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Complete Load Analysis of a residential Hall of CUET in Bangladesh and Design of a Roof Top Solar PV System

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ABSTRACT

In this paper a complete load analysis of a residential hall of CUET in Bangladesh is performed, and a roof top solar PV System is designed. At first the load of this building is estimated, and a complete daily load profile is developed. Using the estimated load profile, the size of solar array and other components are estimated. After that, a complete system is designed connecting the components of estimated rating and size. Additionally, an optimization of system is performed using HOMER. Furthermore, the dynamic response of the proposed system is analyzed using Simulink, MATLAB and based on this response essential control and protection schemes are incorporated with the system. The effectiveness of these schemes is also verified by MATLAB simulation.

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1. INTRODUCTION

With the advancement of modern technology, the demand of energy is increasing day by day. On the contrary, the reserve of fossil fuel which is extensively used to generate electricity is decreasing gradually. As a result, the utilization of renewable resources is becoming popular gradually. Although, hydroelectric generations are the leading energy sources, it is not appropriate for consumers at distribution end. Thereby, the usual renewable sources include solar and wind-based conversion systems. Among the sources the solar PV system is the most popular one [1–4]. The solar PV system utilizes the photon energy to produce electricity. The produced electricity is DC in nature. Thereby some power electronic equipment is required to convert this power to AC and useable to the consumers. Additionally, a storage system is usually installed with the solar PV system. The solar PV is becoming popular and it has several advantages like low transmission and distribution losses, cost effectiveness etc. [5]

Bangladesh is a small country in south Asia region having the area of 147570 Km^2. It lies between latitudes 20° and 27° and longitudes 88° and 93° east. It is an over populated country which needs a lot of electricity [5,6]. Currently Bangladesh has 20000 MW of installed capacity of electricity generation. In 2015, 80% of people were under the advantages of electricity. In 2018 the coverage has increased to 95%. [7]

Bangladesh needs 34000 MW of electricity to produce desired economic growth. Although most of the people are getting advantages of electricity directly or indirectly, the per capita consumption of electricity is very low in Bangladesh. Presently, the power sector of Bangladesh is mainly dependent on natural gas resources to meet the demand. However, it also has hydroelectric power plant at Kaptai, Chittagong and several coal based power plants [7–9]. Figure 1 represents the fuel sharing scenario for electricity generation in Bangladesh. From the figure it is observed that the country has 9843 MW of natural gas based generation which is approximately 53.8% of total generation [10]. The total installed capacity of Bangladesh is about 20000 MW, which also includes the renewable resources [7].

