International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Modeling and Analysis of Local Grid Behaviour Due to Increase Installation of Solar PV System at College of Science and Technology (CST)

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Abstract: ***This paper discusses the impact on the local grid due to the increased installation and integration of the Solar Photovoltaic system in the college of science and technology (CST). The modeling and analysis done in the MATLAB software were with the future provision of SPV system integrated into the local grid of CST. As of now, there is a hybrid photovoltaic system of three-phase 15.6 kW, a grid-tie photovoltaic system of single phase 5.5 kW, 7 kW of a single-phase standalone photovoltaic system, and a three-phase 10.08 kW grid-tied photovoltaic system yet to be integratedinto grid. With the real-time solar irradiance data collected, the solar PV to grid system has been modeled with both static and dynamic load. The real-time dynamic load has been collected and has been simulated in the MATLAB software with the real-time solar irradiance data collected. Power curves and Voltage Current (VI) characteristic graphs have been derived for analysis.***

Keywords: Solar PV System, Static Load, Dynamic Load, I-V Curve, Power Curve

1. Introduction

Generation of electricity by burning fossil fuels has been contributing significantly to global warming. It has become substantial for researchers and power-generating companies to adopt a more eco-friendly method of electricity production resulting in renewable energy gaining more popularity over the years. With this, its penetration into the grid has also been increasing due to which the per-unit cost of generation has been decreasing, benefiting the users with minimal negative environmental effects. Increase in the capacity and integration of the renewable resources in the grid has impacts on the grid these renewables are integrated to.

CST is located in the southern region of Bhutan with longitude 89.39° east and the latitude 26.85° north. CST receives power from two distribution transformers (three-phase), one rated at 750kVA and the other rated at 1000 kVA. The solar PV system mounted on the roofs of the CST buildings is integrated with a 1000 kVA transformer that supplies loads or powers to the library building, student mess and the common kitchen, student hostel RK, and president quarter.

CST's total connected load can be calculated to 5047.316 kW as of year 2020. The working load, or the actual load, consumed would be around 3028.3896 kW if the load factor taken was assumed to be 0.6. Over the winter break when the student hostels are mostly empty, the 1000 kVA transformer is normally underutilized. The load data of a 1000 kVA transformer with four feeders connected to it was registered or taken into account for research purposes especially during the times the loads are low.

The power produced by a grid-tied solar PV system is continuously fluctuating, effecting the power reliability (both active and reactive), which may influence the voltage profile and voltage stability of the grid it is integrated to.

This paper aims to compare and study the total energy or power that the installed solar PV system will generate and deliver to the load connected to the 1000kVA transformer. The comparative study between power generated by the solar PV system and power consumption will give a concrete idea of the power export and import to/from the grid. This paper will also guide the future PV system installation at CST.

2. Methodology

Thorough literature review on related topics were carried out to identifyand learn the modeling and analysis needed to be done. With the real-time connected load data, real-time solar irradiance data and real-time consumed load data collected, the local CST grid was modeled using the MATLAB software. The simulation results obtained were used to study the behaviour of the local grid.

3. Solar Photovoltaic System Modeling

Modeling of the solar PV system was done in MATLAB/SIMULINK software. Modeling was done for College of Science and Technology (CST) solar PV system of its existing installed capacity of 38.2 kW. It also consists of incremental MPPT algorithms and their implementation through a boost converter. Modeling was done to study and analyze the local grid behavior due to increased solar PV systems in CST for both static and dynamic load. The research work conducted mainly focuses on the amount of renewable energy systems that can be injected into the main grid in the future.

Figure 1 lays the outline of the modeling done. It represents the grid-tied solar PV system, which includes the PV array, boost converter, inverter, MPPT controller, Local Grid, and the load.

