

Load analysis of RUET, ECE building and design of a rooftop PV system to meet all its energy needs

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Abstract— In this research, Rajshahi University of Engineering & Technology (RUET), Electrical and Computer Engineering (ECE) building load is used to design an isolated PV system. Building yearly electrical load data and available roof area was collected. The system sizing is done using Homer Pro. The designed system consists of complete photovoltaic mini-grid systems. The total installment cost, operating and maintenance cost, and the complete system design and analysis are presented in the paper. The designed system dynamic simulations using Simulink are also included in the paper. A detailed analysis shows that the designed system can provide all the electrical needs of that ECE university building.

Keywords— Load analysis, PV mini-grid, Matlab/Simulink, inverter, battery, installation cost, control and protection, installation.

I. INTRODUCTION

Bangladesh is a densely populated country, developing and a probabilities country, with a small area. People need a considerable amount of electrical energy for living and production. However, electricity is generated from conventional sources. At present, 93% of the people have access to electricity, per capita generation is 464 kWh [1]. Power generation is mostly dependent on natural gas; around 60% of electricity is being produced from our gas reserve, the renewable percentage is only 1.6%. The demand for electricity in Bangladesh cannot be fulfilled with a limited amount of conventional energy. So it would try to use more amount of renewable energy [2].

The percentage of renewable energy-based generation is very samll. The total generation is 18,192 MW, but the renewable energy-based generation is only 518.6 MW, which is 2.85%, only including hydro [3] [4].

In this research, the focal point is to study the installation of the solar mini-grid systems for electricity generation and mitigate the necessary power demand at the ECE building in Rajshahi University of Engineering & Technology (RUET), Bangladesh (Northern part of Bangladesh)[5].

II. SOLAR RESOURCE ANALYSIS

At that location, the amount of hours of sunlight each day throughout a year is shown in Fig. 1. The overall solar resources for that location is shown in Fig. 2. Solar radiation varies from season to season in this country and receives an average daily solar radiation of 4-6.5 kWh/m². In a recent study conducted by the renewable energy research center, it is found maximum amounts of radiation are available in the month of March-April and minimum in December-January. In Bangladesh, the average solar energy per square meter is 193 W, whereas the current consumption per square meter is only 0.17 W.

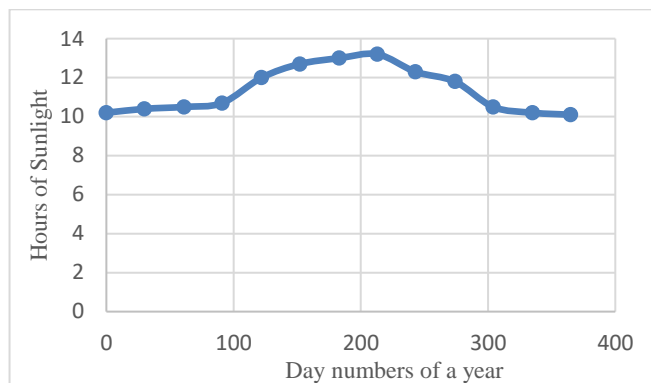


Fig. 1 The year-round sunshine hours scenario in Bangladesh [5].

