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Analysis of energy production design from grid-connected 40 MW large PV power plant

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ABSTRACT

Electricity is an important source of energy in everyday life. In recent decades, growing energy demand worldwide has significantly fueled energy production, leading to environmental impacts such as global warming and ozone depletion. it has also endangered the species. Hence, the whole world has started shifting towards green energy generation, eliminating all the negative impacts on the environment. Solar energy is the most CO_2 emission save compared to non-renewable energy sources. A photovoltaic generator is useful in areas well exposed to the sun. This paper is aimed at the total amount of energy generated by the solar system connected to the grid on the 230 kV transmission line. This result was conducted by comparing the energy generated with the tilt angle of 15°,20°,25°,30°and 35°. The most energy generated is produced with a 25° of tilt angle according to the simulation result in this paper. The result was simulated by using PVsyst. This paper presents the energy production of a 40-MW grid-connected photovoltaic system located at Minbu Township in Myanmar. The simulation is carried out in order to get maximum energy production and the incident radiation, performance ratio, energy into the grid, and energy output at array and losses. Based on the simulation result, it is concluded that the maximum energy production and performance ratios are 75730 MWh and 81% through the year. The CO_2 emission was saved 424781.5 tons per year. The incident energy in the collector plane is 5.220kWh/m^2/day. This research is only conducted for analysis of existing grid-connected utility-scale solar PV systems and not provided for advanced techniques.

Keywords: Solar Power; Solar Module; Inverter; Grid Connected; PVsyst.

How to Cite:

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1. INTRODUCTION

The source of solar energy is the sun. Photovoltaic and thermal systems are the two topologies that use solar energy to produce electricity. The term "photovoltaic" derives from the sun's light (photo), which creates a DC voltage (voltaic). By exposing PV cells to solar irradiance, which causes the electrons to flow and create an electric current, electrical power is produced [1]. The usage of solar photovoltaic energy in electrical energy sources is growing as a result of its advantages, which include being environmentally friendly, having low maintenance requirements, and providing an abundance of free energy [2].

In previous research, design, and simulation of grid-connected solar PV systems have been done through PVsyst by considering solar photovoltaic systems at different sites location around the world. It presented design modelling and simulation as well as the technical and economic potential of a solar PV grid-connected electricity generation plant and to reduce the energy consumption of 100MW of electricity at Umm Al-Qura University [3] It also demonstrates the energy production potential of a small-scale grid-connected photovoltaic architecture situated in the Magallanes region of Chile and uses photovoltaic energy in Patagonia [4]. It is compared for different tilt angles to validate the effectiveness of the proposed framework and it is found that the best optimal tilt angle is 25 degrees [5]. The previous research also designed and simulated a “60kWp solar power plant" which has been done for seasonal tilt angles an on-grid type solar photovoltaic system and to overcome the energy crisis in the rural region [6]. It presented the design, simulation, and actual installation of a 3 kWp PV grid-connected system which observed and measured data in this work were done in Thailand [7]. It analyzed and compared the actual measuring and simulation the performance of a 454 kWp grid-connected photovoltaic system installed on the rooftop of the university building which the weather has the greatest impact on the yield [8]. It compared the total annual energy productivity generated from the PV system in all 10 areas in Sudan and chose the best place in terms of high annual energy production to connect it with the network [9].

With the release of fossil fuels into the atmosphere, global temperatures are rising day by day. Ozone layer depletion is occurring as a result of rising global temperatures. The primary cause of the rise in global temperatures is the sharp increase in the emission of fossil fuels from the Earth's atmosphere caused by the burning of natural resources. With the high rate of growth activities requiring power, fossil fuel-based resources such as coal, gas, and oils are depleting year over year. Therefore, it is necessary to minimize the amount of these fossil fuels that are released into the atmosphere [10].

In order to protect the earth's atmosphere, the non-conventional power generating plants which use wind, solar, tides, geo-waste etc. These are inexhaustible sources of the atmosphere for power generation. For the installation of a solar plant, it is important to know certain specifications of the area, such as the geographical latitude, climatic conditions, average daily incident sunlight, tilt angle, and azimuth angle. These factors drastically affect the overall output produced by a solar system [11].

A Photovoltaic (PV) system is a solar power-generating system installed to generate electricity from solar radiation. The grid-connected photovoltaic (PV) system is a more favorable system as they are easy to install and don't need a battery system. The important parameters in the field of solar generation are the reference gain, solar yield, Performance Ratio and system losses [12]. Renewable energy technologies are able to provide sustainable and clean energy from the sources such as sun, wind and bio-materials. A photovoltaic system is one of the most important and promising technologies that are able to produce electricity to meet the electricity demand of the whole world. From the literature survey, it was founded that PVsyst is the best software that is able to calculate the proposed output power and do accurate sizing of the system. This paper presents the finding of a research study, aimed to analyze the energy production design of a 40 MW grid-connected PV power plant in Myanmar, the performance ratio, and reduce greenhouse gas emissions. Global warming and environmental protection are the key motivating factors. In this analysis, the number of modules is used 158400 modules by using PVsyst. The system is designed to provide electricity to the grid all over the year and electricity will be sold out to the grid. The government has a plan 100% electrified in 2030.