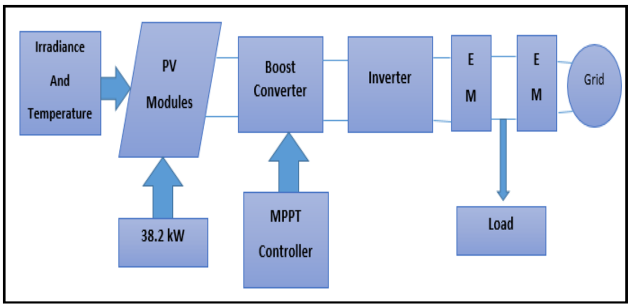

Figure 1: Block diagram of grid-connected PV system

3.1 PV module

A PV system consists of various kinds of PV modules. In the simulation of the solar PV system to study the local grid behavior in MATLAB monocrystalline-made solar panels are used with 325Wp. Technical detail of the PV module used for the system is given in table 1.

Table 1: Panel specification of one of the system

Parameters	Specifications
Power output	250 W
Maximum voltage(V_{MPP})	29.95 V
Maximum current(I_{MPP})	8.35 A
Open current-voltage(V_{OC})	37.2 V
Short circuit current(I_{SC})	8.75 A
Module efficiency	15.54 %
Number of cells	60

As per the theoretical calculations, the output generated from the module should be 38.2 kW. The parameters in the module were set so that the total generated power generated was 38.2kW at 1000 watt/m^2 solar irradiance and a temperature of 25°C. The real-time solar irradiance data collected from the microgrid lab using the instrument Pyranometer was fixed on top of the new librarybuilding of CST.

For the real-time solar irradiance data, the maximum power output from the solar panels wasn't 38.2kW since the peak real-time irradiance data was about 720watt/m^2. The maximum power output was about 28kW as shown in figure 3.

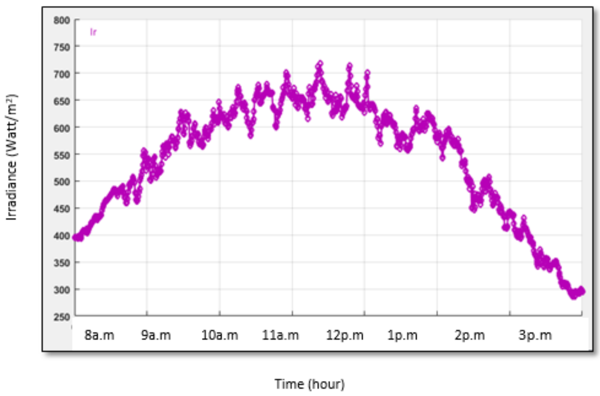

Figure 2: Real-time solar irradiation data

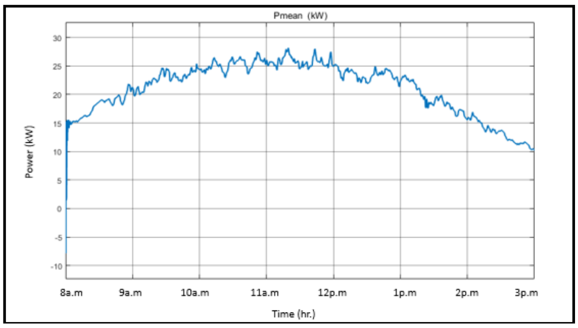

Figure 3: Real-time power output from the SPV system

3.2 Boost Converter

One of the most basic types of the switch-mode converter is the boost converter [6]. It takes an input voltage, and boosts or enhances it, as the name implies. A boost converter in this case was used to raise or increase the solar PV array MPP output voltage (VMPP) from 290V at STC to 700V. The switching frequency of the boost converter in this case is 5 kHz. The MPPT controller here generates the required duty cycle of the Boost converter.