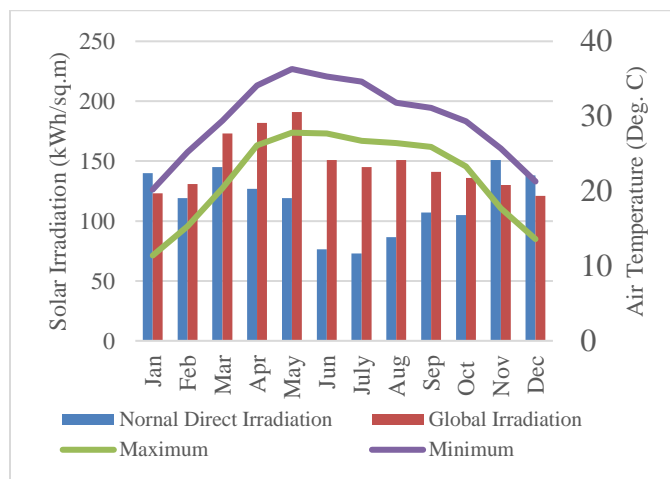


Fig. 2 Yearly solar radiation and temperature data

The selected place is considered in Rajshahi, Bangladesh. Based on the Homer software analysis, the minimum wind speed for power generation is 0 m/s, the maximum value is 7.1 m/s, and the average wind speed is 1.1 m/s, which is not sufficient. The average daily solar radiation is 4.88 kWh/sq.m/d, which is enough to generate heat or electricity. The average minimum and maximum temperature are the 11.4°C and 36.3°C, respectively.

III. BUILDING FEASIBILITY STUDIES

Rajshahi University of Engineering & Technology (RUET) is one of the largest engineering university in Bangladesh. There are almost 15 numbers of 7 stored buildings, and almost 100 numbers of different categories of the building exist. Currently, there is no renewable energy-based energy supply system in RUET. The electric power is coming from the national grid. The total land area is 153 acres or 619169 m² among them at the end of the university residential halls; there are around 50 or 202343 m² acres of land is just space [6]. The rooftop is entirely free space, and it is sufficient for installing the necessary solar panel. The RUET ECE, building physical structure, is shown in Fig. 3.

The latitude of the location is 24.4 degrees, and the longitude is 86.6 degrees. The solar radiation of this place is an average of 4.87 kWh/m²/day, according to NASA.



Fig. 3 The ECE building, RUET

In this research, the focal point is to study the installation of the solar panel for electricity generation and mitigation of the necessary power demand at the ECE building in Rajshahi University of Engineering & Technology (RUET), Bangladesh. The available rooftop measurement RUET ECE building is shown in Fig. 4, which is 2734 m².

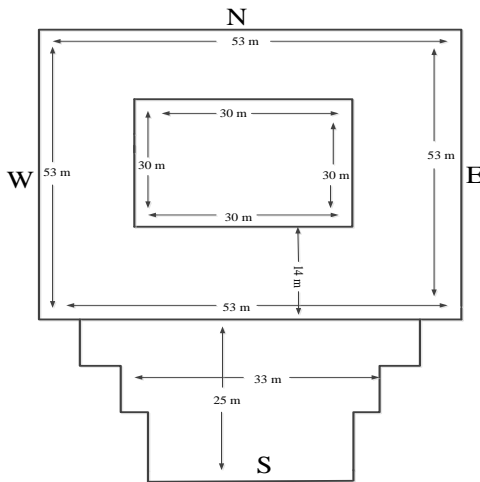


Fig. 4 The available rooftop space of RUET ECE building.

In the ECE building, most of the rooms are used for academic purposes. It is a standard four-storied building. The building total energy consumption is 58008 kWh. Based on the PV system types such as mini-grid, microgrid, etc., we have to design mini-grid systems to mitigate the all energy needs for the ECE building, RUET.

IV. BUILDING LOAD CALCULATION

The monthly electric meter readings of the ECE building shown in Fig. 5[7].

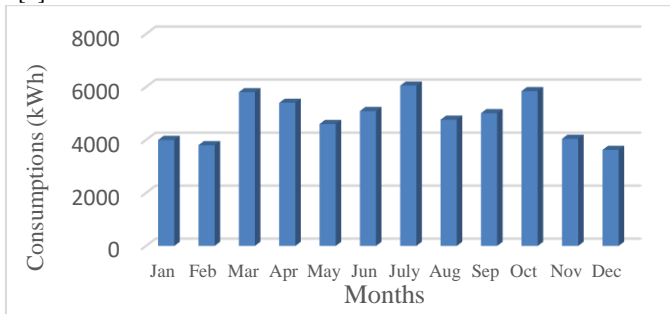


Fig. 5. The building monthly power consumption

The weather in Bangladesh is excellent, and the temperature in the winter and the summer is not a big difference. All load consumption is

the same around the year. Just a few air-condition (cooler) is connected in Jun/July months only. So, from the above figure, we can assume that the winter (December to February) month's consumption is lower, and the highest consumption is in the summer (June-July) [8].