2. MATERIAL DAN METHODS

When the solar cell semiconductor is exposed to light, photons are absorbed by electrons. The incoming energy will break the electron bonds so that the released electrons are drawn through the electric field to the N-region. The holes that are formed due to the transfer of electrons move in opposite directions to the P-region. This process, as a whole, is called the photovoltaic effect [13]. Solar PV technologies can be divided into three groups, these are Crystalline silicon, thin film, and multi-junction solar PV cells [14].

Photovoltaic systems are classified according to construction type and function or purpose of the installation. Fundamentally, there are three types of photovoltaic systems. These are standalone, grid-connected and hybrid PV systems. Standalone photovoltaic systems can be categorized into two groups; DC standalone or AC standalone or DC/AC standalone system. Basically, standalone systems are not connected to the utility or grid. The hybrid PV system is a combination of PV systems and other forms of energy-producing units such as diesel or gas generators, wind turbines and hydro plants [15]. The grid-connected system is connected to the utility grid. There are large or medium-scale photovoltaic plants called PV power plants. These plants are usually mega-watts installed and cover a large area of land.

2.1 Design and Selection of PV Modules

PV has been the most significant component of a grid-connected PV system since it converted solar radiation energy into electrical energy. A solar array is created by connecting a number of PV modules to increase the output voltage and power. To supply electricity throughout the year, the performance of PV array must be carefully measured. Photovoltaic modules are an important part of photovoltaic systems [16]. The monocrystalline PV module is more efficient than Polycrystalline PV module [17]. The actual data of PV module rating is chosen from 315 Wp monocrystalline in solar power plant located at Minbu township, Myanmar. The 315 Wp mono-crystalline 72 cells module was chosen for this solar power plant. To receive the most amount of solar radiation, the panel must be positioned at a specific fixed angle [18]. For maximum solar exposure, the panel must be positioned at an angle corresponding to the altitude of the site location. Table 1 shows PV module specifications and parameters and Figure 1 shows a block diagram of grid connected PV power plant.

Table 1: PV module specifications and parameters

Specification	Parameters
Module	Mono-crystalline
Rated power	315 Wp
Short circuit current	8.95 A
Open circuit voltage	45.28 V
Maximum voltage	36.88 V
Maximum current	8.510 A
No. of modules	158400 modules
No. of Arrays	20
No. of Inverters	20
No. of series modules per Array	20
No. of Parallel strings per Array	396

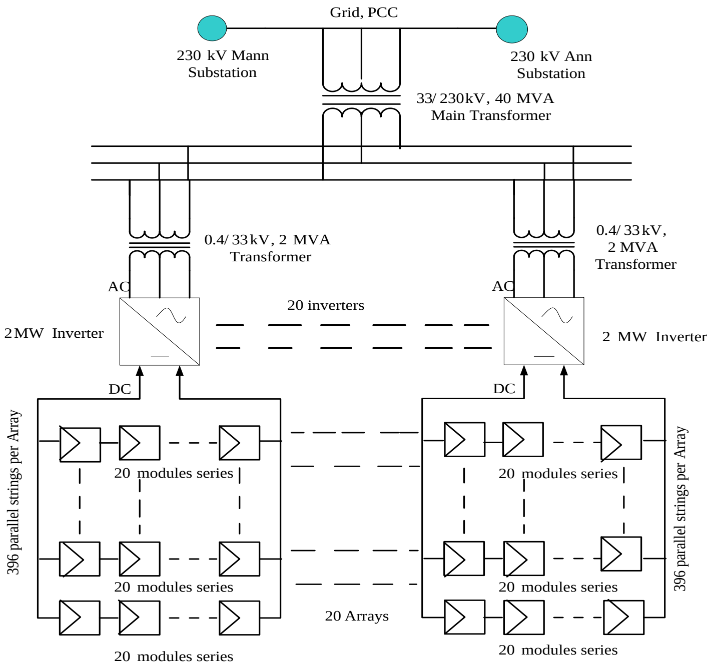

Figure 1: Block diagram of grid connected PV power plant

Depending on the module technology selected for the PV plant, the total number of PV panels required in the system will vary as well as the area needed for the implementation of the PV plant will also differ depending on that parameter. The main factors affecting the selection of a PV module for grid-connected systems are the efficiency of the module and the product warranty because grid-connected systems are designed to last for a long time. Mono-crystalline modules are selected because their efficiency has also to be considerably high. For energy required from the PV panels, the following equation is used:

$$P_{dc,STC} = \frac{P_{ac}}{\text{conversion efficiency}} \quad (1)$$

Where P_{ac} is AC Power and $P_{dc,STC}$ is the DC power of the array obtained by simply adding the individual module ratings under standard test conditions. The conversion efficiency estimates the impacts of temperature, inverter efficiency, module mismatch, and dirt to come up with conversion efficiency from DC to AC [19]. In actual data of Minbu power plant, the DC output of PV plant is 1.2474 time of AC power. For calculating the required number of PV modules, N_{pv}, the following equation is used:

$$N_{pv} = \frac{P_{dc,STC} \times 10^6}{P_{M,STC}}$$

(2)where, $P_{dc,STC}$ [W] is the power plant design capacity, $P_{M,STC}$ [W] is the PV module power rating.

