plant visitations and plant personnel interviews. Power outage data on both power plant and distribution facility were also gathered. The record covered the monthly outage rate for the year 2013-2017. Another data collected was the power demand of Tablas's grid. Knowing all these data, the total power performance of the grid was made for the next stage. Moreover, data on the proposed plant location, land area and terrain was determined to determine the PV capacity for installation.

2.2 Preliminary Assessment

Gathered data were then evaluated. A forecast of the power demand and power purchase towards the year 2030 was made. By evaluating the current grid capacity with the forecast document and the record of the power outage, information on how much power supply on the grid for the coming years was computed.

2.3 Pre-design & Simulation of the System

Selection of the PV module and inverter took place with respect to its specification. An equation was used to calculate the amount of AC power for distribution relating to the desired DC installed capacity and the inverter's performance factor. It was called inverter-loading ratio (ILR) and was calculated as:

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

This stage also included conceptual design elements of the equipment and devices with its specification. It was simulated using PVsyst photovoltaic software where a complete estimation of solar power production, system sizing, hourly estimation, and report generation was provided.

2.4 Design of PV Power System

The basis of the design for capacity sizing of the PV plant greatly rely on the inverter-loading ratio of the 60kW inverter. It can be calculated as follows:

$$DC\ Input\ per\ Inverter(Wp) = Inverter\ Output(W_{AC}) * ILR$$

$$No. of\ Modules\ per\ Inv. = \frac{DC\ Input\ (Wp)}{Module\ Power\ Rating\ (W)}$$

$$No. of\ String\ per\ Inverter = \frac{No. of\ Modules\ per\ Inv.}{No. of\ Modules\ per\ String}$$

The total number of PV module per string is 20 connected in series that will have an output voltage of 918V, which is below the maximum DC system voltage requirement of inverter of 1000V.

$$Overall\ No. of\ Modules = No. of\ Modules\ per\ Inverter * No. of\ Inverter\ per\ Block * No. of\ Block$$

$$Inverter\ Output = \frac{No. of\ Modules\ per\ Inv. * Module\ Power\ Rating}{ILR}$$

The actual value of inverter output will be 60kW maximum because the ILR varies from 1.25 to 1.4. 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.

$$Total\ Power\ Output\ per\ Block = Inverter\ Output * No. of\ Inverter\ per\ Block$$

$$Total\ Power\ of\ the\ Plant = Total\ Power\ Output\ per\ Block * 3$$

A block is a combination of array of modules which constitutes a power collection station.

According to Naksrisuk and Audomvongseree (2013), the dependable capacity for solar plant at 100% nominal power is 20.11% of its installed capacity. However, higher level of nominal output rating can lead to higher dependable capacity.

Table 1: Dependable Capacity Rating

Level of nominal output rating	Dependable capacity (%)
50%	11.0516
100%	20.1066
150%	27.7874
200%	32.1102

Because the energy penetration for solar PV is variable, the dependable electrical supply will only range from 50% to 200% nominal output rating.

Based on the simulation results, a complete electrical system design for PV facility was created using AutoCAD v.2013. It included the sketch of the solar array layout, single-line diagram, schedule of loads, cable schedule, grounding layout, the location of the project, design specifications, legends & symbols, and electrical notes & specifications.

2.5 Technical & Financial Analysis

Technical analysis included the electrical design analysis of the system as per compliance to technical standards stated in the Philippine Electrical Code. It involved voltage drop (VD) calculation for power flow efficiency on pressed emf through conductors. MSExcel spreadsheet was used to calculate the voltage drop of the branch circuits. It may be calculated as follows:

Presented at the 6th DLSU Innovation and Technology Fair 2018
De La Salle University, Manila, Philippines
November 22 & 23, 2018

