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Simulated Energy Production and Performance Ratio of 5 MW Grid-Connected Photovoltaic under Tropical Savannah Climate in Kupang Timor Island of Indonesia

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Abstract

The objective of this paper is to obtain energy output and performance ratio of 5 MW grid-connected PV plant. The plant is located near the city of Kupang in the southeast of Indonesia. The location belongs to dry tropical climate with 28^{o}C average daily temperature and 67% and 87% average sunshine index during the rainy and hot season respectively. Daily solar irradiation varies from 5.52 to 6.38 kWh/m^2. The plant uses 21,840 poly-crystalline 230 W modules configured as 1,040 array strings, and each array consists of 21 series-connected modules. The array is ground-mounted, fixed-tilted at 15^{o} and facing north. Maximum output is 5,023.2 kW. Conversion to AC is done by 250-unit inverter of 20 kW. Grid connection is via 10-unit of 630 KVA transformers. PVSyst simulation is fed with synthetic meteorological data which yielded annual energy of 7,476 MWh that varies monthly from 526 to 770 MWh, with an average of 623 MWh. Average annual yields are 4.08 kWh/kWp/day. Variation of tilt angles from 10^{o} to 20^{o} has small effects on energy output. Monthly performance ratio varies from 80% to 86% and average at 82%. Low-performance ratio is shown during May to August period which is likely caused by the high ambient temperature that affects the output of the solar module. PV loss due to temperature is the highest losses component at 11.2%.

Keywords: grid-connected photovoltaic, tropical climate, energy production, performance ratio, IEC 61724

1. Introduction

Timor Island is one among 6,000 inhabited islands that part of 13,466 islands belong to Indonesian archipelago as listed in the United Nations on Standardization of Geographical Names. It has a total land area of 30,777 square kilometers but around half of it in the eastern part is the territory of the Republic of Timor-Leste. The west of the island is part of East Nusa Tenggara, one of Indonesia's provincial administrative area. In 2014, the total population of West Timor was 1,620,017 and 437,529 households. By the end of 2015, electrification ratio was 59%. Meanwhile, total electrical power generation capacity of the island is currently around 70 MW, which consists of 80% diesel power plant, 13% steam power plant, and 7% renewable generation [1].

The government of Indonesia plans to complete electrification of the whole country, including West Timor, by 2020 as stated in the National Energy Policy (NEP) released in 2014. According to the NEP, PV plant is set to contribute around 870 MW power by 2025. Currently, most of Indonesia's PV plants is government-led projects and little contribution from the other

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energy stakeholders. This condition is one of the reasons why the progress in national photovoltaic capacity is rather slow, and currently, the figure is still below the target. The central government introduced a policy to attract wider participation by releasing a new feed-in-tariff (FIT) for grid-connected PV system in 2013. The new feed-in tariff could reach as high as US 30 cent per kWh but subject to terms and conditions. One of the condition states that plant components shall be at least 40% domestically manufactured. In Indonesia, the grid is owned by *Perusahaan Listrik Negara* (PLN), a state-owned electricity company which generates most of the 51 GW national power capacity and responsible for its distribution throughout the country. By government regulation, the company has to buy energy injected by any distributed generation connected to its network including the 5 MW Kupang PV plant.

The year 2013 is an important period for photovoltaic development in Indonesia due to the release of new photovoltaic-based FIT and completion of three 1 MW grid-connected photovoltaic plants. Two of the demonstration projects are located in Bali and another in Sumbawa Island. The central government funded the development of these pilot projects and granted the plants to district governments after completion of testing and commissioning period. The district governments then set up local government enterprises to manage the plant including to sell the energy to the utility. These three pilot projects among others had generated interests within the private sector to participate in renewable energy development projects which led to the development of the 5 MW Kupang PV plant which currently is the largest grid-connected PV plant in Indonesia. *Lembaga Elektronika Nasional* (LEN) Indonesia is a state-owned semiconductor company, and also a PV system developer who proposed the development of the power plant in Oelpuah sub-district, near the city of Kupang on Timor Island. After awarded contract by Ministry of Energy and Mineral Resources, the company signed Power Purchasing Agreement (PPA) with local power distribution company PLN East Nusa Tenggara Area in January 2015. According to LEN, the power plant has utilized more than 69% domestically manufactured components [2] hence met government requirement to receive the new FIT. PLN and LEN signed the PPA with energy tariff at US 0.25 dollar per kWh and last for 20 years [3]. The project construction which covers civil, mechanical and electrical works commenced in March 2015 and took ten months to complete [3]. The plant was energized on December 2015 and was inaugurated by President of Indonesia Mr. Joko Widodo. This project is an important milestone for Indonesia due to some reasons. Firstly, this power plant is currently the largest grid-connected PV plant in the country and built using a high content of domestically manufactured components. Secondly, the power plant is a private-sector -funded project with a total investment of USD 11.5 million [4] partly financed by one of Indonesian national bank [2]. In this regard, stakeholders is watching closely the experience drawn from this project including how the plant performs and meets economic aspect of the project. Many believe this project could become the future model of large-scale PV development in Indonesia on system specifications, project funding as well plants operation and management. Consequently, its success and challenges are of interest both domestic energy stakeholders as well as the international party given abundant sun energy potential of the country and currently only around 10% realization of 870 MW solar generation target by 2025.

This paper discusses energy production of the 5 MW Kupang grid-connected PV plant including its performance ratio. It starts with a brief background of the Kupang PV project and followed by the main part which consists of three sections; review on the technical specification of the plant, environmental profile of location, and simulation results on energy output and performance ratio of the plant. The simulation is carried out using PVsyst, which computes performance ratio based on IEC 61724. The simulation provides useful information regarding energy production and performance of the power plant. Also, the simulation result is compared with plant's projected energy production.

2. Research Methodology

The results presented here are obtained through site observation, secondary data, and computer simulation. Site measurement and observation are conducted to collect data such as latitude, longitude, azimuth, array tilt-angle, array configuration, surrounding area of the plant, the existence of structures or objects that cause shading, and other site-specific data. Secondary data includes measurement of plant's parameters during commissioning, technical specifications of plant components, historical meteo data, data from East Nusa Tenggara Central Bureau of Statistics and Agency for Meteorology, Geophysics, and Climatology. Local environmental data is presented to show characteristics of the location on sun energy availability. Summary of the technical specification of the power plant is presented to show electrical parameters and environmental operating ranges of the major components to assess their suitability with local environmental conditions. Simulation is carried out using PVSyst to calculate annual energy production and performance ratio of the plant according to IEC 61724 but with no factor for site-shading.