2.2 Inverter

The inverter is also a critical component of a grid-connected PV system. This component converts the DC power from the PV module into an AC power source. The system voltage is 800 V. A 2 MWAC Central inverter was chosen for this paper. The inverter rating of Minbu Power Plant is 2MW. The total number of inverters are 20 numbers and one inverter is connected to one array. The number of inverters is as follows:

$$N_{inverter} = \frac{P_{design}}{P_{inverter}} \quad (3)$$

Where P_{design} is rating of PV Plant, $P_{inverter}$ is rating of inverter and $N_{inverter}$ is the number of inverters [20]. The maximum voltage of PV module is nearly approximately equal to 40 V. The following equations are the number of series modules per array, number of modules per array and number of parallel strings per array.

$$\text{Number of series modules per Array} = \frac{\text{System voltage}}{\text{PV module voltage}} \quad (4)$$

$$\text{Number of modules per Array} = \frac{\text{Total number of modules}}{\text{Number of inverters}} \quad (5)$$

$$\text{Number of parallel strings per Array} = \frac{\text{No of modules per Array}}{\text{Number of series module per Array}} \quad (6)$$

2.3 Solar Radiation

Solar radiation is one of the important parameters in solar power system because the size of solar radiation will affect the electricity produced by PV [21]. Solar radiation is an instantaneous power density in units of kW/m^2 it depends on location and local weather. Global solar radiation is the total amount of solar energy received at a particular location during a specified time period often in kWh/m^2 [22].

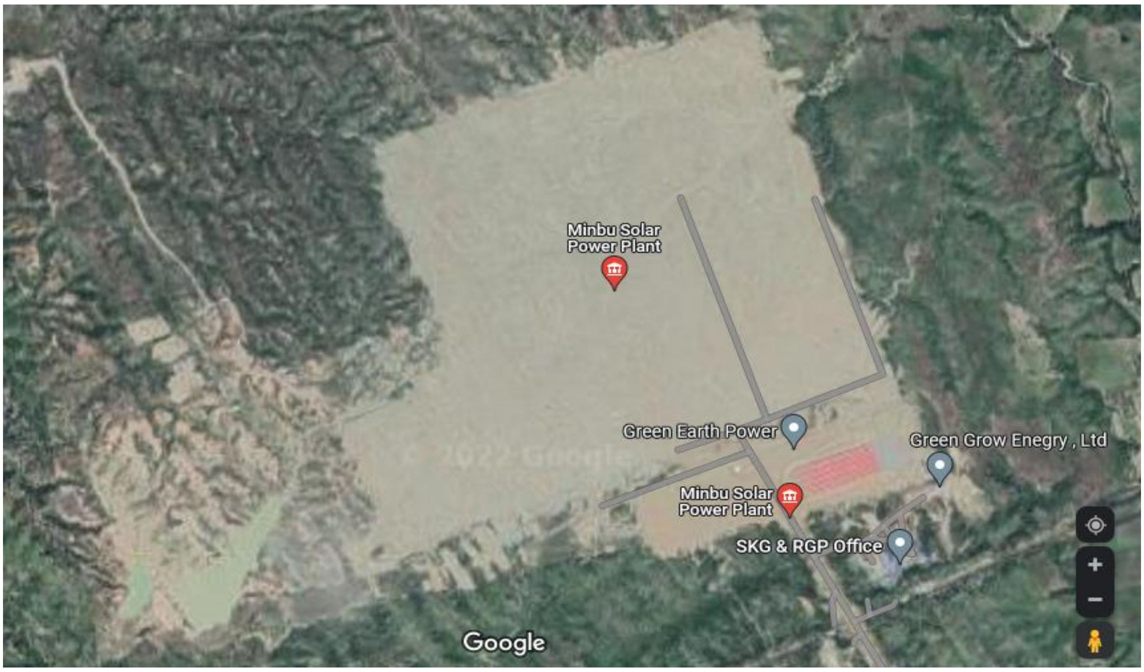

Figure 2: Grid-Connected Minbu Solar Power Plant

2.4 Geographical Location

Minbu Solar Power Plant is located in Minbu Township in Myanmar. The latitude of Minbu Solar Plant is 20.0495° (N) and the longitude is 94.6828° (E). Solar and temperature data are taken from the solar radiation resource assessment of Meteronon. This paper is based on real meteorological data and geographical location (latitude, longitude, altitude and time zone). Data are provided by the available website on the internet to provide meteorological data and the geographical location of Minbu Solar Plant in Myanmar. The system is designed for Grid Connected in Minbu Solar Plant. The tilt angle is 25 degrees. Figure 2 shows the location of Minbu Solar Power Plant.

