Analysis and Simulation of Grid-Connected Rooftop Solar PV System Using MATLAB

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Abstract – The day-by-day demand for electricity is rising and fossil fuels are depleting continuously. There is an urgent need for renewable energy sources to meet the current market. Renewable energy sources emerge as a critical alternative to fill the energy gap with research and advancement in power electronics devices, systems, and control. Solar energy is the richest endless, and this energy clean of all the renewable energy resources to date. Solar Photovoltaic technology is one of the most excellent ways to harness solar power. This is to analyze and simulate the grid-connected rooftop solar photovoltaic system for the industrial building. The detailed study and data collection will be conducted at Myanmar Pharmaceutical Factory (MPF), Gyogone, Insein. The simulation results were analyzed by using MATLAB/Simulink.
Key Words- Solar Photovoltaic, Grid-connected rooftop system, Industrial building, MATLAB

I. INTRODUCTION

During the case study, state assessment, available area for installation, orientation and dimensions, near-shading objects, and electricity consumption pattern will investigate. The grid-connected rooftop solar system will be used for an industrial building at Myanmar Pharmaceutical Factory (MPF), Gyogone, Insein. A photovoltaic system connected to the grid without batteries. This system is the straightforward and most economical solar energy installation available. Since it did not required batteries, it was more cost-effective and requires less maintenance and reinvestment than standalone systems [1]. It should note that a grid-connected solar energy system feeds its solar energy directly back into the grid. On a sunny day, the photovoltaic solar system produces more electricity, this solar energy instantly reintroduces into the grid based on isolation conditions and actual electricity demand. Grid-connected photovoltaic systems are composed of photovoltaic panels connected to the grid via a DC-AC inverter with a maximum power tracker, a bidirectional interface between the alternating current output circuits of the photovoltaic system and the grid, the primary electricity grid and the direct current and alternating current loads as well as the control system necessary to ensure the safe operation of the group [1]. The impact of photovoltaic modules on power grids cannot be ignored [1]. This is focused on the model and Simulink of a photovoltaic grid-connected system using a controller for monitoring the maximum power point of the photovoltaic farm of type to ensure synchronization with the grid for inverter operation of three seasons, summer, rainy and winter using MATLAB/Simulink. Figure 1 shows the location of the selected building.

Fig.1. Location of Selected Building

II. METHODOLOGY

This paper intends to analyze and simulate the grid-connected rooftop solar system. The simulation results carried out with the load and irradiation data by using maximum power point tracking controller and then converts PV output direct current electricity which synchronize the voltage and frequency at both sides with grid tied solar inverter for three seasons, summer, rainy and winter with MATLAB/Simulink. Figure 2 shows the overall system block diagram for the grid-connected rooftop solar system. Figure 3 shows a single-line diagram of a complete system for modelling.

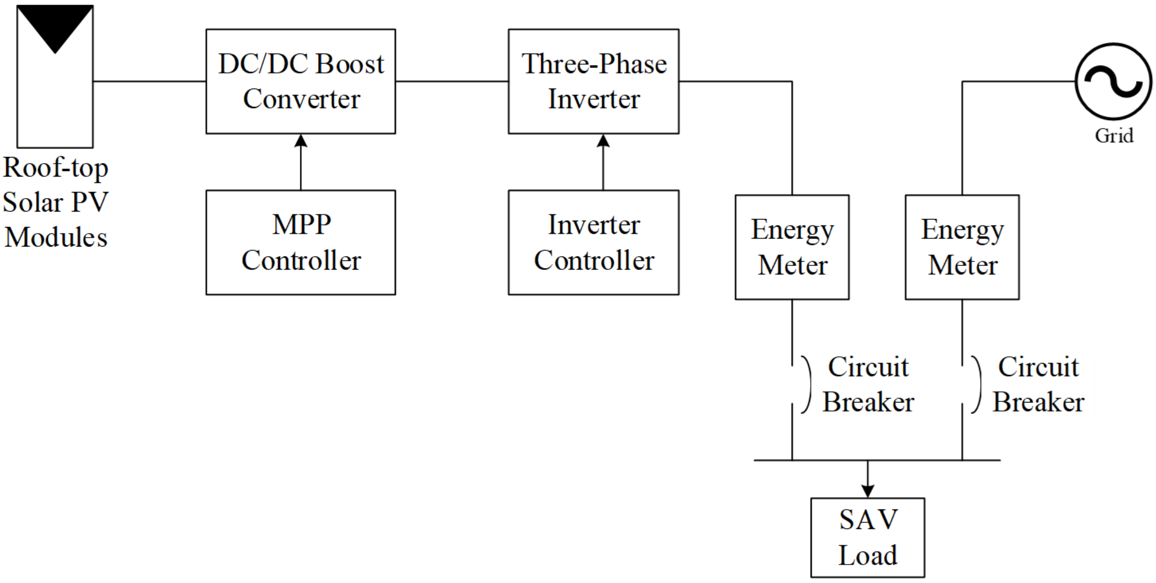


Fig.2. Block Diagram for Grid-Connected Rooftop Solar System

From the design calculation of solar system, there are 625 photovoltaic modules by spacing 0.357 m and 14 inverters are used with 28 MPPTs. The power from modules produces 196.88 kW. There are composed of two types of inverters, inverter type I and inverter type II. Inverter type I composed of 12 modules, two lines and 21 modules, one line. Inverter type II includes with 12 modules, two strings and 20 modules, one string.