3. Technical Specification of 5 MW Kupang PV Plant

3.1. Technical Specification of Components

A large grid-connected PV plant normally consists of the array, inverter, and step up transformer. The 5 MW Kupang PV plant does not employ energy storage device. Its output is directly injected into utility medium voltage network. A monitoring system is in place to capture both plants' electrical parameters and environmental data. Fig. 1 shows the schematic of the plant.

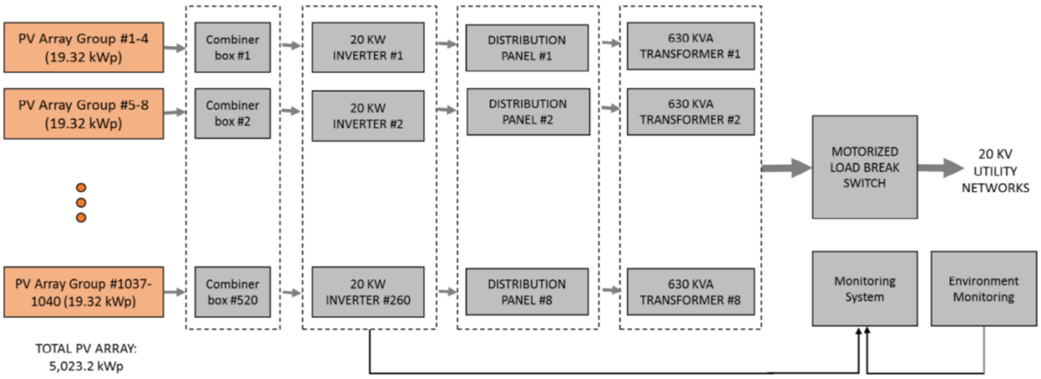
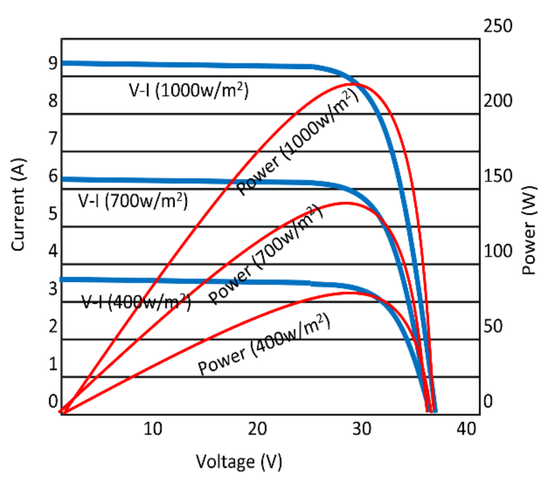


Fig. 1 Schematic of 5 MW Kupang PV plant

Table 1 Technical specification of photovoltaic module

Electrical Characteristics		Mechanical Characteristics	
Opt. operating voltage (Vmp)	29.3 V	Solar Cell	Poly-crystalline
Opt. operating current (Imp)	7.86 A	No of Cells	60 (6 x 10)
Open circuit voltage (Voc)	37.4 V	Dimensions	1650 x 990 x 50 mm
Short circuit current (Isc)	8.31 A	Weight	21 Kg
Max. Power at STC (Pmax)	230 W	Junction box	IP65
Module efficiency	14%	Operating temp	-40°C to +85°C
Temp. Coeff. of power	-0.44 %/°C	Front glass	3.2 mm tempered glass
Power tolerance	+0 - 3%	Frame	Anodized aluminum alloy

I-V and P-V Curve at 25°C



PV arrays are constructed from 21,840 poly-crystalline modules of 230 W. Each module is constructed using 60 units of photovoltaic cells. The modules are configured as 1,040 array strings. Each array is made from 21 series-connected module to generate DC voltage in the range of 320 – 820 volts to match inverter's input operating voltage. The array is ground-mounted and supported by galvanized steel structure. The mechanical frame is fixed and tilted at 15° from horizontal and at an azimuth angle of 0°. Each module has a surface area of 1.63 square meter which gives total generator capture area of 36,164 m^2. The PV module has passed certification from Indonesian National Standard (SNI), SNI# 04-3850.2-1995 on voltage and current characteristics and SNI# 04-6298-2000 on corrosion tests. The module is manufactured by LEN Indonesia which is a state-owned company working in the field of electronics components and systems including solar energy conversion technology. Table 1 shows the summary of technical specification of the PV module [5].

The 5 MW Kupang PV plant uses 250-unit inverters each capable of producing 20 kW maximum power with 98.5% conversion efficiency. Each unit has an inbuilt maximum power point tracking facility. It is capable of operating in active and reactive power supply mode. The voltage output inverter is three-phase voltage system 230/400 volt 50 Hz. On the site, each of the inverters is ground pole-mounted using steel support structure installed under the array at the high side. Table 2 shows the technical specification of the inverter [6].

Table 2 Technical specification of inverter

DC Side: Electrical Characteristics	
Max DC Voltage	1,000 V
Min DC Voltage	188 V
MPP DC Voltage	320 to 800
Max Input Power	20.44 kW
Rated DC Power	20.4 kW
Rated DC Voltage	600 V
Max Input Current	33A (33
Number of strings	A:3/ B:3

AC Side: Electrical Characteristics	
Rated output	20 kW
Max output	20 kVAR
Rated output	29 A
Rated voltage	3/N/PE,230V/400V
AC voltage range	180V to 280V
Rated frequency	50 Hz
Output current	<3% nominal
Max efficiency	98.4%

Mechanical Characteristics	
Enclosure	IP65
Safety Class	I/ AC: III, DC: II
Climate	4K4H
Ambient	-25^{o}C to 60^{o}C
Relative	100%,
Environment.	Outdoors
Max Altitude	3,000 m
Weight	61 kg

The output voltage of the inverter is fed to 10-units 630 KVA step up transformer to increase plant's voltage output to 20 kV suitable for connection to utility distribution network. The transformers are ground mounted supported by concrete pads. A motorized load break switch (LBS) is installed at the endpoint to disconnect the plant from the network. Table 3 shows the technical information of the transformer and type of environmental data measured on the site.