3. RESULTS AND DISCUSSION

Photovoltaic module is the most important component of the grid-connected PV system as PV change solar radiation energy into electrical energy. Photovoltaic power production depends on meteorological conditions, the type of photovoltaic units and the photovoltaic inverter [3]. The system that is designed using the PVsyst software is shown in Figure 3.

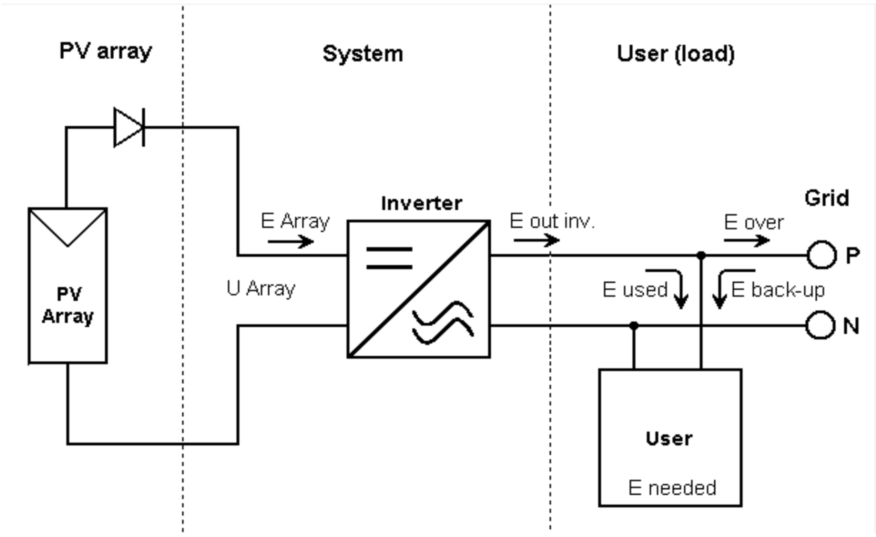

Figure 3: Components and connection of grid-connected PV system

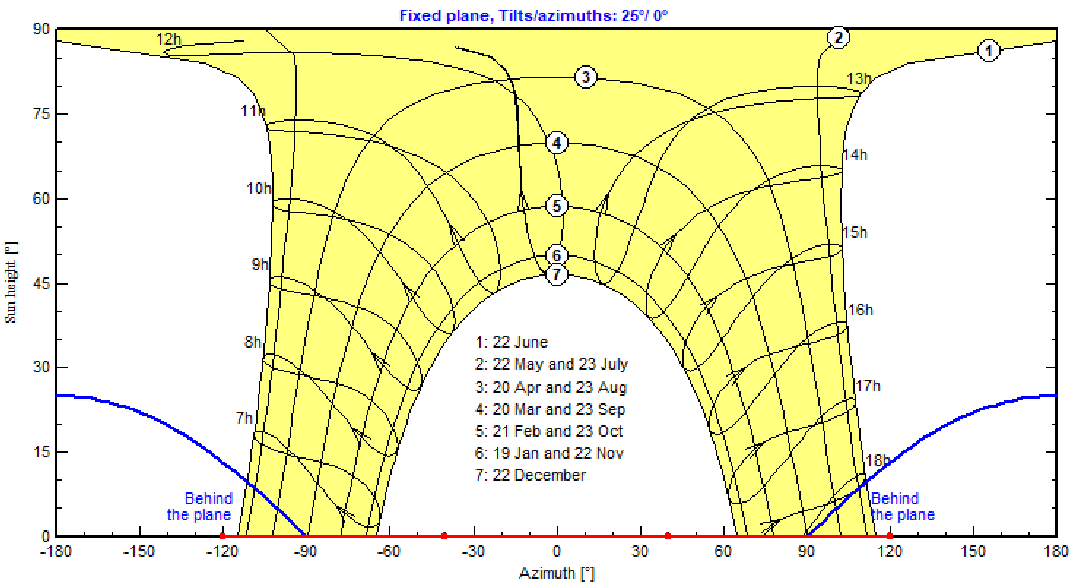

Figure 4: Sun path for Minbu solar power plant

It consists of a PV array-feeding inverter that feeds the power into the user and the grid. The grid-connected systems must be identified by the geographical location of the site to reduce the loss of irradiation received by PV array and increase the output power. Figure 4 shows the sun path for the Minbu Solar Power Plant. From Figure 4, it is shown that sunshine is the higher sun path in the summer session whereas sunshine is the lower sun path during the winter session. Hence solar irradiation is vastly obtainable in summer at the selected location. The generated electricity from Minbu Solar Power Plant is fed to the 230 kV Minbu-Ann transmission line via 33/230 kV transformers.

3.1 Fixing of Tilt and Azimuth Angle

The tilt angle can be modified depending upon the place of installation and also to maximize the yield of solar energy. The power amount produced by PV Plant at different tilt angle is shown in Table 2 [5]. The tilt angle is kept at 25 degrees. Azimuth angle is specified as zero. The lowest power is extracted from the panel with 35º tilt angle. It is found that the panel with a 25º tilt angle produced more energy compared to the panel with 15º, 20º, 30º, and 35º tilt angles. The results show that the fixed tilt angle of PV panels is 25° for high-power solar energy applications in Minbu region. Therefore, maximum power can be obtained from solar PV system and a large amount of energy will be supplied to the utility grid. The CO_2 emission is the most saved with 25° tilt angle.