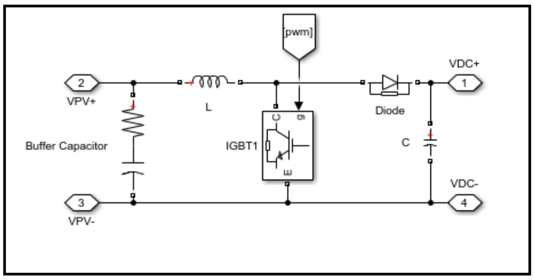

Figure 4: SIMULINK model for boost converter

Specification

- V input = 250 to 350V
- V output = 700 V
- Rated Power = 38.2 kW
- Switching Frequency Fsw = 5 kHz
- Current ripple ΔI = 5% of input current
- Voltage ripple = ΔV = 1% of output voltage

$$\text{Input Current} = \frac{\text{Rated Power}}{\text{V input}} \quad [I]$$

$$\text{Output Current} = \frac{\text{Rated Power}}{\text{Voutput}} \quad [II]$$

$$L = \frac{\text{Vin (Vout} - \text{Vin)}}{\text{Fsw} \times \Delta I \times Vout} \quad [III]$$

$$C = \frac{\text{Iout (Vout} - \text{Vin)}}{\text{Fsw} \times \Delta I \times Vout} \quad [IV]$$

3.3 MPPT

Since solar irradiation changes over time, the output voltage and power fluctuates as well. It is difficult to maintain a steady output PV voltage. This is accomplished through the use of MPPT. MPPT algorithms are commonly utilized in PV system controller designs. To have the maximum power output from the PV system at all times, the algorithms take into account variables such as fluctuating irradiance (sunlight) and temperature.In a PV system, the approach of using an incremental conductance compares incremental conductance to instantaneous conductance.It boosts or decreases the voltage depending on the outcome till the point where the maximum power point (MPP) is reached, and once MPP is obtained, the voltage remains constant.

3.4 Inverter

In a grid-connected solar photovoltaicsystem, the inverter plays a vital role. The inverter's primary duty is to convert the DC-DC converter's changing DC voltage output into an AC voltage of acceptable amplitude and frequency, as well as high quality (which includes low harmonics and EMI). Thus, this AC output can be fed into the grid. Although the PV array generates DC energy, the grid energy is AC. The generated energy should be transformed into AC energy with regulated amplitude, phase, and frequency before being sent to the grid. An Inverter was employed to accomplish this.

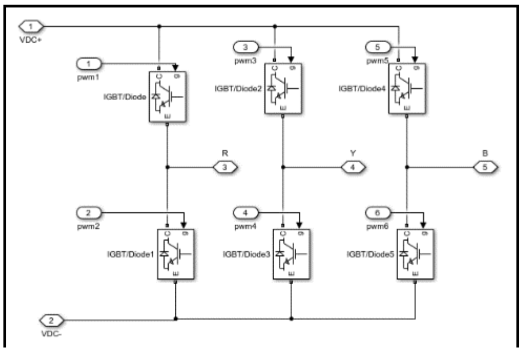

Figure 5: SIMULINK model of inverter

4. Modeling With Static Load

With the recorded solar irradiance data and with the standard temperature of 25°C, the grid was simulated with assumed static loads. Unlike dynamic load, the load here is constant throughout the day. One value of the load assumed (10kW) was lower than the solar power generation capacity of SPV installed in the campus and the other value (50kW) of the load assumed was higher than the solar power generation capacity of SPV installed which is 38.2kW. This was done to study the grid behavior when the connected load to the system is lower than and also higher than the power generated by the installed solar panels on the campus.

4.1 Simulation model

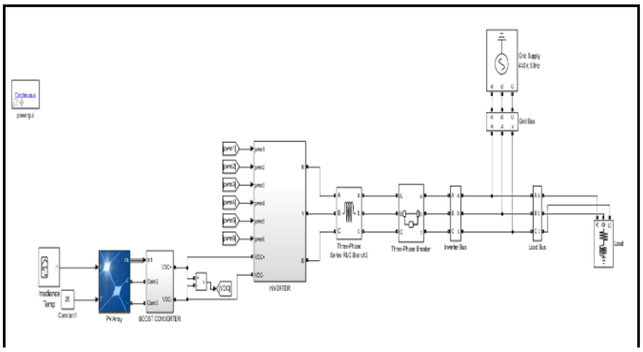

Figure 6: Model of static load

4.2 Analysis

When the PV system's power output is zero for a 50 kW connected load, the load receives power from the grid. The power input from the grid reduces as the PV system generates more power. For example, at around 9:30 a.m. in Figure 7, PV system power generation is approximately 25 kW, and grid power supply is 25 kW, totaling 50 kW. At 2:30 p.m., the PV system's power output is about 9 kW, while the grid's power output is more than 41 kW.