- The average consumption in summer is 5570 kWh
- The average consumption in winter is 3806.6 kWh

It is found that the average solar radiation in summer is 5.2 kWh/m²/day, and in the winter it is 4.0 kWh/m²/day.

Yearly consumption (kWh)=sum(monthly consumptions (kWh))=58008 kWh

Average daily consumption (kWh)=yearly consumption (kWh)/(12×months×30×days)=161.1 kWh.

V. DESIGN AND OPTIMIZATION IN HOMER

The Homer software is a useful software for component sizing. The load profile has been given based on the actual use, and the other components have been selected as optimized. The components price is taken from the bdstall.com. The simulation steps are given below:

A. Load Profile

In Rajshahi Bangladesh, the total temperature is 25.8 deg, and solar radiation is 4.88 kWh/m²/day. RUET ECE building is an academic building. The operation time is 9.00 AM to 5.00 PM, two days a week is the holiday, and some lights are operating for the rest of the time. It is found that the peak load is 20 kW, and the scaled annual average is 161 kWh/day, as shown in Fig. 6.

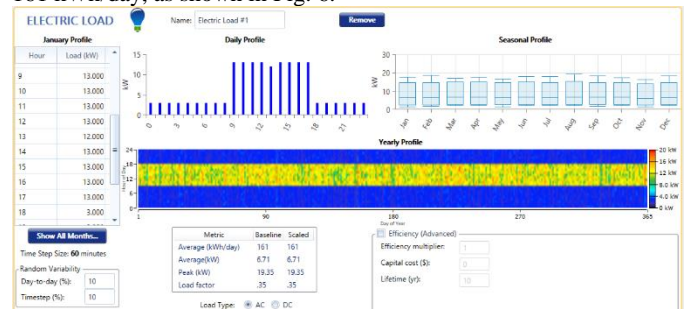


Fig. 6 The daily load profile of the ECE building.

Based on the peak load, a 25 kW inverter has been selected in this research. It may be one 25 kW or five numbers of the inverter with 5 kW each, but the actual inverter capacity and power in/out information will come from the homer optimization result.

B. Storage Battery

The solar energy is not constant, so for continuous supply, we need a battery bank. When the solar energy is available, then the battery will get the charge, and when not available, then the power supply will be continued from the battery bank. For this research, 12 V, 260 Ah lead-acid battery has been considered as shown in Fig.7. If I connect 30 numbers of battery in series, then the total voltage will be 360 V, which is called the bus voltage of a string. The number of batteries and the number of strings will be found from the homer optimization.

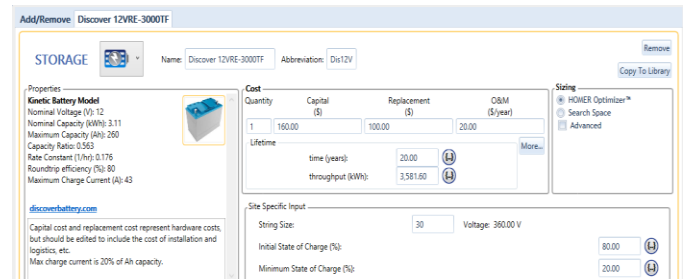


Fig. 7 selected DC Battery

C. PV Module

The solar PV module is the primary source of electricity generation from the sun. For this research, polycrystalline type 72 cells, 350 W solar module is considered with 24 nominal voltage as shown in Fig. 8. The number of PV modules will be found from the homer optimization result.

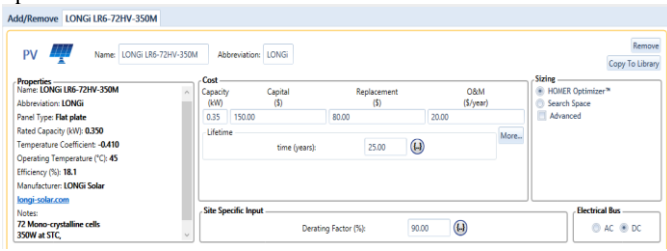


Fig. 8 Seven selected solar PV module

To get the maximum power output from the solar panel, the MPPT charge controller is essential that will make the sure maximum output of the battery bank. For this research, the charge controller is also used. The complete system schematic is shown in Fig. 9.