Table 2: The power amount produced by PV plant at different tilt angle

Tilt Angle (degree)	Energy Array (MWh)	Energy User (MWh)	Energy Grid (MWh)	CO_2 Emission saved (Tons)
15	77655	2628	75121	420740
20	78189	2628	75648	424242
25	78271	2628	75730	424781.5
30	77908	2628	75373	422394.4
35	77113	2628	74590	417167.2

3.2 PV Array Voltage-Current Characteristics

A grid-connected photovoltaic system for 40MW power plant is simulated in the PVsyst software. From the simulation, it is found that 158400 modules and 20 inverters are required. To obtain the specific voltage, twenty modules are connected in series and form a string. There are 7920 strings of 20 series PV models in the system. Based on the acquired solar radiation and temperature, the output of the PV system is varied. Figure 5 shows the voltage-current characteristics of the PV module. At the 60°C temperature, the maximum power point voltage is 550 V whereas at the 20°C temperature maximum point voltage is 780 V.

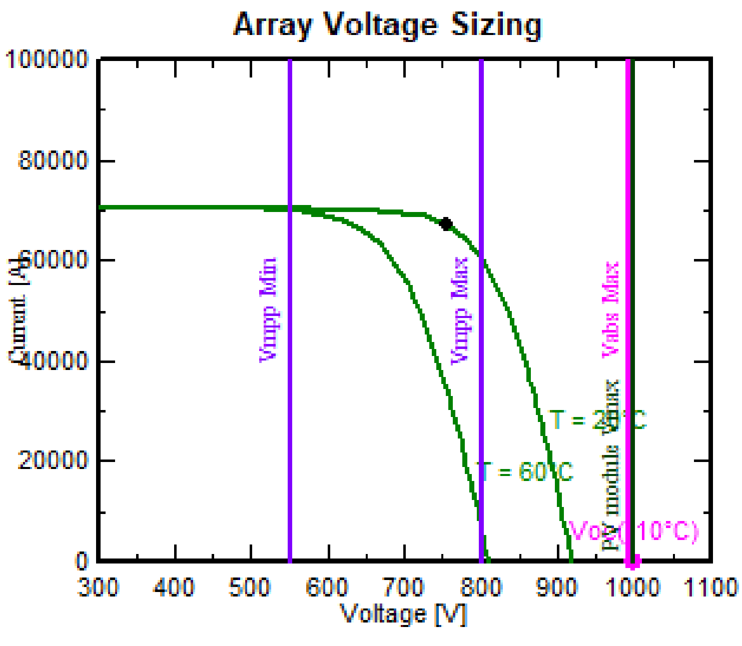

Figure 5: PV Array voltage-current characteristics

3.3 Energy Production

Electricity production from solar energy is more interesting. PV systems are also able to share energy with grid power and convert DC power to AC power [7]. A high amount of radiation of about 1781.2 kWh/m^2 energy is received on the PV array in a year. By the grid-connected system, 78271 MWh of electricity will be generated out of that 75730 MWh of electricity is available to the grid. 75730 MWh of electricity will be supplying the electricity to the grid throughout the year. Table 3 shows the monthly electricity production by the PV Plant [4].

Table 3: Monthly electricity production

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EfrGrid MWh
Jan	144.9	43.36	22.09	187.4	183.6	7758	223.2	98.8	7535	124.4
Feb	153.1	49.77	24.37	184.4	180.6	7547	201.6	92.4	7337	109.2
Mar	172.3	77.11	28.39	184.8	180.7	7479	223.2	104.3	7255	118.9
Apr	179.8	83.47	31.34	175.8	171.1	7043	216.0	107.8	6821	108.2
May	177.8	88.07	30.29	161.5	156.3	6568	223.2	112.5	6346	110.7
Jun	143.5	85.51	28.66	127.4	122.9	5285	216.0	112.1	5079	103.9
Jul	121.5	77.33	28.51	109.9	106.2	4565	223.2	114.1	4366	109.1
Aug	137.7	80.69	28.06	130.6	126.5	5410	223.2	112.2	5203	111.0
Sept	146.1	70.95	27.88	148.6	144.6	6100	216.0	105.4	5892	110.6
Oct	141.3	70.06	27.69	157.3	153.9	6474	223.2	103.4	6262	119.8
Nov	128.5	53.51	25.12	159.4	155.9	6609	216.0	91.1	6411	124.9
Dec	133.8	42.42	22.57	178.0	174.2	7432	223.2	93.0	7223	130.2
Year	1781.2	822.26	27.09	1905.2	1856.6	78271	2628.0	1246.9	75730	1381.1

Figure 6 shows the performance ratio of the PV Plant. It is one of the key parameters for performance evaluation of a PV plant. It is the ratio of the final yield to the reference yield. Thus, performance ratio is an indication of overall effect of losses on a PV array's normal power output. Hence, performance ratio is an indication of how closely the actual performance of solar PV system approaches the ideal performance and facilitates comparison of PV systems independent of location, tilt angle, orientation, and nominal rated power.