Table 3 Technical information of the transformer and monitoring system

Transformer Electrical	
Nominal KVA Primary	630 kVA
Nominal KVA Secondary	630 kVA
Input Voltage	400 V
Output Voltage	20 kV
Input Current	909.3 A
Output Current	18.2 A

Transformer Mechanical	
Type of Cooling	ONAN
Type of Oil	Mineral Oil
Installation	Indoor/Outdoor
Temperature Rise (^{o}C) - Oil	60 kV
Temperature Rise (^{o}C) - Winding	65 kV
Oil Weight	357 kg

Environmental Monitoring System	
System	Sunny Webox
Module temperature	yes
Ambient temperature	yes
Sun irradiance	yes
Local monitoring	yes
Remote monitoring	yes

From the tables above, it is very clear that PV module and inverter are both suitable to be installed on the location which has high humidity and high ambient temperature all year round. The PV module is domestically manufactured and has carried Indonesian National Standard [5]. Similarly, the inverter has displayed various international certification or compliance such as CE, TUV, IEC, VDE and other standards [6]. In brief, the main components of the power plant are suited for the location which has a high-humidity and high-temperature ambient which are the main characteristic of tropical climate.

3.2. Installation of PV plant

Kupang PV power plant is located at latitude 10.8^o south and longitude 123.44^o east. The coordinate is important in calculating optimum tilt and azimuth angles of the array. The array is mounted on the support structure at fixed tilt angle. There is no provision for changing the tilt angle of the array. Optimum tilt angle depends on location and can be calculated using formula discussed in [7]. Mose [3] reported that the tilt angle of the array is 10^o. On-site measurement found actual tilt angle of close to 15^o. Also, the azimuth angle of the array should be chosen to allow for maximum sun's energy capture. As the plant is located in the south of the equator, then azimuth angle of zero is used, or effectively array faces north. Fig. 2 shows the entire layout of Kupang PV arrays [3]. Fig. 3 shows part of the Kupang PV arrays. The power plant occupies land with total area of 75,000 square meters.

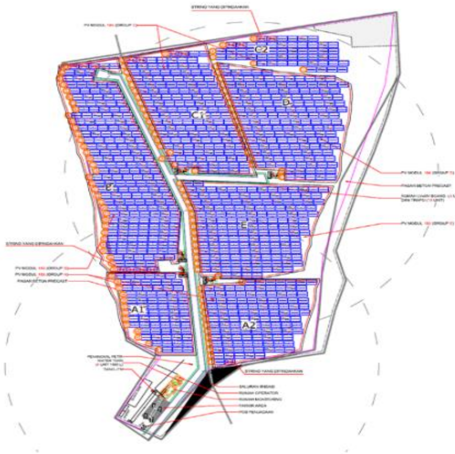


Fig. 2 Array plan layout [3]

Fig. 3 Photo of array Kupang PV plant

Indonesian electricity network is owned by the state-owned electricity company called PLN. The company has a sole right in the transmission, distribution, and sale of electric power to the consumer. However, the generation sector has been opened for others to participate in developing more power stations to cater for continuously increasing demand. Since this new regulation, Independent Power Producers (IPP) have started to develop and operate power stations around the country. The IPP include companies that generate their power from renewable energy sources such as photovoltaic, biomass, hydro, wind and ocean energy device. For the purpose of power distribution and energy sale in the 34 provinces of Indonesia, PLN set up a local company called PLN *Distribusi*. The distribution systems consist of 20 kV medium voltage networks and 220/380 V 50 Hz low voltage networks connected to either single or three phase consumers. The connection of renewable energy plant or distributed generation is made via the 20 kV networks. Guidelines for connection to distribution networks are described in PLN Regulation #0357/2014. The guidelines cover connection for all type of renewable power plants. The photovoltaic injection guidelines cover requirements for inverter, harmonics, unintended islanding operation, short circuits, power factor operation, and other. In general, the guidelines adopt international standards such as IEC 61727-2004, IEC 62116-2008, UL 1741, and also the California Model Electric Rule 21.

4. Geographical Profile of the Plant Location

Fig. 4 Map of Timor Island

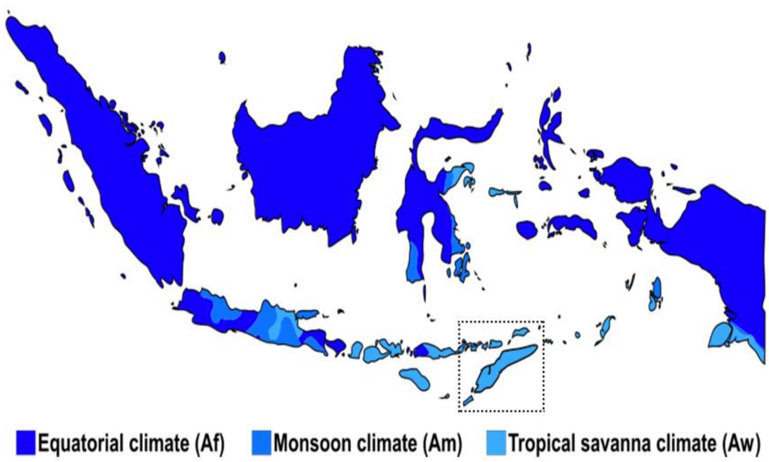


Fig. 5 Indonesian climate class based on Koppen-Geiger [9]

Kupang is the capital city of East Nusa Tenggara province and located in the west part of Timor Island. Fig. 4 shows the map of Timor Island. The climate of Timor Island according to Koppen-Geiger classification is belong tropical savannah climate or designated as Aw-type [8]. Fig. 5 shows the map of Indonesia rendered in Koppen-Geiger classification [9]. A tropical savannah climate is characterized by warm temperature throughout the year with distinctive wet and dry period. The wet or rainy seasons occur from November to February and the dry seasons from March to October.