III. DESIGN COMPONENTS FOR PROPOSED SOLAR PHOTOVOLTAIC SYSTEM

A. MPPT Control (Maximum PowerPoint Tracking)

Maximum PowerPoint Tracking algorithms are necessary for photovoltaic applications. The maximum power point of a solar panel varies with the irradiation and temperature, so the use of maximum power point tracking algorithms is required to obtain the maximum power from a solar array. These techniques differ in many aspects, such as needed sensors, complexity and cost, range of effectiveness, convergence seed and accurate tracking. When irradiation and temperature change, hardware is needed for the implementation or popularity, among others. There are two methods of maximum power point tracking, conventional techniques and artificial intelligent methods [4].

Conventional Methods:
1. A Fractional open circuit voltage
2. A Fractional short circuit current
3. An Incremental Conductance
4. A Perturb and Observe (Hill Climbing)

Artificial Intelligent Methods:
1. a Fuzzy Logic Control
2. A Neural Network

This control is associated with an inverter that allows an adaptation between the photovoltaic and the load. The power generated corresponds to its maximum value and it is transferred directly to the grid. MPPT control is established in our study using the algorithm (Perturb and Observe (P&O)). This controller automatically varies the direct voltage reference signal of the inverter’s DC voltage regulator to obtain a DC voltage that will get the maximum power from the photovoltaic generator [4].

B. Grid Tied Solar Inverter (GTSI)

In a grid-connected photovoltaic system, the grid inverter is employed to convert the DC power, which is generated from the photovoltaic arrays, into AC power to match the grid voltage and frequency. The grid inverter is different from a typical stand-alone inverter. The main specification of the grid inverter is the current drawn from the inverter delivered to the utility grid or loaded at a unity power factor. The grid inverter needs a pure sinusoidal reference voltage to ensure that the sinusoidal output of the inverter is synchronized with the grid frequency. AC electricity produced by the grid-tie inverter is the same as the electricity on the grid-both of them use alternating current, 230 volts, 50 Hz [6].

A grid-tied solar inverter is a particular type of power inverter that converts photovoltaic output direct current electricity into alternating current electricity so one can flow the electricity out into the power grid or expected load. GTSI is a "grid-interactive inverter", which is also known as synchronous inverter because of its capability to synchronize (i.e., same voltage and frequency at both sides) with Grid power. Grid-interactive inverters typically cannot be used in standalone applications where utility power is unavailable. The AC electricity produced by a power inverter is the same and the power on the grid-both of them use alternating current 230 volts (phase to neutral voltage), 50 cycles per second [6].

Grid-tie inverters used in solar, hydro and wind energy installations that connect to the public utility grid, which can be helpful to run household appliances such as TVs, radios and computers which utilize AC power. The GTSI ensures that the converted solar power is supplied to the distribution panel of the house with the grid power. On the direct current side, maximum power point tracking optimizes the power output by varying the closed-loop system voltage. On the alternating current side, these inverters ensure that the sinusoidal production is synchronized to the grid frequency (nominally 50 Hz) [6]. The complete diagram of the grid-tied solar inverter is shown in figure 3.

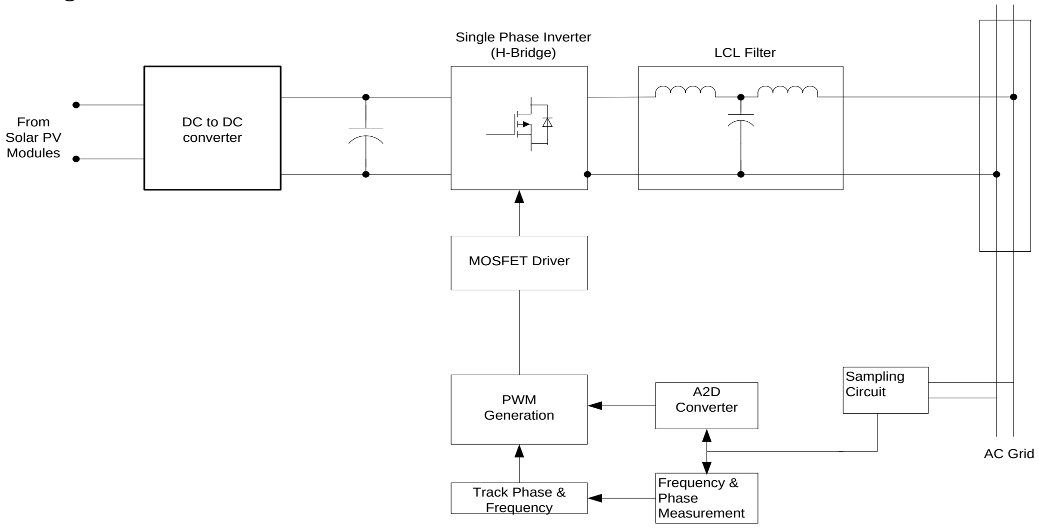


Fig.3. Complete Diagram of Grid-tied Solar Inverter [6]