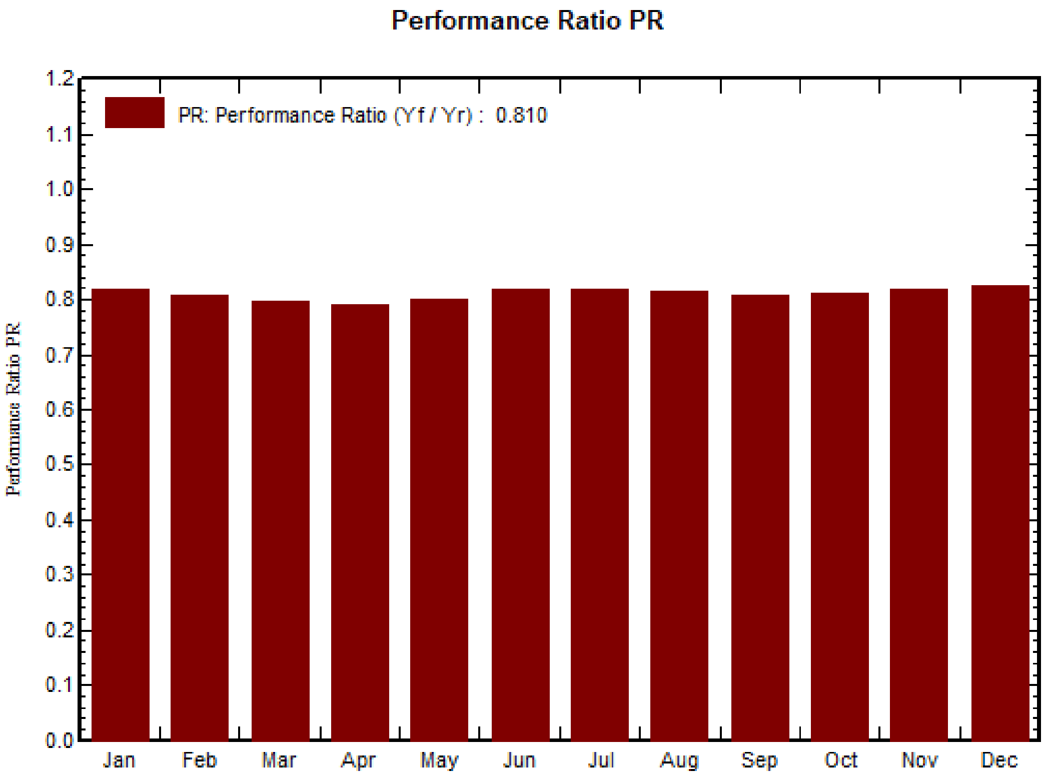

Figure 6: Performance ratio of PV plant

Figure 6 reported that for the system, the highest value of PR was found 82.4% in December whereas the lowest value was 79.0% in April. The average annual performance ratio of the system is 81%. The reference incident energy in collector plane is described in Figure 7.