Voltage drop at single phase:

$$VD = 2ILR$$

Voltage drop from the three-phase AC inverter side to Low-side of transformer:

$$VD = \sqrt{3} * I * \frac{L}{305} * (R\cos\theta + X\sin\theta)$$

Voltage drop from the three-phase high voltage side of transformer to MVSG feeder:

$$VD = \sqrt{3} * I * L * (R\cos\theta + X\sin\theta)$$

Another requirement for technical analysis was the short-circuit fault calculation that used MVA method of calculation needed for protection sizing on branch circuits. The financial analysis involved estimated investment cost, return on investments and annual energy sale revenue, which can be calculated as follows:

$$Estimated\ Investment = Project\ Cost + Fixed\ O\&M\ Cost$$

$$Annual\ Energy\ Sale\ Revenue = Annual\ Energy\ Sale - Fixed\ O\&M\ Cost$$

$$Annual\ Energy\ Sale = Annual\ Generated\ Energy * peso\ per\ kilowatthour$$

$$Return\ of\ Investment = \frac{Estimated\ Investment}{Annual\ Energy\ Sale}$$

3. RESULTS AND DISCUSSION

3.1 PV System Design

There will be 9,240 units of 325W modules to be used in this PV plant. PV modules were interconnected to form a string, in order to increase the voltage of the DC system for the selected inverter. This created a maximum system DC voltage of 918 Volts, which was below the maximum DC system voltage of 1000V input to the selected inverter. Each of the strings was then wired in parallel through combiner boxes to feed an inverter. There will be 462 strings to be used in this PV plant with 20 modules per string. A block is a group of arrays associated with a given set of inverters with the capacity to generate 1MWp of DC power. The system uses an inverter-loading ratio of 1.3 and array performance ratio of 0.79, that for every block, the AC output power will be 780kW. Therefore, the AC output power will be 2.3MW from a total of 3.0MW peak DC capacity of the plant. There were 39 units of 60kW inverters, which constituted 13 inverters per block. The inverters per block were constituted in one power collection station. This plant will have three-power collection stations.

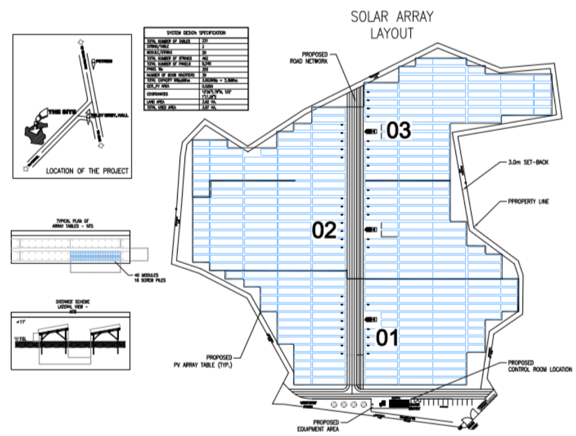

Figure 5: Preview of the Electrical Design for the PV System

In order to meet the system size and performance of the proposed project, the GCR was 0.76. The PV modules as designed will be installed using steel components and pile-driven foundations. These mounting structures can withstand wind speeds of up to 250kph, far above the wind zone of 200kph categorization of the area. Additionally, these structures are galvanized up to 85 microns on the post and 100 microns (versus the 55-micron industry standard) on the pile to prevent corrosion over 25 years.

The PV installation will be split into tables. Each table will have 40 PV modules installed vertically, split into two rows of 20 PV modules each. The PV modules will be installed facing south, with a tilt of 11° and an azimuth of 21° East. This tilt was determined to be the optimum angle for maximum energy production based on the PV system simulation software PVsyst. The east-west distance between tables will be 0.4 meters. The north-south distance between tables will be 2 meters. These distances were measured from the edges of the PV modules. The tables will have a ground clearance of 0.6 meters.

The system has a Ring Main Unit (RMU) that used ring layout configuration for feeders with transformers stepping up power from 480V to 13.2 kV. Among other configuration, the ring has the highest reliability among others that if one feeder circuit has malfunctioned; the system can still be operational while the said problematic circuit is being fixed. Reliability is the advantage of this configuration.