A significant part of a grid-connected photovoltaic system is the inverter and its control unit for grid synchronization. The control unit includes a Phase-Locked Loop controller, which is used to synchronize of the photovoltaic system with the grid. Figure 4 shows the Simulink subsystem of the inverter with a current control loop for grid synchronization [7].

It consists of a three-level power inverter with three arms of power switching devices. Current controller of the inverter consists of phase locked loop, V_{dc} regulator, current regulator, reference generator and Pulse Width Modulation (PWM) generator. V_{dc} regulator measures the DC voltage and compares it to the reference voltage. The active power depends on the current I_q, so to inject real energy into the grid, I_q must be set to zero. Current controller consists of an integral controller used to set $I_q = 0$ thus reactive power injection to the grid is set to zero. Output of the current controller is fed into the switching pulses through the PWM generator to generate the gate pulse of the inverter.

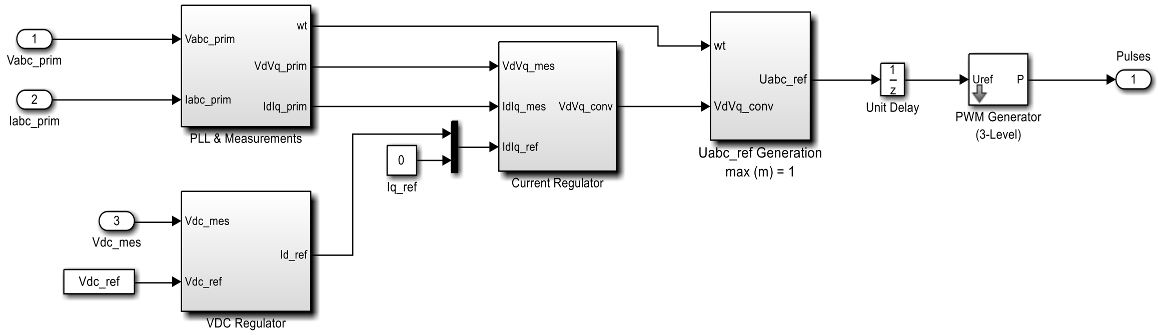


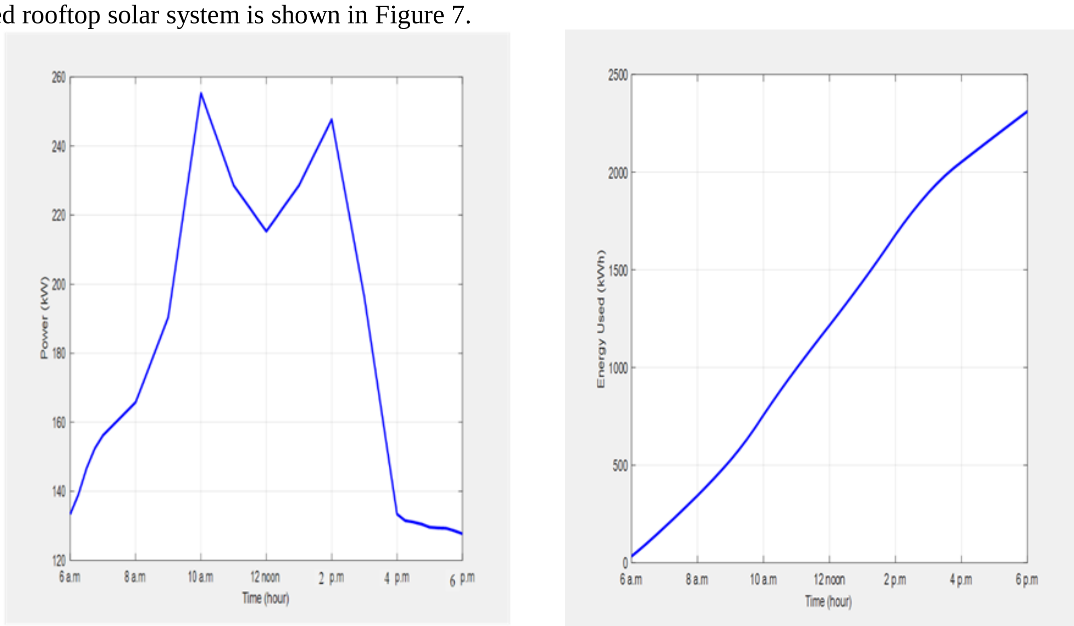
Fig.4. Main Controller of GTSI

IV. THE SIMULATION MODEL

This system will provide the required electricity for Snake Anti-Venom (SAV) building from rooftop solar photovoltaic system and utility grid system. Grid-tied solar inverter is used to observe the power and energy supply performance of the rooftop solar photovoltaic system, the simulations are carried out to represent 12 hours duration. i.e., from 6:00 am to 6:00 pm operation. The data collection for the SAV will be carried out in November 2021. The recorded data of power and energy use on the typical day is shown in figure 5.