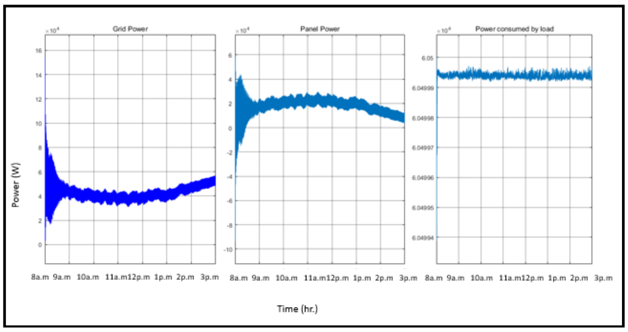

Figure 7: Power supply from PV system and grid to 50 kW load

In the case of a 10kW load, the PV system's power supply is greater than the connected load. When the PV system generates 0 kW of electricity, the grid supplies 10 kW of power to the load at 0 sec or the beginning. As power generation in the PV system begins at around 8:30 a.m. to 9 a.m., power from the grid is turned off. In this case, the PV system provides power to a 10 kW load. When the PV system's power generation exceeds the connected load, excess power is pumped into the grid. For instance, the PV system generates approximately 25 kW at around 10 a.m. 10 kW is delivered to the load, with an additional 15 kW added to the grid as shown in figure 8.

If all PV systems produce rating power in this scenario, free electricity would be pumped into the grid. Bhutan currently has no feed-in tariff regulations in place, which means CST would be pumping electricity into the grid without receiving any compensation.

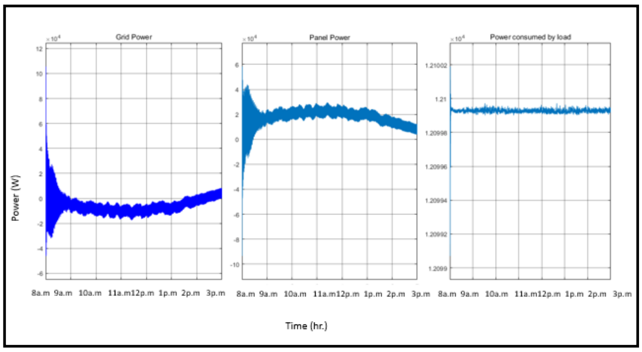

Figure 8: Power supply from PV system and grid to 10 kW load

5. Modeling Dynamic Load

After modeling the local grid with assumed ranges of static load, the load grid was modeled with the changing or varying load of the CST campus. The areas taken into consideration were feeders connected to a 1000 kVA transformer located below helipad, CST. The simulation of the local grid with the dynamic load connected gave the idea of real-time power consumed, power generated, and excess power.

5.1 Data Collection

Real-time power consumed by loads connected to the transformer was recorded with the help of Fluke 435, Series 2, and power quality and energy analyzer. The power quality and energy analyzer were connected to 4 feeders collecting the data from the student service officer quarter, student hostel RK, student mess, and the college president quarter. The PQA measured and recorded the data at an interval of 30 seconds. The PQA was connected to each feeder for a week. The average power recorded was in terms of active power (MW) and reactive power (MVAr) which were input used during the modeling process.

5.2 Load Data

After the load data collected using PQA, the load consumed by four residences were added at a particular instance of time from 8 a.m. to 3 p.m. and was given as input to the dynamic block in MATLAB Simulation model of the CST local grid. The maximum average power consumed was around 32.5kW in the morning hour at around 8:40 a.m. and the lowest power consumed was around 1.55kW at around 10:47 a.m.