During the dry season, the temperature could reach as high as 42^o Celsius and during the rainy season temperature could reach as low as 18^{o}C. However, the daily temperature fluctuates between 27^{o}C up to 35^{o}C. Local weather parameters such as rainfall, ambient temperature, and sunshine index are sourced from the Kupang Office Bureau of Statistics and Agency for Meteorology Climatology and Geophysics. Fig. 6 showed the volume of the rainfall and the sunshine index in Kupang area in 2014. The graph in Fig. 7 shows the minimum, average, and maximum temperature in the area. The temperatures shown are all averaged values.

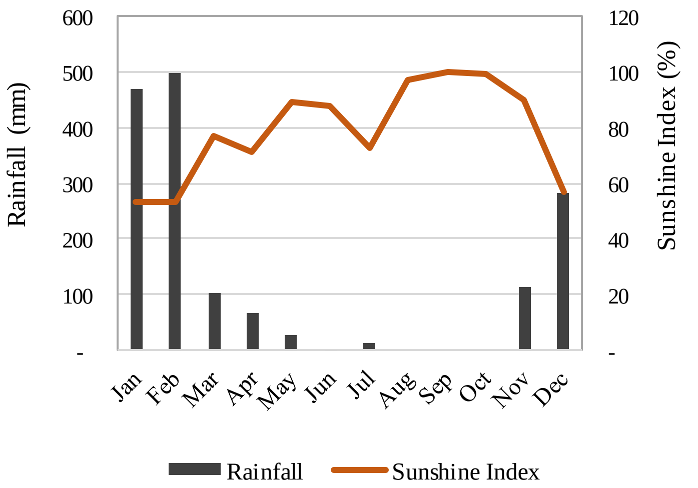


Fig. 6 Rainfall and sunshine index in Kupang area

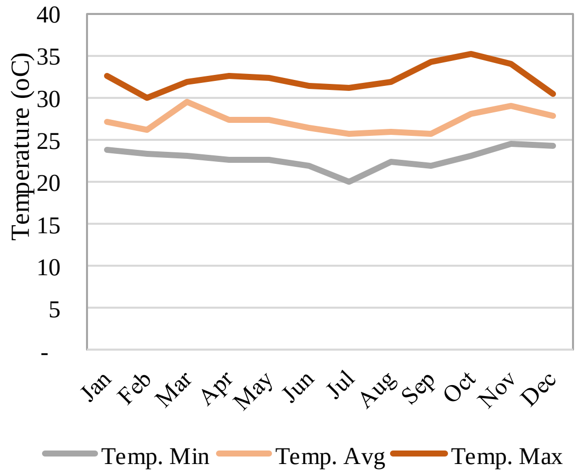


Fig. 7 Temperature variation in Kupang area

From Fig. 6, it is clear that Kupang area has abundant of sun power, particularly during the dry season. Even during rainy season sunshine is still available generously with a monthly average sunshine index of 63%. During the dry season, the average sunshine index is 87%. Sunshine index is associated with the brightness of the sky and measured as the length or hours of sunshine that has direct solar irradiation exceeds 200 W/m^2. Although this measurement is different from the index of solar radiation, it provides general information about the availability of the sun in a specific location on earth. Local weather data is important in designing PV plant on hardware's environmental operating conditions as it also affects energy production. Environmental factors and how they affect energy production of PV plant have been well understood. Many researchers have published reports on the effect of shading from nearby objects to the power generated by PV module. Also, factor such as the deposit of dust on PV module affects the output of plant from zero and up to 26% output reduction [10, 11].

5. Projected Energy Production of 5 MW Kupang PV Plant

A measurement of plant's power output during commissioning is reported in [1] generating a peak power of 4,600 kW and it fluctuated throughout the day as shown in Fig. 8. It is also reported the energy measured during this one-day test is 27.54 MWh [1]. Further, based on this measurement results, the annual energy output is projected around 9,914 MWh [1]. In another publication, the power plant developer stated that daily average of plant energy output is 25 MWh and with the average monthly output of 750 MWh obtained by simply multiplying the average daily output with the number of days of the month [2]. With this method, the annual energy output is founded at 9,125 MWh, and the monthly output is shown in Fig. 9. The projected energy outputs presented here are quite high as they are derived from incidental high measurement result and using rough estimation method to project the annual energy production.

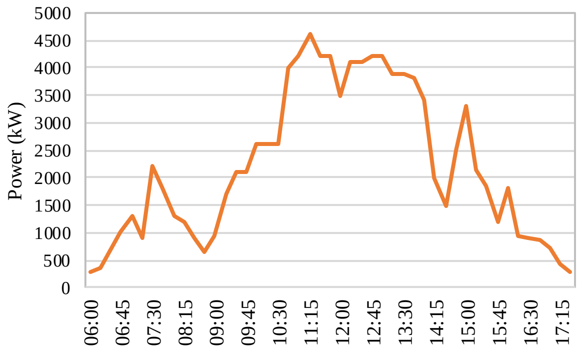


Fig. 8 Measurement of plant output [1]

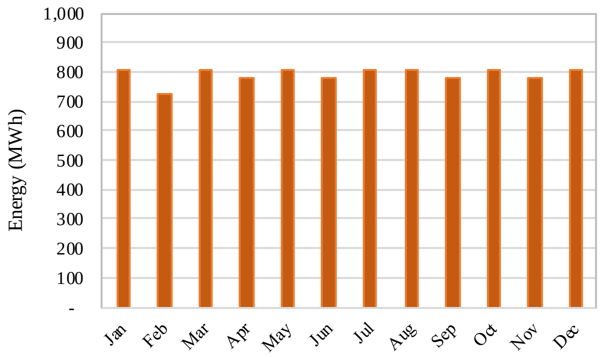


Fig. 9 Projected monthly energy output

6. PVSyst Simulation of 5 MW Kupang PV Plant

Assessment of the performance of PV plant including requirements of the hardware system for data acquisition and type of data required are specified in IEC 61724. Over the years, various tools have been developed to simulate the performance of the photovoltaic plant. Survey of such platforms is discussed in [12]. PVSyst is one of the tools for PV simulation that is originally developed by Geneva University but now available as commercial tools. On simulating the performance of PV plant, it requires data such as geographical position, array configuration, technical specifications of plants' components, and meteorological data. On this simulation, meteorological data designated as synthetic MeteoNorm 7.1 station available in the simulator is used. Comparison of other meteorological data for simulation on accuracy is discussed in [13].