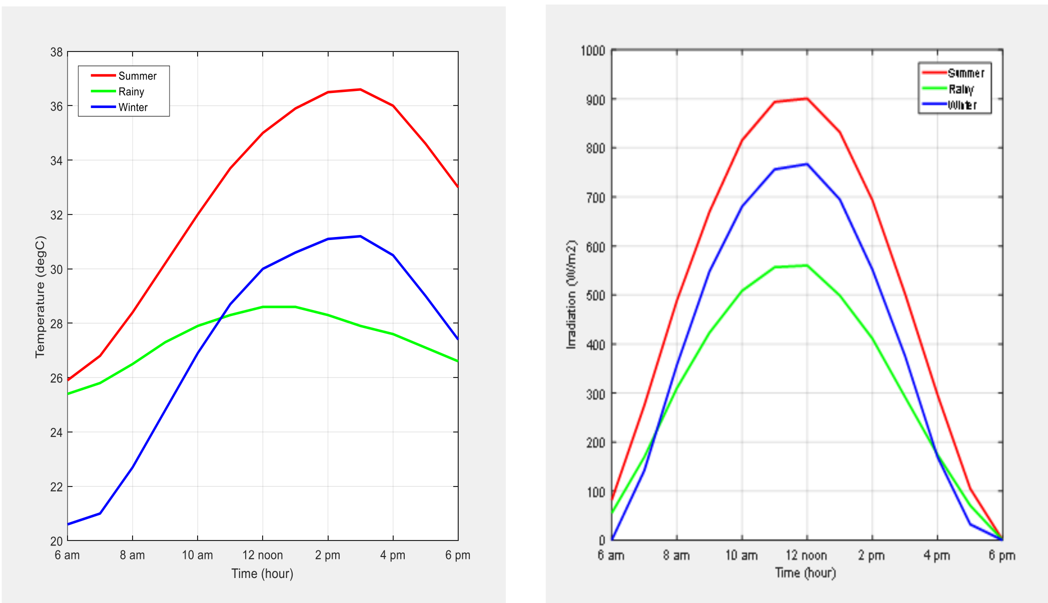
The data was recorded in every 15 minutes. The input data for a solar photovoltaic system, i.e. the radiation and temperature, are varied with the times of the day and the seasons of the year. This data collection for the photovoltaic system is carried out from the ‘weather spark’ page for three seasons. The data are average five-year values for the specific days of each season as shown in Figure 6.

Since the solar irradiations and the output powers from the photovoltaic system varied with weather conditions, the simulations were carried out for three seasons summer, rainy and winter. For all simulations, the power demand of the SAV building is kept constant according to the recorded data. Simulation model for the grid-connected rooftop solar system is shown in Figure 7.



(a) (b)

Fig.5. Collected Load Data for SAV Building: (a) Power Demand (b) Energy Used



(a) (b)