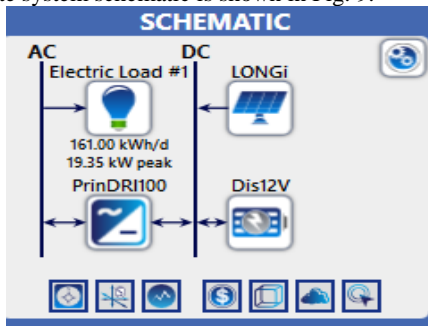


Fig. 9 The overall system schematic

D. Homer Optimization Result

The components size and market prices have been inserted in homer pro software. After running the simulation, homer software generated the optimization value of the overall systems. Homer generated so many optimization results; the system has been selected, which has lower cost, lower number of batteries, lower excess energy, etc. The Summary of the complete systems based on optimization result is given in the table below:

Description	Rating
The solar radiation in Rajshahi, Bangladesh	4.88 kWh/(m ² .day)
The average temperature in Rajshahi	25.8°C
Inverter size of(peak load 20 kW)	25 kW
PV system	Total Capacity: 70 kW. PV modules: 350 W, 72 cells, 24 V DC. Bus voltage: 360 V DC
Battery Bank (12 V, 260 Ah Led-acid)	No's of Batteries: 180 no's No's of Batteries per string=30 no's No's of parallel strings=6 no's Bus voltage= 360 V DC.
ECE building load	Peak load=20 kW. 220 V (single-phase) 380 V (three-phase) 50 Hz

VI. DYNAMIC SIMULATION IN MATLAB

The isolated mode overall system design [8], sizing and simulation procedure are given below:

A. PV Module Design

The nominal voltage of each 350 W, 72 cell PV module is 24 V, and the string voltage is 360 V is considered, each parallel string consists of 15 modules that make the 360 V DC bus voltage. To meet the full PV system capacity (70 kW), 200 no's of PV modules. The total number of the parallel string is calculated as 13.33; that is why 14 numbers of parallel string have been considered in this research.

B. Load Design

From the system sizing part, it is computed that the ECE building total peak load is 20 kW. The total is divided into two sections one is 10 kW, and another one is 10 kW, and a three-phase circuit breaker is connected in between the two loads for load switching purposes, as shown in Fig. 10.

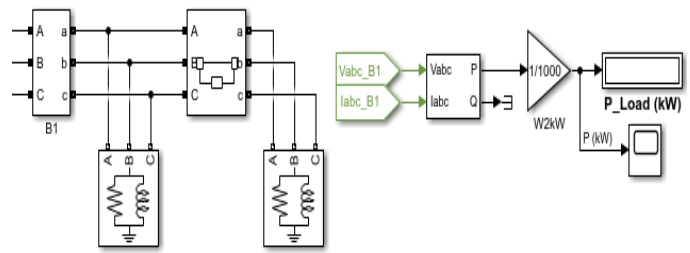


Fig. 10 The ECE building load

C. Battery Bank Design

For a continuous power supply, the battery bank is essential. Based on Homer optimization, the battery bank information is mentioned in the table (50% depth of discharge was assumed), and the Simulink model is given below:

- String voltage 360 VDC
- Current per string=260 A, total number of string=06 no's
- Battery Bank total Ah=260× 6= 1560 Ah

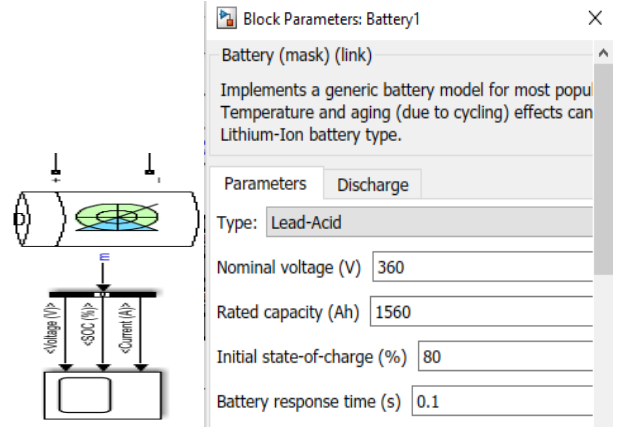


Fig. 11 The battery bank

D. The Complete Propose System Simulink Model

Based on the above design, the complete Simulink model is shown in Fig. 12 Where the control and protection system design will be discussed in the next section.