Using technical specifications and geographical profile as presented in the previous sections, the PVSyst simulation results of the 5 MW Kupang PV plant is shown in Table 4 Simulated output of 5 MW Kupang photovoltaic plant the simulated annual energy production is 7,476 MWh. Monthly energy output fluctuates from 526 MWh to 770 MWh with an average of 623 MWh. The monthly variation is around 12% or 75 MWh. Greater deviation from the average figure is shown during the rainy season, i.e. during October to April period. The minimum energy output occurs on December, which is the rainy season, and the maximum output occurs in May, which is the dry season.

Fig. 10 shows simulated sun energy incidence variation throughout the year. It is shown that Global Incidence (GlobInc), the irradiance received on the tilted array surface, also varies from month to month. GlobInc has a direct effect on energy production of the plant. The higher its value, the greater the energy output of the plant. The graph also shows a close agreement between GlobInc and ambient temperature. Higher ambient temperature indicates greater sun exposure, hence higher energy production, although at the same time the negative temperature coefficient of the modules' electrical parameters will take effect.

Table 4 Simulated output of 5 MW Kupang photovoltaic plant

Month	GlobHor kWh/m^2	T Amb ^{O}C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E-Grid MWh	EffArrR %	EffSysR %
Jan.	131	17	124	120	545	534	12.33	12.08
Feb.	130	21	127	123	549	538	12.10	11.85
Mar.	178	25	180	174	752	736	11.72	11.48
Apr.	177	27	186	180	767	752	11.60	11.37
May	178	28	190	184	785	770	11.59	11.36
Jun.	148	28	158	152	656	643	11.66	11.43
Jul.	153	28	163	157	675	662	11.62	11.39
Aug.	140	28	145	140	598	586	11.56	11.32
Sep.	145	27	148	143	613	600	11.64	11.41
Oct.	140	27	139	134	579	568	11.70	11.46
Nov.	139	23	133	129	573	562	12.06	11.83
Dec.	130	19	122	118	536	526	12.32	12.08
Year	1,789	25	1,813	1,753	7,629	7,476	11.79	11.56

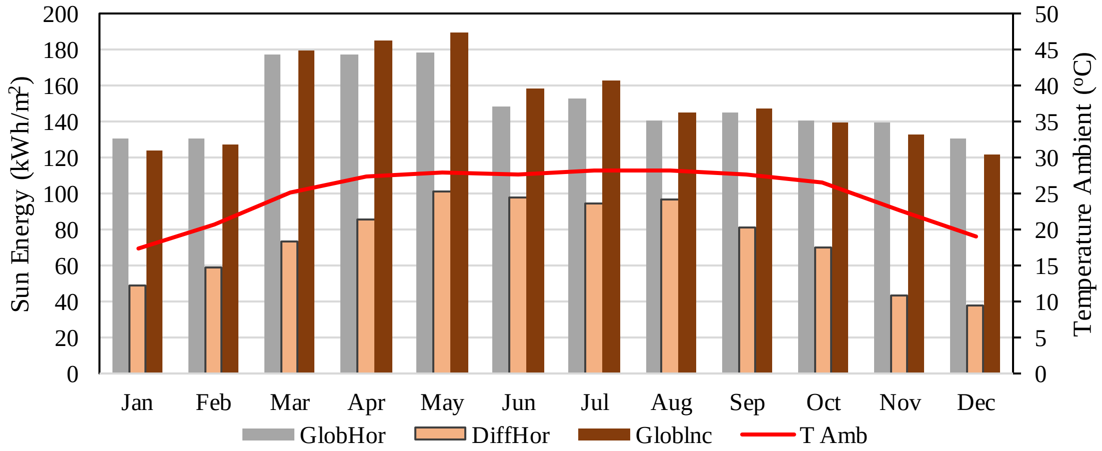


Fig. 10 Monthly sun energy of Kupang plant

Fig. 11 shows the simulated monthly energy production of the power plant. Monthly energy output does not go lower than 526 MWh. It gives an average production around 17 MWh per day. Low energy outputs are shown in the months of December, January, and February which falls within the traditional rainy season period of Kupang area, from November to February. From this simulation, the low energy production is expected to occur within the rainy season period due to reduced availability of sun. Fig. 12 shows how energy is accumulated within a 24-hour period. It is shown the sun energy is available from just after 5:00 in the morning and disappears from 17:00 hence approximately around 12-hour length sun irradiation every day all year round.

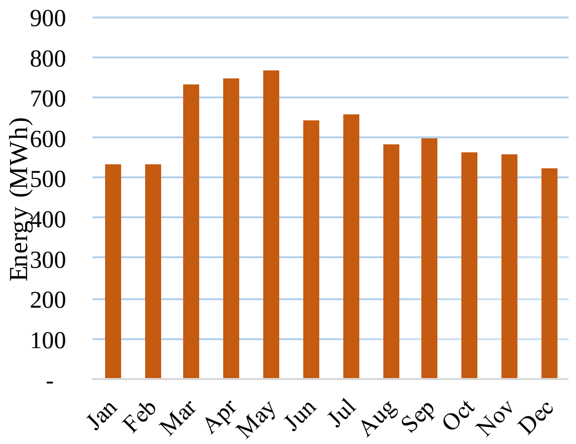


Fig. 11 Energy production of Kupang plant

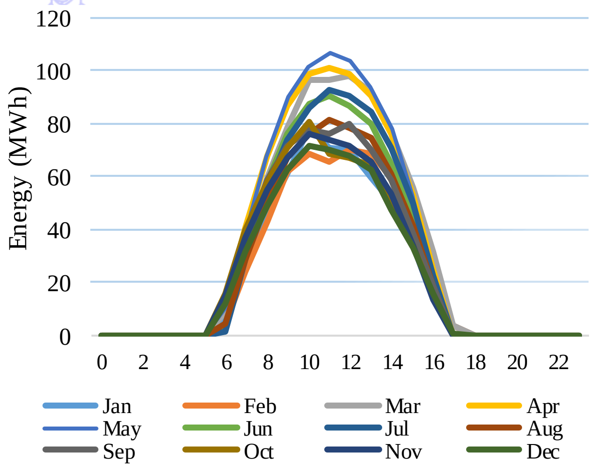


Fig. 12 The 24-hour energy production

As shown in Fig. 11, it is interesting to see that the simulation shows high energy output during March, April, and May. Comparing energy output of Fig. 11 and the sun energy incidence of Fig. 10, it is clear that high energy output is linked to the high sun incidence on the site. The March to May period has high sun incidence and therefore leads to high energy production. However, comparing it with Fig. 6, the period of March to May are not exposed to long sunshine. Data presented in Fig. 6 and Fig. 7 are sourced from the local meteorological office which measures weather parameters in the area. The long sunshine is recorded during the month of June, August, September, and October and up to early November before the cycle of the season begins. So, based on weather data as in Fig. 6, it is highly likely that the actual peak energy production occurs during any of the dry-weather months, i.e. within August to early November time span provided the plant be in good working condition.