Fig.6. General Data from Weather Spark: (a) Temperature, (b) Irradiation

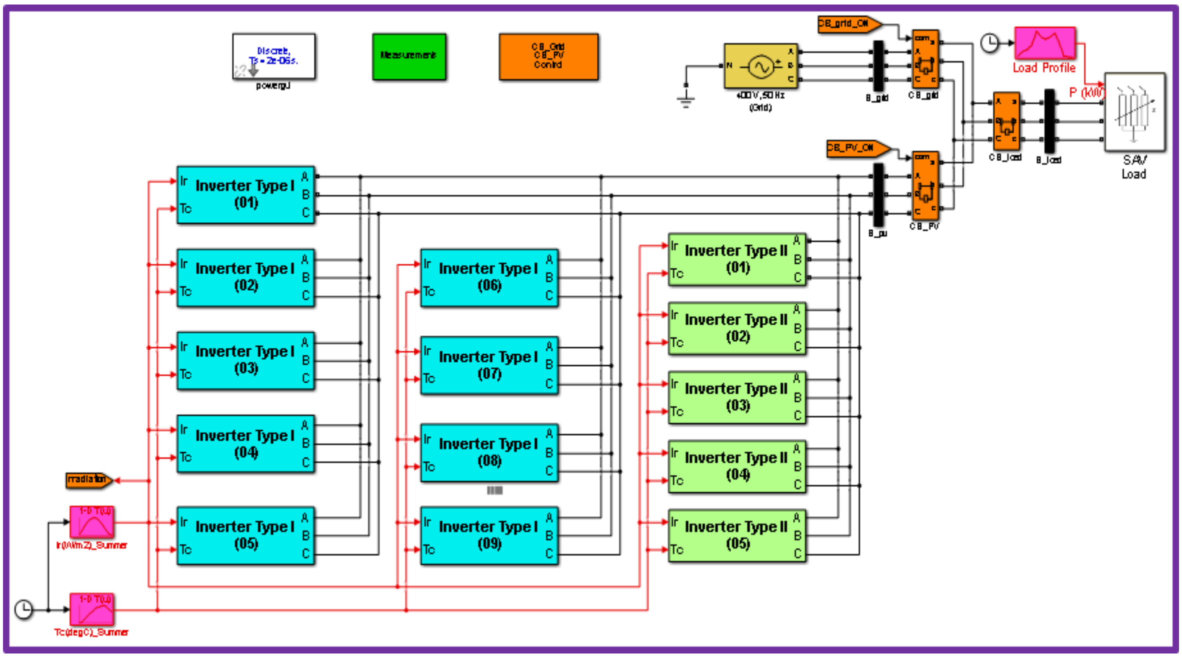


Fig.7. Simulation Model for Grid-Connected Rooftop Solar PV System

The circuit breakers are used to switch the connections between the power sections. GTSIs used to synchronize the photovoltaic system output with the grid system and to supply power to the SAV load. It represents the time-varying loads, irradiations and temperatures; the look-up table blocks used. In the simulations, the measurements carried out for voltages, currents, powers and energies of a grid, PV system and load. In case of a grid power failure or fault, the model arranged to turn off the grid circuit breaker and to supply the load from the photovoltaic system only. In case of no irradiation (e.g., at night), the model arranged to turn off the photovoltaic system circuit breaker.

VI. SIMULATION RESULTS

A. Simulation Results for summer

For the simulation of summer, the input irradiation and temperature data of photovoltaic system are set as shown in Figure 6 (with red colour). The simulation model for a grid-connected rooftop solar photovoltaic system for summer is shown in Figure 7. The input data varied with the time of the day from 6:00 am to 6:00 pm. The simulation was carried out for 12 hours. According to GTSI control, the power output from the photovoltaic system is supplied to the SAV load. The required additional power of the SAV load is taken from the grid. The RMS voltages and currents for summer days show in Figure 8. The power comparison and energy comparisons for summer days show in Figure 9.

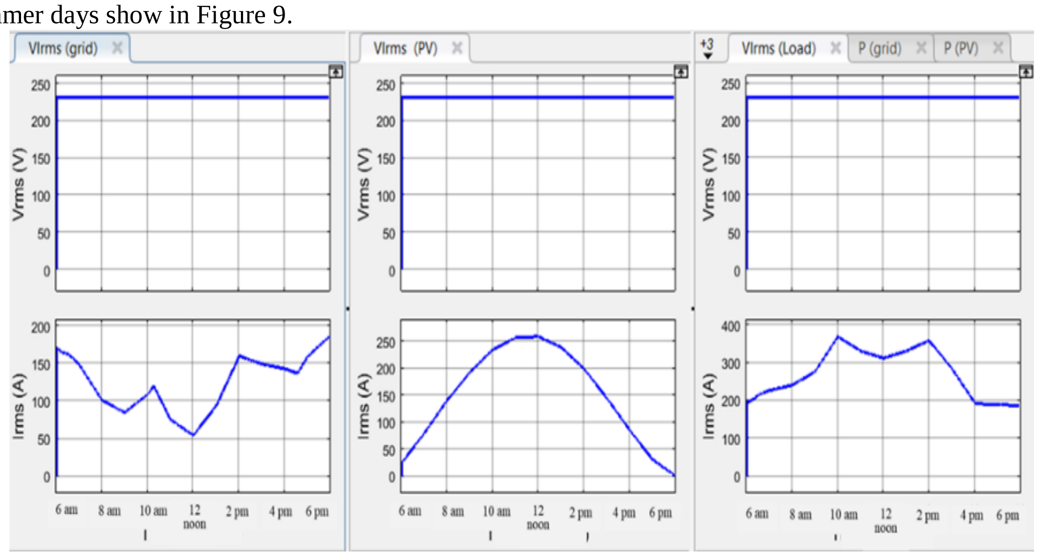


Fig.8. RMS Voltages and Currents for Summer: Grid (Left), Photovoltaic System (Middle) and Load (Right)