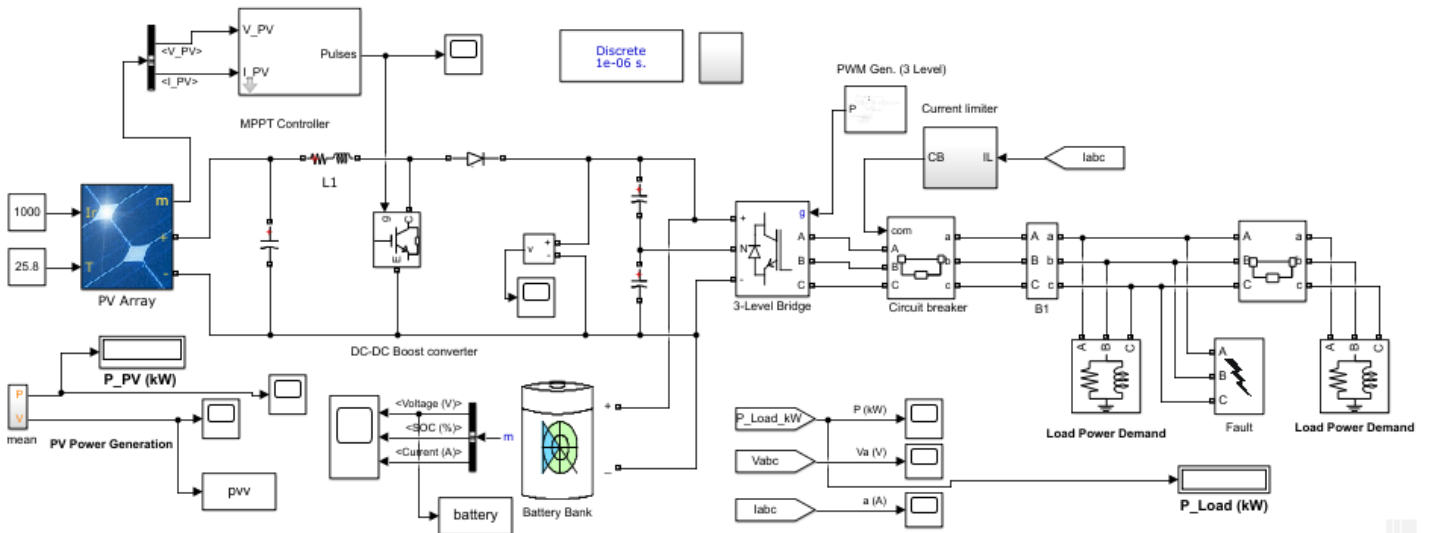


Fig. 12 The complete system Simulink diagram in Matlab.

E. Simulation Result

The dynamic system model has been designed and simulated in Matlab/Simulink environment. The simulation has been done only in private mode. The PV array open-circuit voltage is 380 V as shown in Fig. 13. The theoretical battery bank voltage is 360 V, and from simulation it is found that it is 370 V as shown in Fig. 14, so battery will take charge when needed. The load current is between 20 A and 40 A during half and full load respectively, which are shown in Fig. 15. The switching breaker changes the load power from 10 kW (half load) to 20 kW (full load).