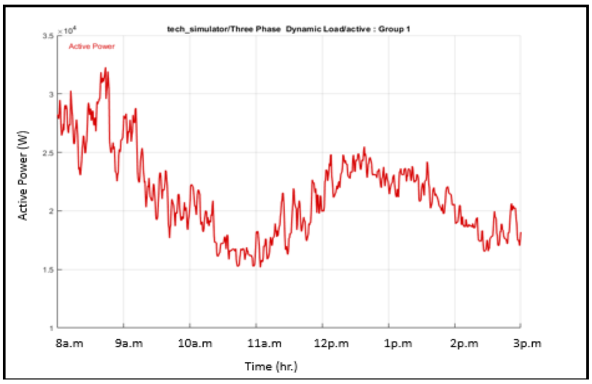

Figure 9: Active power consumed by the load

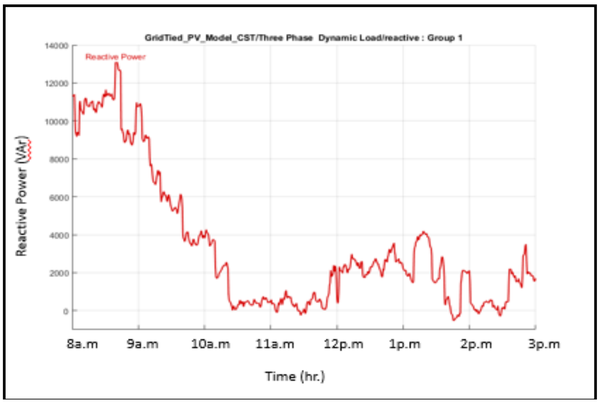

Figure 10: Reactive power consumed by the load

5.3 Simulation model

The model consists of a three-phase circuit breaker that isolates the SPV from the grid and the three-phase load to study the grid behavior with and without the SPV system.

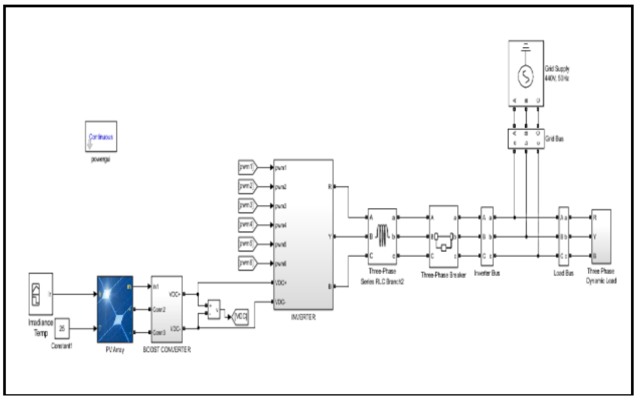

Figure 11: Model of dynamic load

5.4 Grid behavior without solar PV

The local grid simulated in the MATLAB Simulink software was studied, considering disconnected SPV generation. The three-phase circuit breaker block allows this function. When the circuit is kept open, the power from the SPV is disconnected from the system and the power to the load is solely given by the grid. However, there is some residual current in the circuit breaker resulting in some power from the SPV.

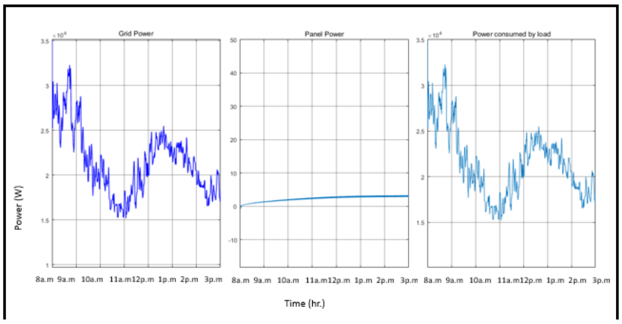

Figure 12: Simulation results of Grid power, SPV Power and Load (without SPV)