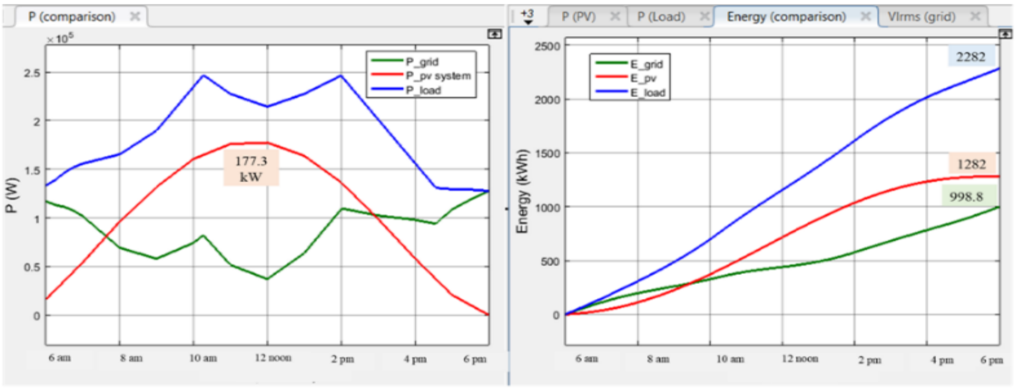


Fig.9. Power Comparison (Left) and Energy Comparison (Right) for summer

Due to high irradiation, the power output from the photovoltaic system is the highest power on summer day. The maximum power output from the photovoltaic system is about 177.3 kW. Most of the demand power is supplied from the photovoltaic system especially between 8:00 am and 3:00 pm. On summer days, the energy unit generated from the photovoltaic system is about 1280 kWh. Thus, the energy taken from the grid is only about 998.8 kWh.

B. Simulation Results for Rainy

For the simulation of rainy season days, the input irradiation and temperature data of the photovoltaic system are set as shown in Figure 6 (with green colour). The atmospheric temperature is lower than on summer days. The irradiation is insufficient due to cloudy conditions. The maximum irradiation is about 560 W/m2 which is about one-half of the normal state of 1000 W/m2. Thus, the power output from the PV system is the lowest power on rainy days. The RMS voltages and currents for rainy season are shown in Figure 10. The Power comparison and Energy comparisons for Rainy Season Day are shown in Figure 11.

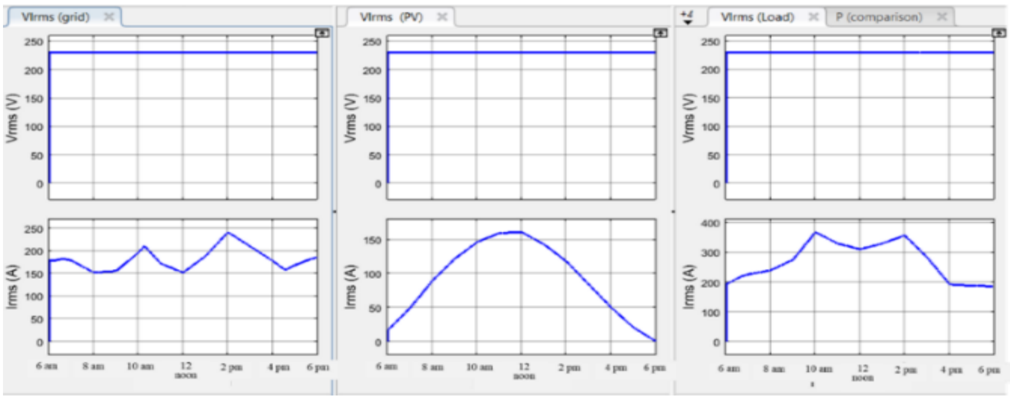


Fig.10. RMS Voltages and Currents for Rainy: Grid (Left), Photovoltaic System (Middle) and Load (Right)

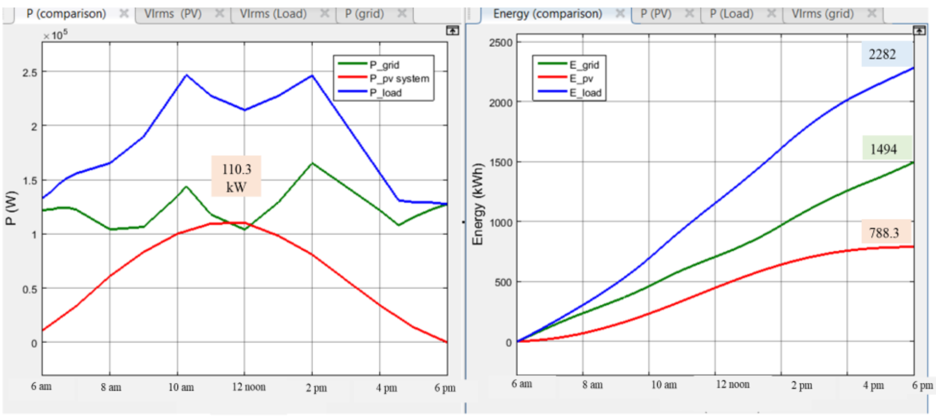


Fig.11. Power Comparison (Left) and Energy Comparison (Right) for Rainy Season

The maximum power output from the photovoltaic system is about 110.3 kW. In this season, most of the demand power is supplied from the grid. During rainy season day, the energy unit generated from the photovoltaic system is about 788.3 kWh. Thus, the required additional energy which is about 1494 kWh, is taken from the grid.