3.2 PVsyst Simulation

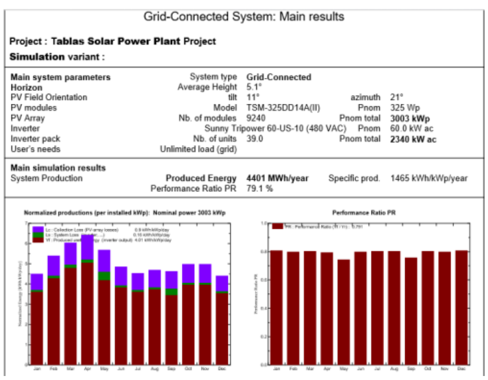

Figure 6: Preview of the PVsyst Simulation Results

Based on PVSyst simulation, the horizon profile in Tablas Island, Romblon had the maximum irradiance for collection at plane tilt and azimuth of 11 and 21 degrees respectively. The PV module used is Trina Solar TSM-325DD14A(II) which had 325 Watt nominal power. The PV array consisted 9240 modules and able to produce a nominal power of 3003 kW. The inverter model to be used is Sunny Tripower 60-US-10 (480 VAC) which was rated 60kW AC capacity. The total AC output will be 2340 kW from 39 inverters for installation. The annual energy production of PV system in Tablas Island, Romblon will be 4401 MWh/year. The annual production of the PV plant had a probability curve of P50 for 4401 MWHr. Meaning the system will be using a very conservative 50% generation of energy. We use P50 as a conservative value for financial analysis purposes.

3.3 Technical Analysis

3.3.1 Voltage Drop Calculation

Voltage drop shall not exceed 5% as required by Philippine Electrical Code 2009 Article 2.10.2.1 FPN No.4 and Article 2.15.1.2 FPN No. 2 for feeder and branch circuit respectively. As stated,

"Conductors for feeder and branch circuit as defined by Article 1.0 shall be sized to prevent a voltage drop exceeding 3% at the farthest outlet of power, heating and lighting loads, or combinations of such loads, and where the maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5%. This is to provide reasonable efficiency of the operation".

For PV String to Combiner Box of DC electrical input, the size of wire used was copper solar cable of 6.0 mm^2 diameter. It carried a safe load current of 9.25 amperes. The branch circuit of the furthest conductor of 100 meters had a voltage drop of 6.272 volts, which was 0.683% drop from the sending voltage of 918 volts.

For Combiner Box to DC Side of Power Inverter of DC electrical input, the size of wire used was copper XLPE cable of 70-mm2 diameter. It carried a safe load current of 111 amperes. The branch circuit of the furthest conductor of 160 meters had a voltage drop of 9.519 volts, which was 1.037% drop from the sending voltage of 918 volts.

For the AC Side of Power Inverter to Solar Switchboard of AC electrical output, the size of wire used was copper THHN/TWHN cable of 38-mm^2 diameter. It carried a safe load current of 72.17 amperes. The branch circuit of the furthest conductor of 60 meters had a voltage drop of 4.1 volts, which was 0.854% drop from the sending voltage of 480 volts.

For Solar Switchboard to Secondary Side of 1000kVA Transformer of AC electrical output, the size of wire used was copper THHN/TWHN cable of 250-mm^2 diameter. It carried a safe load current of 1202.85 amperes. The branch circuit conductor of 5 meters had a voltage drop of 1.2 volts, which was 0.254% drop from the sending voltage of 480 volts.

For the Primary Side of 1000kVA Transformer to Ring Main Unit of AC electrical output, the size of wire used was XLPE aluminum cable of 25-mm^2 diameter. It carried a safe load current of 43.74 amperes. The branch circuit conductor of 5 meters had a voltage drop of 0.2 volts, which was 0.002% drop from the sending voltage of 13200 volts.

For Power Collection Station 1-2 and 2-3, the size of wire used was XLPE aluminum cable of 70-mm^2 diameter. It carried a safe load current of 87.48 amperes. The branch circuit conductor of 60 meters had a voltage drop of 3.3 volts, which was 0.025% drop from the sending voltage of 13200 volts.

For Power Collection Station to Medium Voltage Feeder Line, the size of wire used was XLPE aluminum cable of 100-mm^2 diameter. It carried a safe load current of 131.22 amperes. The branch circuit conductor of 180 meters had a voltage drop of 10 volts, which was 0.076% drop from the sending voltage of 13200 volts.

By analysis, the voltage drop for each branch circuit from PV String to Medium Voltage Feeder Line is acceptable. It conformed to the standards stated by the Philippine Electrical Code for efficient voltage supply.

3.3.2 Short-circuit Fault Calculation

All electrical systems were susceptible to short circuits and an abnormal level of current that may arise. These currents can produce considerable thermal and mechanical stresses in electrical distribution equipment. Therefore, it was important to protect personnel and equipment by calculating short-circuit currents in the design. Fault calculations were life safety related, as mandated by the Philippine Electrical Code, which states:

"Equipment intended to interrupt current at fault levels shall have an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment. Equipment intended to interrupt current at other than fault levels shall have an interrupting rating at nominal circuit voltage sufficient for the current that must be interrupted."