The power to the load here is supplied solely by the grid. The circuit breaker is kept open in this case. For example, at around 8:30 am the power consumed by the load was around 28.48 kW. This power is fully supplied by the grid. A small power of 1.124 kW was supplied from the SPV due to the residual current in the circuit breaker

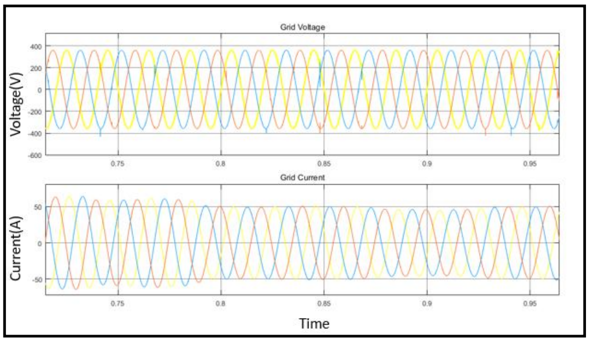

Figure 13: VI characteristic graphs of Grid (Without SPV)

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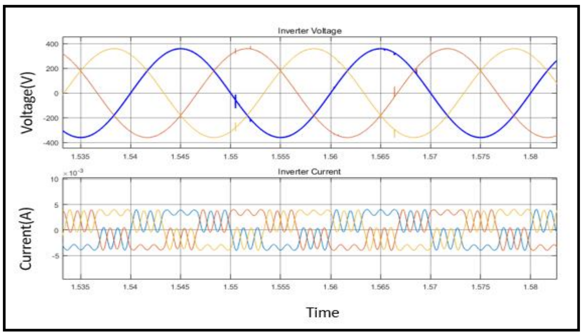

Figure 14: VI characteristic graphs of the inverter (Without SPV)

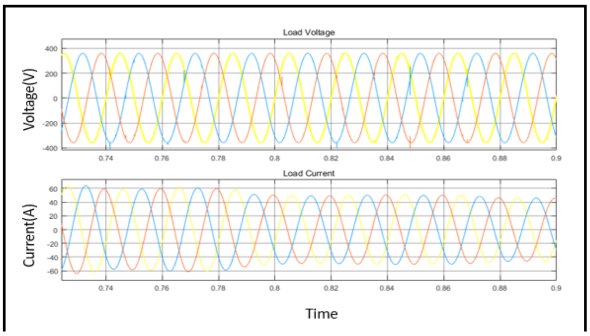

Figure 15: VI characteristic graphs of load (Without SPV)

When the solar PV system is disconnected from the system, the VI characteristic of the grid and the VI characteristics graph of the load is identical which implies that power is solely supplied by the grid. Due to some residual current, there is very small power received from the solar PV.

5.5 Grid behavior with solar PV

The circuit breaker in this case was closed. The graphs obtained from the simulation shows the varying power consumed by the load, power supplied by the grid, and the power supplied by the solar PVs. The power consumed by the load is first supplied by solar PVs. If the power supplied by the solar PVs is insufficient, the power is drawn from the grid as shown in figure 16.

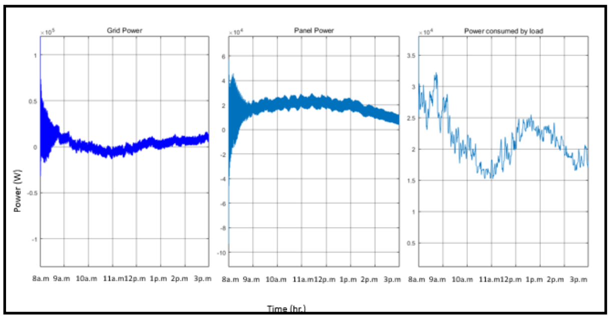

Figure 16: Simulation results of Grid power, SPV Power and Load (with SPV)

For instance, at around 8:40 a.m. the power consumed by the load is 31.03 kW. The power supplied to the load by the SPV system (Inverter power) is 16kW, which is not enough to satisfy the load demand. Therefore, the extra power of 15.03kW is drawn from the local grid. When the power generated by the SPV system is enough to satisfy the power consumed by the load, there is no power drawn from the grid. At certain instances of time, the power generated by the SPV satisfied the power demand of the load, even leaving excess power generated by the solar PV system.