C. Simulation Results for winter

For the simulation of the winter days, the input irradiation and temperature data of the photovoltaic system are set as shown in Figure 6 (with blue colour). The irradiation is intermediate between the summer and rainy seasons. The maximum irradiation is about 567 W/m^2, and the maximum temperature is about 31.2°C. Thus, the power output from the photovoltaic system is moderate on winter days. The RMS voltages and currents for Winter Day show in Figure 12. The Power comparison and Energy comparison for Winter Day show in Figure 13.

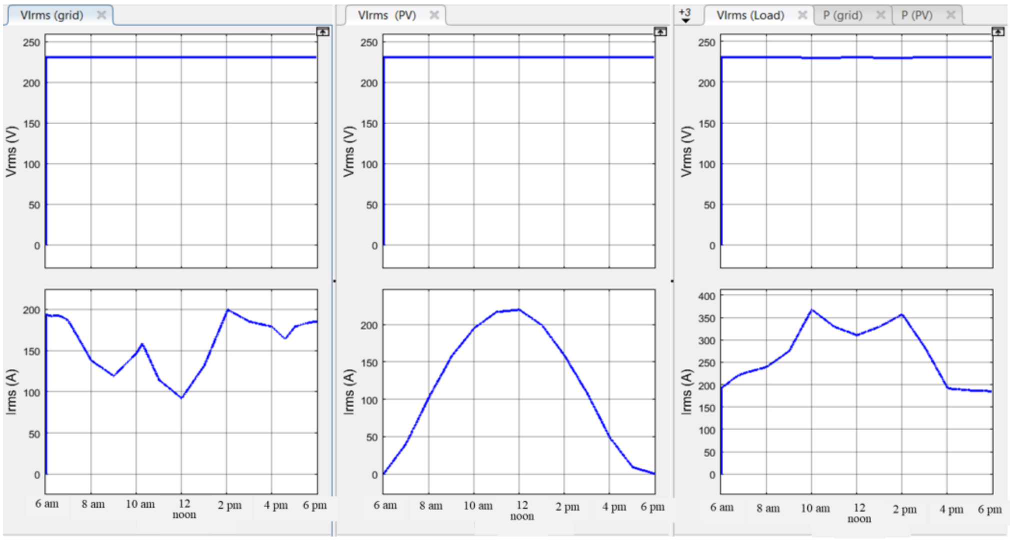


Fig.12. RMS Voltages and Currents for winter: Grid (Left), Photovoltaic System (Middle) and Load (Right)

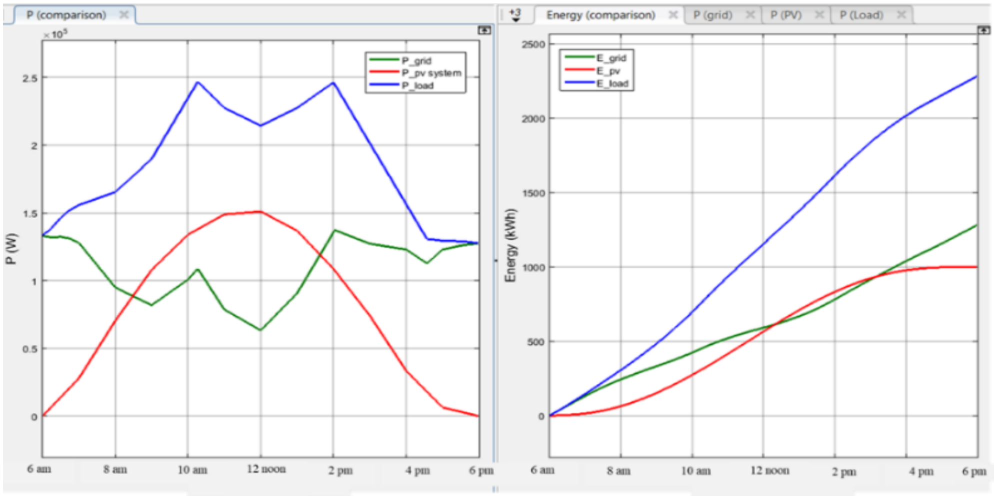


Fig.13. Power Comparison (Left) and Energy Comparison (Right) for winter

According to the simulation results, the power output from the photovoltaic system is more extensive than the rainy season. The maximum power output from the photovoltaic system is about 151.0 kW. This season, the energy supply from the grid is slightly larger than the supply from the photovoltaic system. On a winter day, the energy unit generated from the photovoltaic system is about 999.4 kWh. Thus, the required additional energy, about 1281 kWh, is taken from the grid.

D. Discussion

In the simulation model, the total installed capacity is 196.88 kW. The output power from the photovoltaic system is varied with input irradiation. Power output from the photovoltaic system is maximum in summer and minimum in Rainy Season, as shown in Figure 14.