Fault analysis was required to calculate and compare symmetrical and asymmetrical current values in order to select a protective device for protection of electrical distribution equipment. The method used in the analysis was the MVA method. With this method, the analysis of the system circuitry used an admittance diagram. Fault current occurrences were located at three AC buses. Fault 1 will occur in 13.8kV MVSG Bus with short circuit current of 2335A and can have an interrupting capacity rating of 7500 kAIC. Fault 2 will occur in 13.8kV RMU Bus with short circuit current of 2335A and can have an interrupting capacity of 7500 kAIC. Fault 3 will occur in 480V Switchboard Bus with short circuit current of 16684A and can have an interrupting capacity of 18000 kAIC.

3.4 Equipment Grounding

The importance of grounding the electrical currents in the PV system is to protect the equipment from electrical surges. Power surge is the sudden rise of dangerous high voltage that may occur in case lightning strikes the system or in some cases, power surge might happen at certain points of the branch circuits. Sizing the conductor was necessary, based on the type of conductor selected for use. It can be copper, aluminum or copper-clad aluminum equipment grounding conductors. It shall not be smaller than what was required in Table 2.50.6.13 but in no case shall be permitted to be larger than the circuit conductors supplying the equipment.

Table 2: Equipment Grounding Sizing

Table 2.50.6.13 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size mm^2 (mm dia.)	
	Copper	Copper Aluminum or Copper-Clad Aluminum*
15	2.0(1.6)	3.5(2.0)
20	3.5(2.0)	5.5(2.6)
30	5.5(2.6)	8.0(3.2)
40	5.5(2.6)	8.0(3.2)
60	5.5(2.6)	8.0(3.2)
100	8.0(3.2)	14
200	14	22
300	22	30
400	30	38
500	30	50
600	38	60
800	50	80
1000	60	100
1200	80	125
1600	100	175
2000	125	200
2500	175	325
3000	200	325
4000	250	800
5000	700	1200
6000	800	1200

From PV array to combiner box circuitry that had 15A over-current protective device connected, the size of the equipment-grounding conductor for copper was 2.0 mm^2. From combiner box to DC side of the inverter that had 200A over-current protective device connected, the size of the equipment-grounding conductor for copper was 14.0mm^2. From the AC side of the inverter to solar switchboard that had 100A over-current protective device connected, the size of the equipment-grounding conductor for copper was 8.0mm^2. From solar switchboard to transformer that had 1600A over-current protective device connected at the secondary side of the transformer, the size of the equipment-grounding conductor for copper was 100mm^2. The grounding electrode conductor size for the ground ring, encircling the building or the power collection station (PCS) that was directly in contact with the earth, consisting of at least 6000 mm of bare copper conductor not smaller than 30 mm^2. The bonding conductor from the ground ring to PCS shall also have 30 mm^2 in size.

3.5 Financial Analysis

Financing a solar PV system depends heavily on the available solar energy resource. The solar radiation, atmospheric conditions such as air temperature, humidity, atmospheric pressure, and wind speed, all determine the timing, duration, and amount of energy that a PV system may generate during the course of its operation.

Based on the budgetary cost, the overall EPC (Engineering, Procurement and Construction) cost was around P162M. Assuming a minimum price of power considered in Power Purchase Agreements (PPAs) in a solar power is Php 5.5 / kWh, the annual energy sale will be Php 24, 205, 500 and the return of investment will be around 7 years. The annual energy sale revenue was computed at Php 21, 780, 250, less 10% for the O&M cost. This shows that this project was found financially viable. The LCOE (Levelized Cost of Electricity) for the proposed hybrid PV-Genset system using an 8-1100kVA/880kW generator sets and 3MWp PV system is 14.31 pesos per kilowatt-hour while the LCOE for the 8-1100kVA/880kW alone is 15.282 pesos per kilowatt-hour. This means that there is a 6.36% reduction of the cost of electricity using the hybrid PV-Genset system.