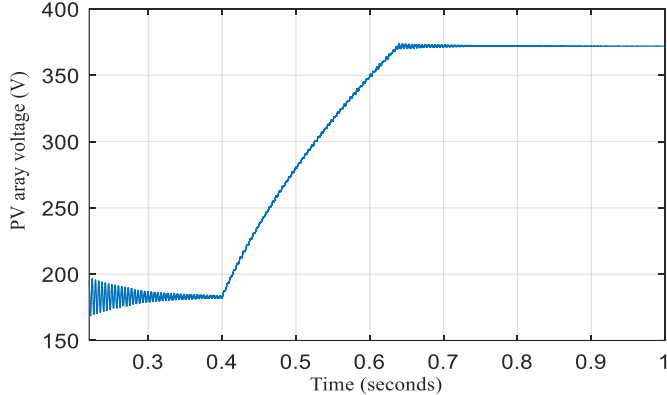


Fig. 13 The PV array voltage (V)

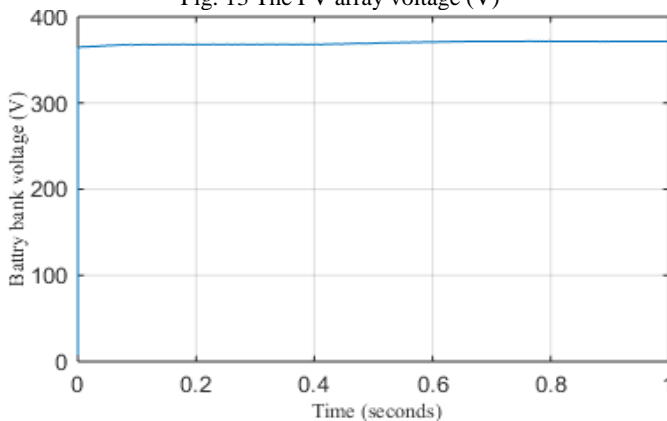


Fig. 14 Battery bank voltage (V) curve

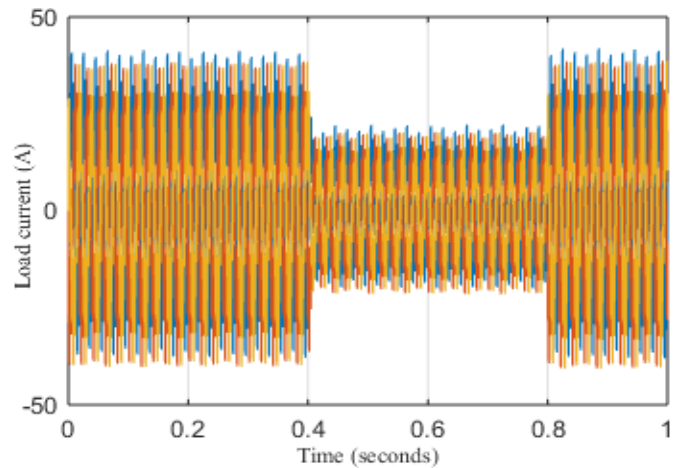


Fig. 15 The load is changing the current in Ampere.

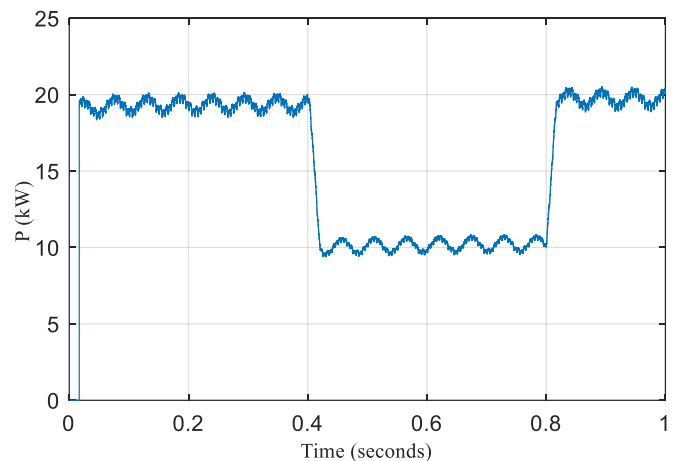


Fig. 16 The load power consumption in changing load conditions.

VII. Control and Protection System Design

In a PV firm, control and protection are very important to protect the equipment and supply continuous power. The protection plan is given below:

A. Load Balance and protection

The ECE building load has been dividing into two Simulink block one is 10 kW, and another one is 10 kW, and a three-phase circuit breaker is connected in between the two loads. It will connect and disconnect the loads based on the given times. A current limiting controller has been connected in the mainline; if the line current is more then the rated (pre-set) value, then it will disconnect the load from the mainline thus, the load will protect from the damage. It is found that the load voltage, current, and power is stable and sufficient.