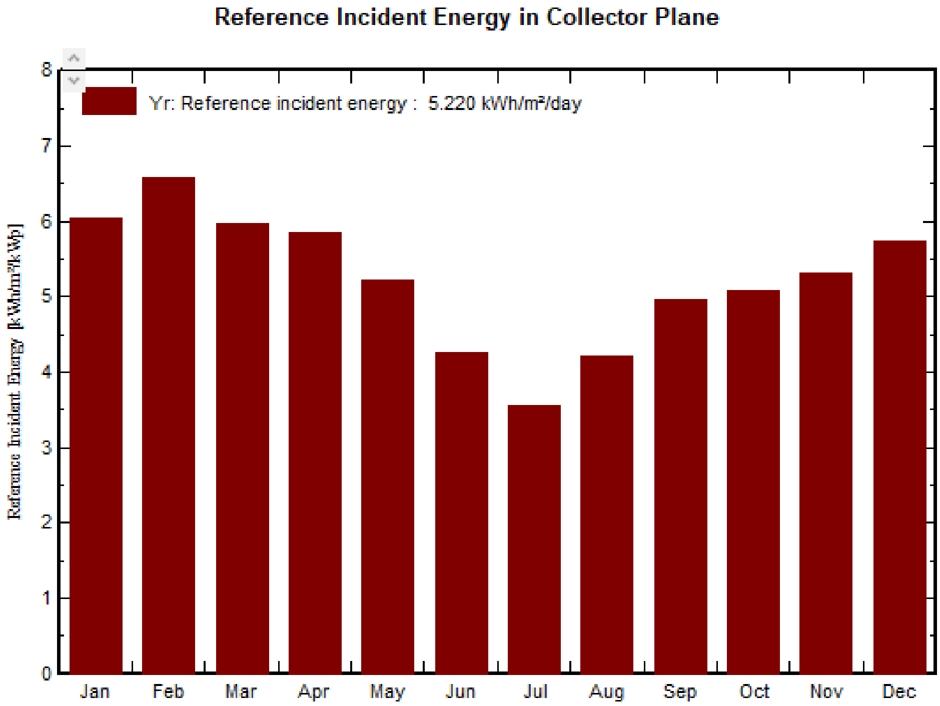

Figure 7: Reference incident energy in collector plane

For the system, the highest value of Incident Energy in Collector Plane was found at 6.59 kWh/m^2/day in February whereas the lowest value was 3.54 kWh/m^2/day in July. The Reference Incident Energy in Collector Plane was 5.22 kWh/m^2/day. Performance indexes of the PV plant are shown in Figure 8. PV-array loss or Collection loss (Lc) is mainly classified into thermal capture loss and miscellaneous losses.

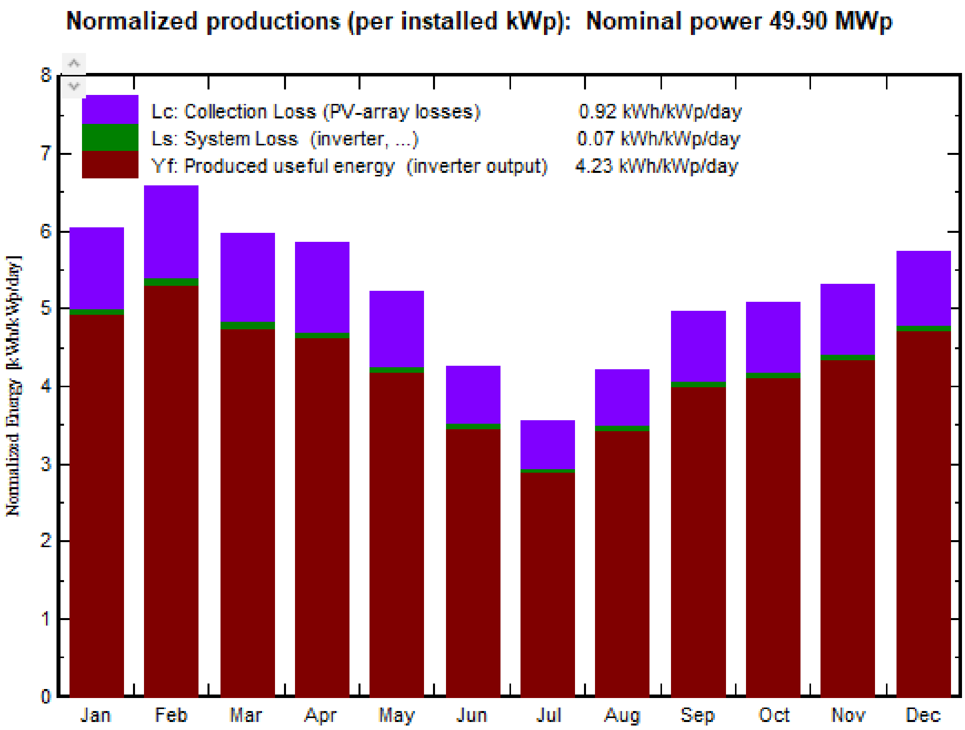

Figure 8: Performance indexes of PV plant

In Figure 8, thermal losses are caused due to the rise in cell temperature beyond 25°C. Miscellaneous losses are caused due to wiring, module quality, mismatching, partial shadows, errors in MPPT and dust. PV-array loss of the plant is 0.92 kWh/kWp/day. System Losses (Ls) are caused due to inverters. System losses of the system are 0.07 kWh/kWp/day. Final yield (Y_f) is defined as the system's useful AC output energy referred to as the nominal power of PV array, measured at standard test conditions of 1000 W/m^2 solar irradiance and 25°C cell temperature. Its unit is kWh/kWp/day. The final yield of the system is 4.23 kWh/kWp/day.

3.4 System Losses

PV system is not able to convert 100% of the energy received from solar radiation because of various losses [6]. Figure 9 represents detailed losses that occur in the grid-connected PV system.