For example, at around 11:10 a.m. the power demand or consumed by the load is around 15.77kW, and the power supplied by the solar PV system is 26.88kW, leaving an excess power of 11.11kW, which may be injected into the grid.

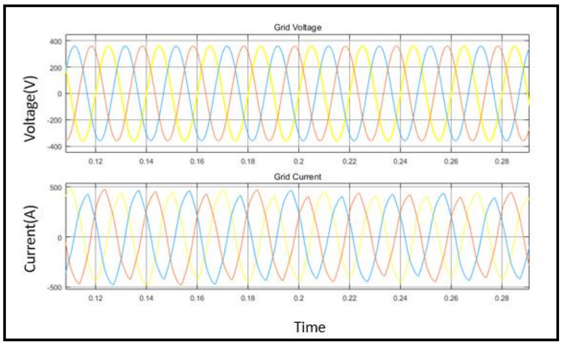

Figure 17: VI characteristic graphs of Grid (With SPV)

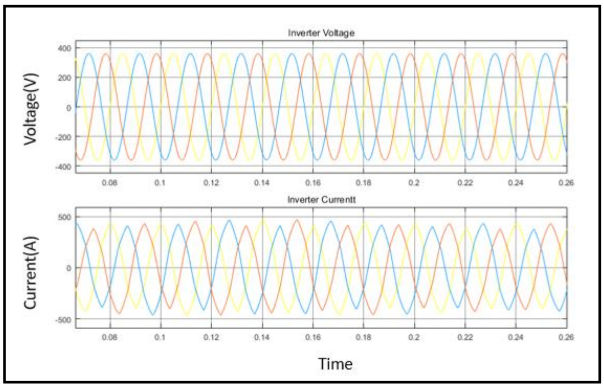

Figure 18: VI characteristic graphs of the inverter (With SPV)

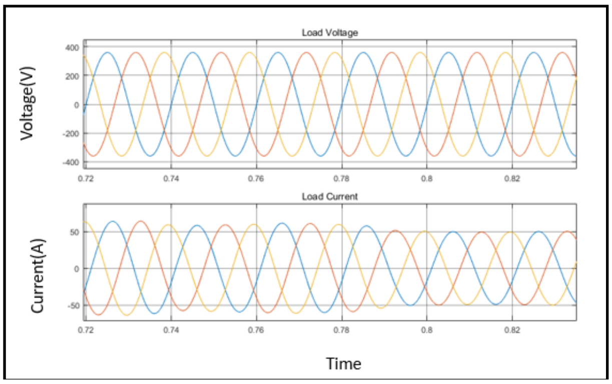

Figure 19: VI characteristic graphs of load(With SPV)

6. Conclusion

The studies of the impacts done before the actual installation and integration of the SPVs will give a concrete idea of the power drawn from the grid and the power given by the SPV system.

When modeling this SPV system with the connected real-time solar irradiance data, the difference between power fed to the load by the grid and the SPV system was obtained.

The assumed static load creates a scenario when the power demand of the load is lower than and when higher than the total power generated by the SPV system. When the constant power of 50 kW consumed by the load is higher than the power generated by the SPV system at the peak solar irradiance, the load first draws power from the SPV system and then from the grid. When the constant power of 10 kW consumed by the load is lower than the power generated by the SPV system at the peak solar irradiance, the load first draws power from the SPV system and there is excess power from the SPV system of 20kW hypothetically. This power may get injected into the grid or it needs to have a solution.

Unlike static load, the simulation done with the dynamic load gives a concrete idea of real-life possible excess power. From the graphs obtained and analysis done, at the instance of maximum generation from the solar PV system the power consumed by the load is much lower than this power, thus the possibility of excess power when the whole SPV system is installed in the CST campus is integrated to the grid.

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