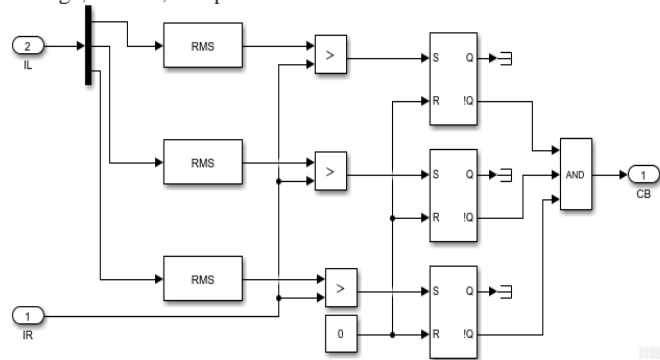


Fig. 17 The internal structure of fault current limiter.

B. Simulation Result

The standard system simulation result is shown in Fig. 15. A three-phase fault has been connected with the load and make a three-phase fault and observed the load power and current, as shown in Fig. 18, and Fig. 19 respectively. So, during the fault time at 0.8 s, the fault current limiter isolates the three-phase circuit breaker, and during that time, the voltage, power, and current are ideally zero. When the fault has been removed, the system will be healthy again.

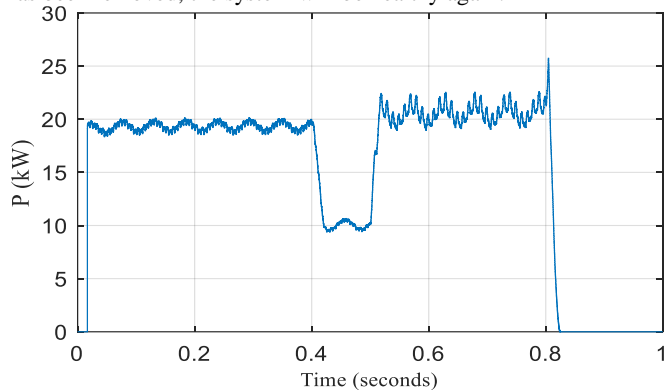


Fig. 18 The load power at the faulty condition

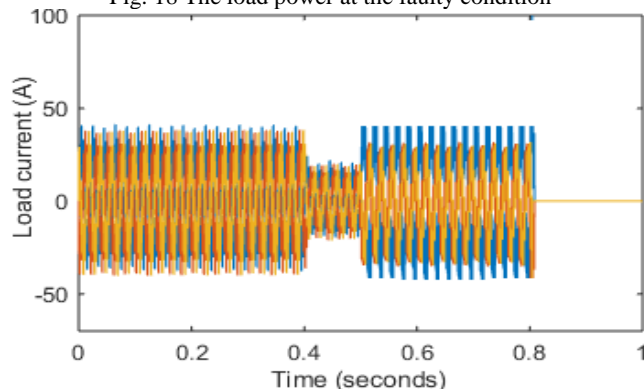


Fig. 19 The load current at the faulty condition

Conclusion

In Bangladesh, there are low wind resources, but the sunshine is excellent; that is why it is an excellent opportunity for solar PV based power generation that will mitigate the energy shortage. In RUET Bangladesh, all energy demand is mitigating currently from the grid power. The system components have been properly sizing by Homer software and verified the load demand mitigation by the Matlab software simulation. For safety issues, the control and protection system have been developed. The description of the MPPT charge controller, overcurrent limiter, has been clearly described. The PV array protection, DC and AC side protection, battery charging, etc. have been discussed. The simulation result proved that all control and protection systems are working correctly. If such a system is implemented in ECE building and all buildings then the authority can save substantial electricity bills. However, as the system has been designed in an isolated mode, that is why total implementation cost is comparatively high and needs vast numbers of the battery bank. The battery maintenance is a significant issue and hazardous. The better option is to design a grid-tie PV system that will be more flexible and cheaper and lower maintenance will be required.

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