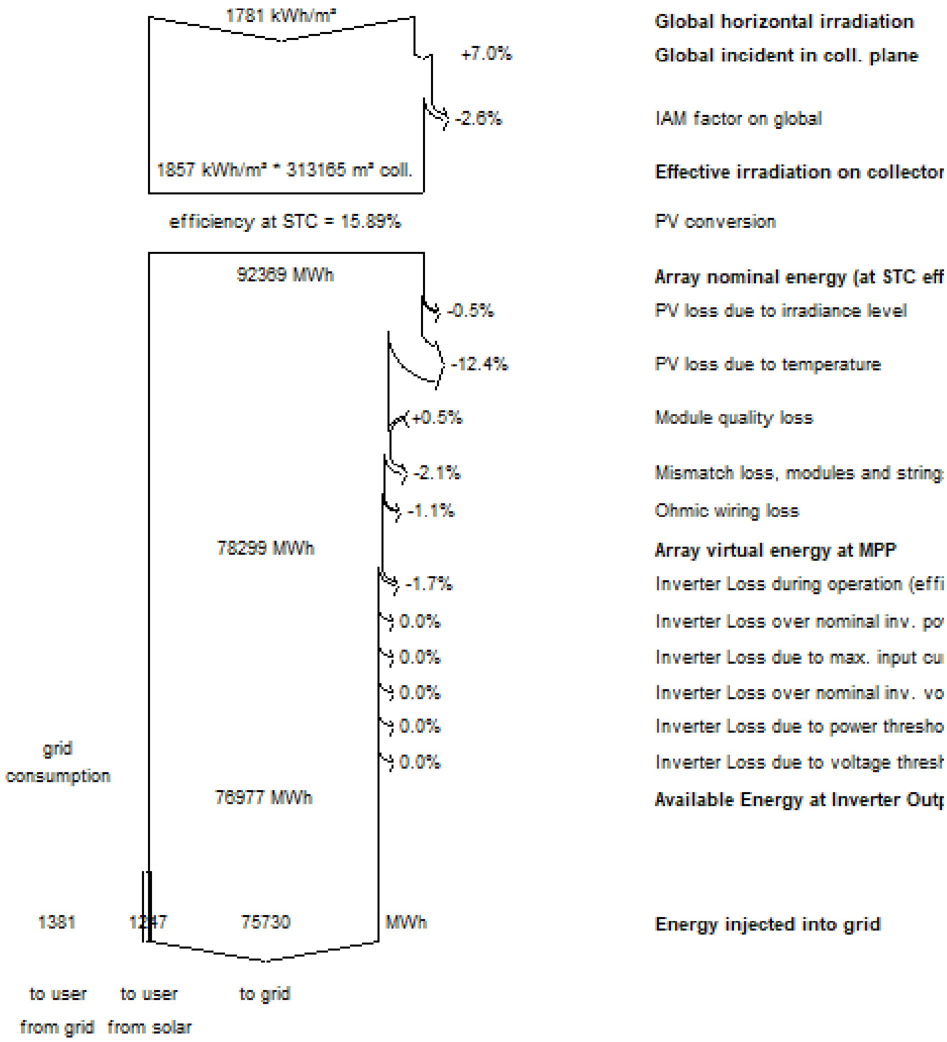

Figure 9: Detailed system losses

Rom detailed system losses, firstly, about 1781 kWh/m^2 radiation is incident on the solar panels. The largest losses have occurred during the conversion of PV system electric production. The mono-crysaline-315 module has 15.89 % efficiency at the STC. By this, 92369 MWh of electricity will be produced in a year by the PV array. After that due to the PV panel losses, energy use from solar, inverter losses, and wiring losses about 75730 MWh of electricity is available to the grid in a year.

4. CONCLUSION

Solar energy continues to play a very important role in the generation and distribution of clean, affordable, sustainable, and environmentally friendly electric power. These are used inexhaustible sources of the atmosphere for the generation of power. For the installation of a solar plant, it is important to know certain specifications of the area, such as the geographical latitude, climatic conditions, average daily incident sunlight, tilt angle, and azimuth angle. These factors affect the overall output produced by a solar system. The national population of Myanmar is 54.4 million (2020) with only 52 % of the population having access to electricity which means that roughly 26 million of the population do not have access to electric power. This paper is analyzed energy production design to increase the electric power supply and at the same time reduce the huge electric power deficit of Myanmar. This was achieved by designing, simulation, and evaluating a 40 MW photovoltaic power plant using PVsyst software. Simulation results acquired for Minbu PV power plant puts the yearly grid-connected power at 75730 MWh for fixed module orientation of power in PV systems. The performance ratio of PV Plant is 81%. This system is reduced CO_2 emission of 424781.5 tons in the atmosphere and protects the earth's atmosphere. The construction of PV power plant at Minbu is feasible and poses no danger to the environment. This study is focused to design a grid-connected photovoltaic system of the phase 1 section for Minbu, Magway division, Myanmar. It is founded with 158400 PV panels of 315 WP solar panels and 20 inverters for 40 MW output are the optimal solution for supplying the grid throughout the year in Minbu PV Plant, Myanmar. It will have a total capacity of 170MW and produce 350 million kWh (kilowatt hours) per annum, electrifying about 210,000 households, according to a government announcement. There are four phases of electricity generation in Minbu Power Plant. Each of the first three stages of construction will add 40MW of power generation capabilities while the fourth stage will add 50MW. With the first stage complete, the plant is now capable of producing up to 40MW of power.

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DECLARATIONS

Author contribution

Khin Moe Moe: Writing - Original Draft, Writing -Review & Editing, Conceptualization, Visualization, Formal analysis, Investigation, Resources. Hla Myo Aung: Conceptualization, Visualization, Investigation, Supervision. Hla Aye Thar: Visualization, Formal analysis, Investigation, Supervision. Yee Yee Win: Formal analysis, Investigation, Supervision.

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Competing interest

The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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