3.6 CO_2 Reduction

Based on the PVSyst simulation result, the potential energy production for the PV plant is 4401 MWh/year. The carbon dioxide avoidance factor for a diesel power plant is 0.764 kg of CO_2 per kilowatt-hour. Therefore, upon installation of the facility, it will have a total of 3,362,364 kg or 3,362.364 tons of CO_2 avoidance per year. It will also save 330,527.292 gallons of diesel consumption per year. This is a huge incentive to lessen greenhouse gas emission where carbon dioxide plays the most in volume.

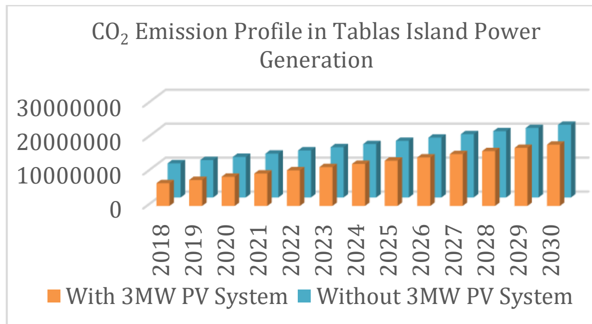

Figure 7: CO_2 Emission Profile in Tablas Island Power Generation With & Without the 3MW PV System

Figure 7 shows that there will be a significant reduction of CO_2 emission in power generation towards the year 2030 upon installation of the 3MWp PV system. Energy demand will peak from 40,234.16 MWh in 2018 to 85,604.83 MWh in 2030. Annually, the potential CO_2 emission will be reduced because the PV system will utilize clean and renewable energy from the sun's solar energy.

4. CONCLUSIONS

Provided by the forecast data, the amount of energy demand towards the year 2030 will significantly rise. The current plant capacity only generates 70 to 80 percent. The 8.8MW dependable capacity drops down to 6.75MW power supply. Thus, the need for more power supply was necessary to consider.

Based on design simulation data generated by the PVSyst software, the best tilt angle and azimuth for the selected PV plant location were 11° and 21°

respectively. Using the 325W TSM-325DD14A(II) Trina Solar monocrystalline panel and 60kW SMA inverter for the design, the amount of energy collection was estimated at 4401MWh per year. The installed capacity was 3003kW DC power and the effective AC power for transmission was 2340kW at a performance ratio of 79.1%. The design conformed to the technical standards stated in the Philippine Electrical Code for protection and cable sizing. The design followed the ring configuration of distribution systems for its efficient and reliable function throughout its operation.

The PVSyst utilized Meteonorm weather data, collated from 8,325 weather stations and five geostationary satellites, for information on global irradiation and temperature data, measured hourly over 20 years. PVSyst simulated production of the system based on this data, and the design of the specific system (module and inverter brands, system losses, orientation and tilt). The energy generation simulation using the PVSyst indicated that 4401 MWh will be produced in the first twelve (12) months of operations for 3MWp solar plant. For this system, PVSyst forecasted over 1465 kWh/kWp per year production. Energy yield was a critical parameter that determines the financial viability of the project. Probability-based energy yield (for example P50 in PVSyst) were modelled over the operating life of the project.

With the power purchase agreement for PV generated power pegged at 5.5 pesos per kWh, the annual energy sale will be 24,205,500 pesos. Ten percent will be deducted for operations and maintenance cost, resulting in annual energy sale revenue of 21,780,250 pesos. The overall project cost was estimated at 162,895,376.34 million pesos including the fixed O&M cost for seven years. The return of investment may be met in the 7th year of operation. This showed that the PV project was financially viable. There will be 6.36% reduction on the cost of electricity, which may provide social impact among the consumers on the island. With this design of PV system, dependable power supply will range from 7.082MW to 7.713MW, which can be utilized in Tablas Island during the daytime using the hybrid power mix. Maintenance shutdown and repair of generators will be lessened because utilization is reduced during daytime. With a reliable and relatively cheaper power source, a positive impact on the lives of the people of Tablas will be realized leading to a better quality of life.

5. ACKNOWLEDGMENTS

I would like extend my deepest thanks and gratitude to Technological Institute of the Philippines, most especially to the dean of the graduate program, Dr. Ruji P. Medina for his valuable support towards the improvement of my study. To my adviser, Engr. Ryan Jayson Bragais, for his unceasing guidance from the start until the end of this study. To Engr. Cristian Mutya and Engr. Bon Bandoquillo of Solar Philippines, for sharing their expertise in the field of PV technology. To Dr. Bilshan F. Servanez of Romblon State University for his valuable support towards the improvement of my study. To my wife and children, for inspiring me everyday, and most especially to Our Almighty God, for His divine guidance and enlightment.