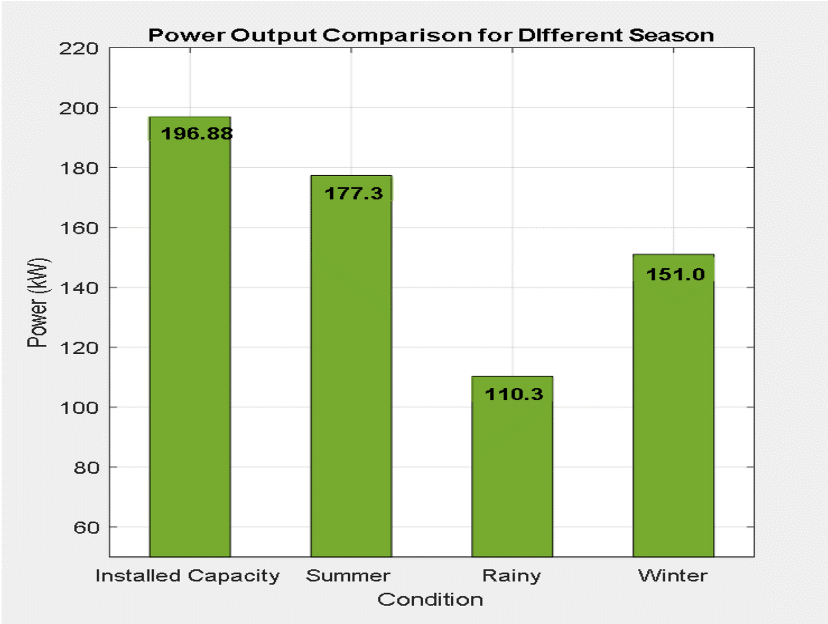


Fig.14. Power Output Comparison for Different Seasons

In the simulations, the load power demand is constant for all seasons. Under this condition, the total load used is 2282 kWh for all days between 6:00 am and 6:00 pm. Due to the limitation of the available rooftop area, only some portion of the load power demand can supply from the photovoltaic system, and the additional required power are taken from the grid. Figure 15 illustrates the energy unit generated comparison for different seasons.

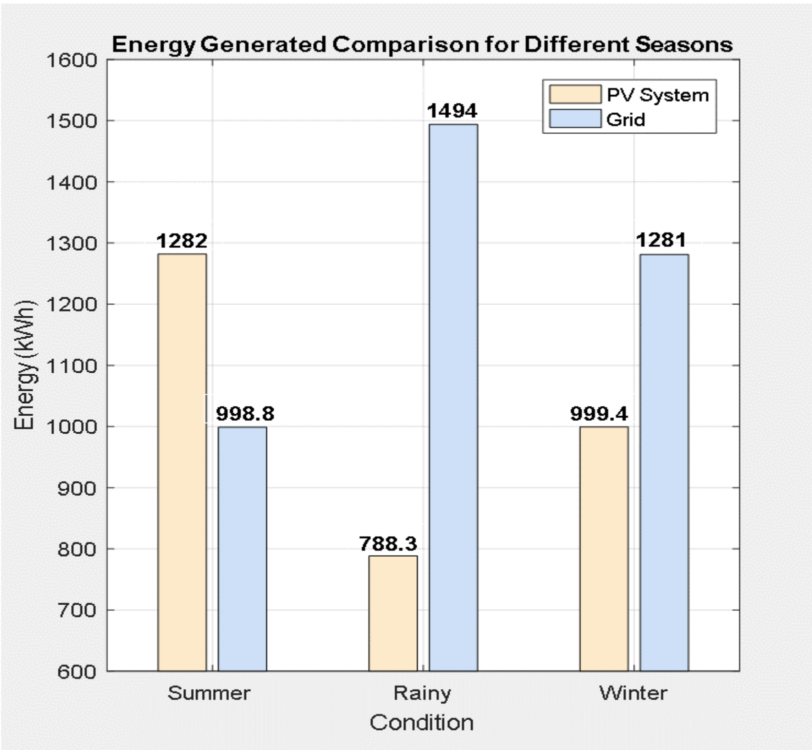


Fig.15. Energy Unit Generated Comparison for Different Season

Energy units supplied from the photovoltaic system are the highest energy in summer and lowest in the rainy season. A photovoltaic system can provide 56.2 % in summer, 34.5 % in the rainy season and 43.8 % in winter of the total required energy of an SAV building. Annually, the total energy supply from the photovoltaic system is about 44.8 % of the total energy. Thus, the electricity charges of SAV buildings can reduce using a roof-top photovoltaic system.

VII. CONCLUSION

In this process, the design, modelling and control of grid-connected rooftop solar photovoltaic system are presented for industrial buildings. For detailed study and practical application, the SAV building of Myanmar Pharmaceutical Factory was selected as a case study. Under the standard irradiation (1000W/m^2) and standard temperature (25℃), the complete photovoltaic system can generate about 196.1 kW. The simulation studies were carried out with actual load and irradiation data for the different seasons. According to the simulation results, the application of roof-top solar PV systems can reduce the electricity charges of industrial buildings.

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