Fig. 13 shows simulated losses of the power plant. The highest loss component is 11.5% due to temperature. High-temperature-loss is closely related to the tropical climate condition of the location which has long sunshine exposure hence high temperature. Actual average local temperature varies from 20°C to 34°C as shown in Fig. 7 which is higher than the STC of the PV module nearly all year round except in the month of July when the temperature is at the lowest point at around

20°C. Also, compared to other Indonesia area which also has a tropical climate, Kupang area is one the of the driest part of the archipelago with a small number of rainy days and low volume of rainfall. The second losses component is 3.3% due to IAM factor on global. Incidence Angle Modifier (IAM) relates to the decrease of irradiance reaching the PV cell due to the sun rays' refraction when passing through antireflective coating and glass of the module. The 2% inverter losses are related to its technical specifications, i.e. overall efficiency of the inverter when converting DC power into AC. As shown, the final energy available at the output of the inverter is 7,476 MWh which is also indicated as energy injected into the grid. However, a small additional amount of energy losses occurs due to transformers and connection from plants' output to the utility's medium voltage distribution networks.

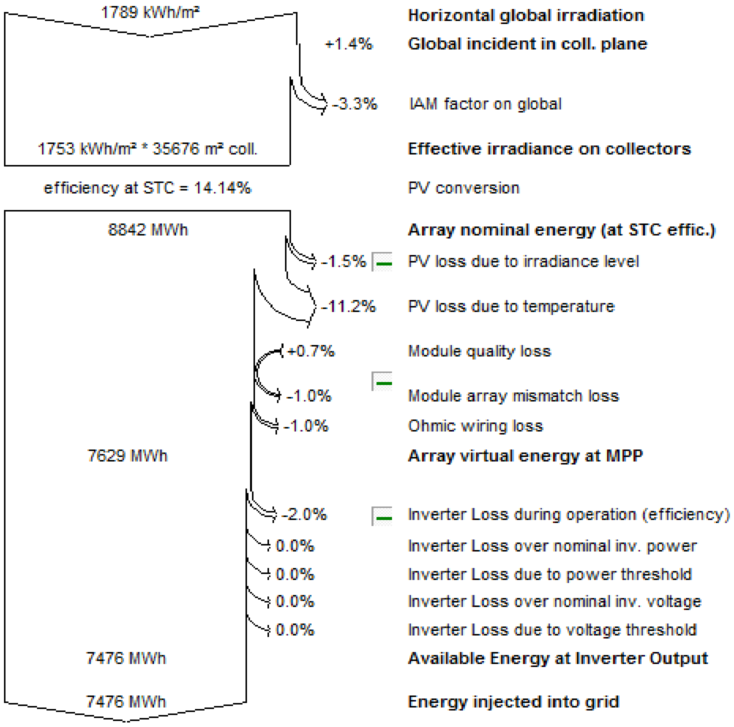


Fig. 13 Simulated losses diagram of Kupang plant

As mentioned in the previous section, the tilt angle of the array is reported at 10° [3] meanwhile site observation found the tilt-angle is close to 15°. PVSyst simulation is carried out to compare energy output of the plant with tilt angles of 10° and 15°. The simulation is carried out by varying array tilt angle from 0° to 40°. Fig. 14 shows annual energy production of the power plant for different array tilt angle. At array tilt angle of 10°, the plant produces an annual output of 7,694 MWh while at 15° angle, it produces 7,715 MWh. The difference is around 21 MWh per annum or 0.27%.

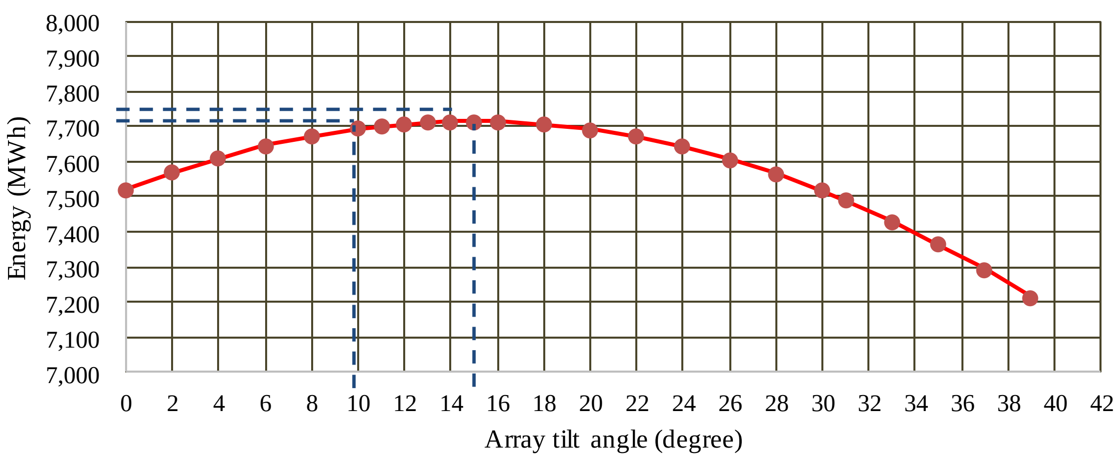


Fig. 14 Energy production of Kupang plant with different array tilt angle

7. Simulated Performance Ratio of 5 MW Kupang PV Plant

There are many indicators to assess the performance of PV plant as described in IEC 61724 and among those indexes, three indexes are considered as the main indicator. The three indexes are final yield Y_f, reference yield Y_r and performance ratio (PR) which defines the overall system performance of a plant. For the last three decades, research on the performance of PV plants around the world has been reported. This trend is due to the increasing interests of developing PV power plant which according to International Energy Agency Photovoltaic Power System (IEA PVPS), global installed PV capacity by the end of 2015 had reached 237 GW. It is reported that performance ratio of plants in some European countries installed in the early 1990s showed average performance ratio of 67% [14]. For plants installed in the 2000s, they showed increasing average performance ratio from 76% to 84% [15]. The trend of increasing performance ratio is associated with the application of more efficient PV module and inverter, more reliable power plant, as well as better understanding of factors that affect plant's performance due to the availability of data recorded by advanced plant's and environmental monitoring systems. Given this trend, newer installed PV plant tends to show higher performance ratio. For example, PV plants installed in Jordan and Syria which have desert climate is reported to show performance ratio of 87.5% and 88.2% respectively [16]. PV plant installed in India which has tropical climate as reported in [17] shows performance ratio of 86.12%.