6. REFERENCES

Anayochukwu, A.V., Nnene, E.A. (April, 2013). Measuring the Environmental Impact of Power Generation at GSM Base Station Sites. Retrieved from Electronic Journal of Energy & Environment.

Bajpai, P., Dash, V., Kishore, N.K. (December 2010). Bi-annual Sun Tracking for Solar PV Module Support Structure: Study and Implementation. Retrieved from www.ieee.org

Bhattacharya, Indranil (2015). A detailed study of 7 unique solar PV design and simulation software(s). Retrieved from https://www.linkedin.com/pulse/7-most-popular-solar-pv-design-simulation-software-eslam-allam.

Cinco, M. (2015, June 12). Romblon Power Woe Won't Spare Even Hospitals. Inquirer.net. Retrieved from http://newsinfo.inquirer.net/697851

Cusick, D.(2013, October 25). Scientific American. Fossil Fuel Use Continue to Rise. Retrieved from https://www.scientificamerican.com/article/fossil-fuel-use-continues-to-rise

Fajardo, J. E., Ruales M., Wilhelm B., Meller H., Larona F., Kuvarakul T., Schweinfurth A., (2014, October) Renewable Energy Guideline on Large Solar Photovoltaic Project Development in the Philippines. 1st Edition. Retrieved from https://www.international-climate-initiative.com

Ineichen, P. (February 2011). Global Irradiance on Tilted and Oriented Planes: Model Validations. Retrieved from www.pvsyst.com

Jordan,D. C., Kurtz, S. R. (June 2012). Photovoltaic Degradation Rates – An Analytical Review. Retrieved from www.nrel.gov

Joyce, K. (2012). Optimizing PV Plant Design to Achieve a Low Levelized Cost of Energy. Black & Veatch

Karateppe, et. al. (2007). Development of a Suitable Model for Characterizing Photovoltaic Arrays with Shaded Solar Cells. Solar Energy 81, 977-992.

Lejeune, T.; Mermoud, A. (September 2010). Partial Shadings on PV Arrays: By-Pass Diode Benefits Analysis. Retrieved from www.pvsyst.com

Lejeune, T.; Mermoud, A. (September 2010). Performance Assessment of a Simulation Model for PV Modules of Any Available Technology. Retrieved from www.pvsyst.com

Makarova, A. (November 2017). Study, Design and Performance Analysis of a Grid-Connected Photovoltaic System. Case Study: 5MW Grid Connected PV System in Namibia. Retrieved from www.elsevier.com

Mermoud, A. (September 2012). Optimization of Row-Arrangement in PV Systems, Shading Loss Evaluations According to Mobile Positioning and Connexions. Retrieved from www.pvsyst.com

Naksrisuk, C.; Audomvongseree, K. (August 2013). Dependable Capacity Evaluation of Wind Power and Solar Power Generation Systems. ECTI Transactions on Electrical Engineering, Electronics and Communications, vol.11, pp. 64-65.

Spertino, el. Al. (2009). Optimal Configuration of Module Connections for Minimizing the shading effect in multi-row PV Arrays. 24th EPVSEC, Hamburg.

Sklenarova V., Medved, D., Kvakovsky, M. (2010, May). Electricity From The Sun Photovoltaic Electricity. Retrieved from home.zcu.cz/~tesarova/IP/Proceedings/Proc_2010/.../010%20IP2010_Sklenarova.pdf

Wies, R.W.; Johnson, R.A.; Agrawal, A.N. and Chubb, T.J. (2005). Simulink model for economic analysis and environmental impacts of a PV with diesel – battery system for remote villages. IEEE Trans Power Systems.vol.20. no.2, 629-700.

Wittmer, B.; Mermoud, A. (September 2014). A Tool to Optimize the Layout of Ground-Based PV Installations Taking Into Account the Economic Boundary Conditions. Retrieved from www.pvsyst.com

Wittmer, B.; Mermoud, A.; Schott, T. (September 2015). Analysis of PV Grid Installations Performance, Comparing Measured Data to Simulation Results to Identify Problems in Operation and Monitoring. Retrieved from www.pvsyst.com