Table 5 Monthly performance index of 5 MW Kupang photovoltaic plant

Month	Yr kWh/m^2.day	Lc	Ya kWh/kWp/day	Ls	Yf kWh/kWp/day	Lcr	Lsr	PR
Jan.	4.00	0.50	3.50	0.07	3.43	0.12	0.02	0.86
Feb.	4.54	0.64	3.90	0.08	3.82	0.14	0.02	0.84
Mar.	5.80	0.97	4.83	0.10	4.73	0.17	0.02	0.82
Apr.	6.18	1.09	5.09	0.10	4.99	0.18	0.02	0.81
May	6.13	1.09	5.04	0.10	4.94	0.18	0.02	0.81
Jun.	5.26	0.90	4.35	0.09	4.27	0.17	0.02	0.81
Jul.	5.26	0.92	4.34	0.09	4.25	0.18	0.02	0.81
Aug.	4.68	0.84	3.84	0.08	3.76	0.18	0.02	0.80
Sep.	4.92	0.85	4.07	0.08	3.98	0.17	0.02	0.81
Oct.	4.48	0.76	3.72	0.08	3.64	0.17	0.02	0.81
Nov.	4.44	0.64	3.80	0.07	3.73	0.14	0.02	0.84
Dec.	3.94	0.49	3.44	0.07	3.38	0.13	0.02	0.86
Year	4.97	0.81	4.16	0.08	4.08	0.16	0.02	0.82

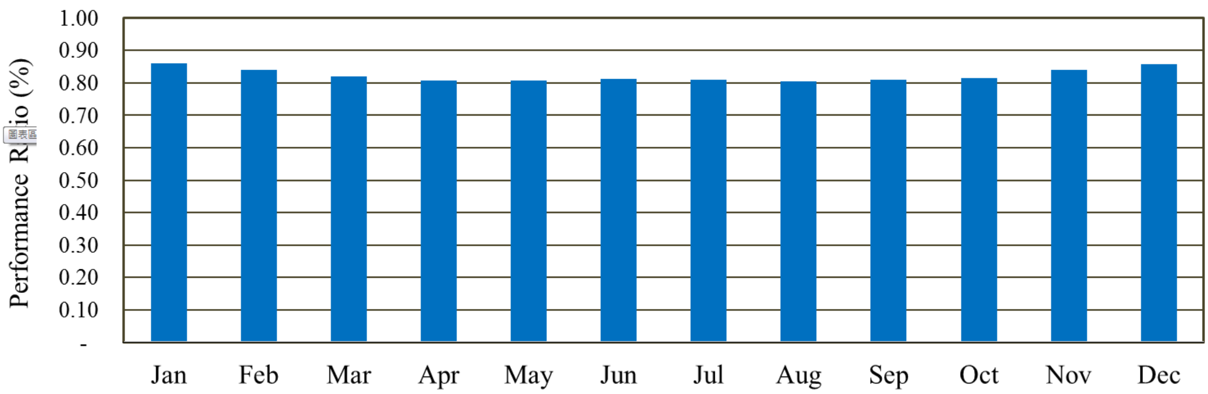


Fig. 15 Monthly performance ratio of the plant

Table 5 shows the monthly performance of the Kupang PV plant from January to December. Fig. 15 shows the corresponding performance ratio of the plant. It can be seen that monthly performance ratio is relatively stable throughout the year. Monthly performance ratio varies from 80% to 86% with an average value of 82%. The average annual yield Y_f of the plant is 4.08 kWh/kWp/day. It is shown that the month of May, June, July, and August show the period of low performance. One explanation for this condition is related to the high ambient temperature. From Table 4 we can see that during the month of May, June and July the temperature of the location is of the highest among other months with temperature average at 28^o C.

Also, from the losses schematic diagram in, it is shown that loss due to temperature is the highest losses component. The high losses due to temperature likely occurs during this period hence slightly lower performance. The lowest performance ratio occurs in August with PR equal to 80%. Similar performance reduction during these four months period also shown for PV plant installed in Bangi Malaysia [18]

8. Discussion

Over the years, Kupang city has experienced high ambient temperature. For example, a high temperature of 37°C occurred on Nov 9, 2015, as reported by the local paper. Another high temperature reaching 42°C was reported around early November 2008, and so far, it becomes the highest recorded temperature in the area. In general, the typical daily temperature in Kupang varies from 27°C to 35°C. High ambient temperature in Kupang area indicates a high level of the sunshine which is important for PV generation. However, high ambient temperature necessitates for high-quality equipment so they can reliably operate in such harsh condition. As discussed above, the equipment or components used in this power plant, particularly PV module and inverter both have operating ranges which are well within the local weather conditions and therefore reliability is expected to be high. Also, protection against lightening has been installed to ensure protection from lightening strikes. Fig. 2 shows the area protected by the lightening protection system as shown as dotted circles.

Simulation of energy output of the power plant for different arrays tilt angles found the best tilt angle for the location is 15° and on-site observation confirmed that 15° tilt angle is used. The energy output of the plant with 10°, 15° and 20° tilt angles does not produce a significant difference.

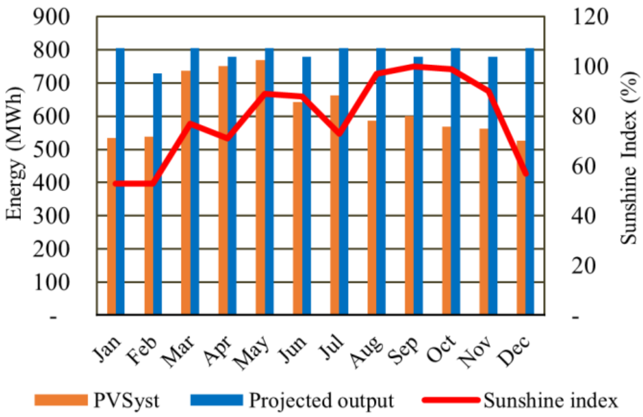


Fig. 16 Plant output and the sunshine at the location

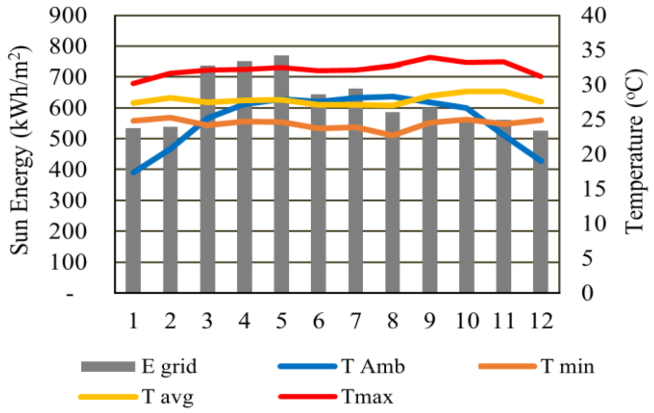


Fig. 17 Temperature and energy output

Weather condition and their effects on energy production of PV plant are discussed in [11]. Other factors such as array shading and its impact on PV plant is discussed in [19]. The reliability of inverter and its impact on energy production is reported in [20]. Over time, PV plant also exhibits degradation on its performance due to cells materials and manufacturing process as reported in [21]. Apparently, non-technical aspects of plant operation also affect energy production as discussed in [22]. Therefore, it is clear there are many factors which affect actual energy production of PV plant. The simulation results presented here is somewhat ideal as those factors are unaccounted. In the absent of these factors, the actual energy output would be lower than the simulation results. Fig. 16 shows PVSyst results, plant's output using simple projection approach as described in the previous section together with the local sunshine index. The graph shows that both energy outputs does not correspond closely with the measured local weather condition, i.e. sunshine index. Therefore, discrepancies on actual energy output and PVSyst simulation is somewhat expected. Further, it is shown in Fig. 17 that the average meteorological temperature (T amb PVsyst) is lower than the actual measured local temperature (T min, T avg, T max) while the local average temperature varies but relatively stable around 30°C. This recorded temperature is higher than STC, and so it will reduce the output of the module by 0.44% per 1 °C temperature increase beyond the STC condition. With the high ambient temperature in Kupang area, the PV module temperature will also increase much higher than its surrounding hence further reduction of module's output.

9. Conclusion

Review over technical specification of the grid-connected 5 MW Kupang PV plant has been presented. It is clear that all of the components used have carried specifications that suit the local weather and geographical conditions which are characterized by high ambient temperature, high humidity, and low elevation. Therefore the plant is likely to show a high reliability, and hence energy production would be affected only by local climate and weather conditions.

From a natural resources perspective, Timor Island has a huge potential for photovoltaic electricity generation with monthly global horizontal irradiation (GlobHorz) varies from 131 kWh/m^2 to 192.1 kWh/m^2 or daily index solar irradiation between 5.52 to 6.38 kWh/m^2. Local weather is also promising due to low monthly average rainfall of 132 millimeter and high monthly average sunshine index of 79% hence long period of sun exposure. The small number of annual rainy days of the region means the rain is short and could provide the benefit of washing the array from dust or debris deposits during the dry season.

Based on the PVSyst simulation, the 5 MW Kupang PV plant could generate an annual energy of 7,476 MWh. This figure is lower compared to the projected annual output of 9,914 MWh, which is calculated based on one-day energy measurement result. The PVSyst simulation is calculated based on historical meteorological data which varies from month to month hence monthly energy production also fluctuate but provide more realistic output compared to simple projection technique. Based on recorded local weather parameters such as temperature, volume of rainfall, and sunshine index, the actual weather condition in Kupang area varies considerably from month to month compared to the historical meteorological data used. Therefore, the actual energy production is likely lower than the simulation results. The monthly average yield of the plant varies from 3.38 to 4.99 kWh/kWp/day with an average of 4.08 kWh/kWp/day. The monthly performance ratio of the plant slightly varies from 80% to 86% with an annual average at 82%. Based on literature reviews presented, the performance ratio of the more recent installed power plant should be at this level. The simulated energy output and performance ratio presented here are the results of a simulation to provide an initial insight of plant performance and also a comparison when the actual plant's performance is available. The simulation results could provide a realistic performance insight of the plant. Currently, the power plant is reaching its nine months operation. Research to monitor and evaluate the actual performance of the 5 MW Kupang PV plant together with aspects of its management is currently underway.

Nomenclature

EArray	effective energy at the input of array (kWh)	PPA	power purchasing agreement
EffArrR	efficient E_{out} array/ rough area (%)	PR	performance ratio (%)
EffSysR	efficient E_{out} system/ rough area (%)	LEN	Indonesian electronics state-owned company
E_Grid	energy injected into grid (kWh)	PLN	Indonesian electricity state-owned company
FIT	feed-in tariff (IDR/ kWh)	PV	photovoltaic
GlobEff	effective global irradiance (kWh/m^2)	SNI	Indonesian national standard
GlobHor	horizontal global irradiation (kWh/m^2)	STC	standard conditions 25^{o}C, 1000 W/m^2, A.M.=1.5
GlobInc	global incident in coll. plane (kWh/m^2)	T amb	ambient temperature (^{o}C)
IAM	incidence angle modifier	T avg	average temperature (^{o}C)
LBS	load break switch	T max	maximum temperature (^{o}C)
Lc	array capture loss	T min	minimum temperature (^{o}C)
Lcr	array loss/ incident energy ratio	Ya	normalized array production (kWh/kWp/day)
Ls	normalized system losses	Yf	normalized system production (kWh/kWp/day)
Lsr	system loss/ incident energy ratio	Yr	ref. incident energy in coll. plane (kWh/m^2.day)
NEP	national energy plan		

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