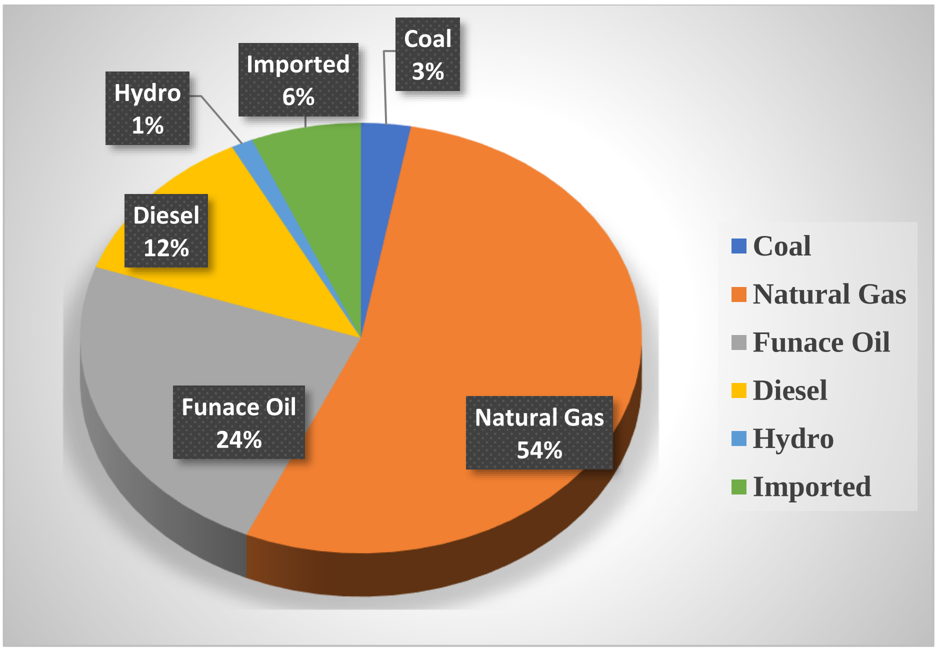


Figure 1. Fuel sharing scenario for electricity generation in Bangladesh [10].

Bangladesh although having adequate solar resources, the utilization of renewable energy is not sufficient. However, many projects and initiatives are taken to utilize solar energy recently in Bangladesh. Currently Bangladesh has about 17 MW of total solar and wind power generation. The weather condition of Bangladesh is very suitable for producing solar PV energy. This country has the weather condition to generate 20 GW of renewable energy [7]. At present, Bangladesh has 15 MW of distributed solar energy capacity which are being utilized to support rural household loads. The government of Bangladesh has already taken steps to set up nineteen grid connected solar power plant; those can contribute up to 1070MW in near future [7]. The government organization Bangladesh Power Development Board (BPDB) and other national and foreign Non-Government Organizations (NGO) are working together in various project regarding to renewable energy [6,7,11–14].

In Bangladesh usually two types of solar systems are used. They are solar home system (SHS) and solar microgrid system. A solar home system (SHS) is a small power supply unit which is appropriate for the residential load. Usually the solar home system includes solar panel, a small storage and a power conditioning unit. Solar home systems are useful for remote areas where grids are not available. However, it is not applicable for support medium or high load and the systems are not usually interconnected. On the other hand, solar microgrid is a small and integrated arrangement for converting solar energy to electricity. There many panels are interconnected as well as some controller and monitoring devices are embedded in the system. The loads of the microgrid may be distributed or lumped at a point [6,7,10,11].

Significant researches have been done based on renewable energy sector of the whole world as well as Bangladesh. However, the researches can be categorized into two main streams. One group of the researchers focus on the study of present scenario of renewable energy. They mainly discuss about the potentials and viabilities of renewable energy, status, government plan, market of renewable sources etc. The researchers in this stream usually present statistical data and analysis in their papers [5, 6,8,9,13–21]. However other group focus on designing renewable energy based systems and structure considering various technical specifications, limitations and other conditions [1–4,22–31].

In this paper, a total load analysis will be performed for Shahid Mohammad Shah Hall, a residential hall of CUET in Bangladesh. At first the load analysis will be performed, and a complete load profile will be developed based on the energy consumption data. Furthermore, the feasibility of a roof top solar PV system will be analyzed. After that, optimization of system will be performed using HOMER. Moreover, a dynamic simulation model will be built and required control and protection schemes will be designed for this model.

The paper is organized as follows. In section II the solar availability and load estimation for the proposed site is performed. The design, sizing and optimization of the roof top solar system is described in section III. The dynamic simulation and design of control & protection scheme is presented in section IV. At last a conclusion is drawn in section V.

2. THE SOLAR AVAILABILITY AND LOAD ESTIMATION FOR THE PROPOSED SITE

2.1. Solar radiation and Temperature Condition

Chittagong is situated at 22.3^0 latitude and 91.8^0 longitude. and the main port city of Bangladesh. This place has a great potential to generate solar energy as it has 120 Km of coastal beach. The average temperature profile of Chittagong is presented in Figure 2. Furthermore, the monthly radiation profile is presented in Figure 3. From these profiles it is observed that there is a very good scope to produce solar electricity throughout the year. However, from February to May the temperature is relatively higher, and it is considered as summer season. The average daily solar radiation is found 4.71 Kwh/m2/day.

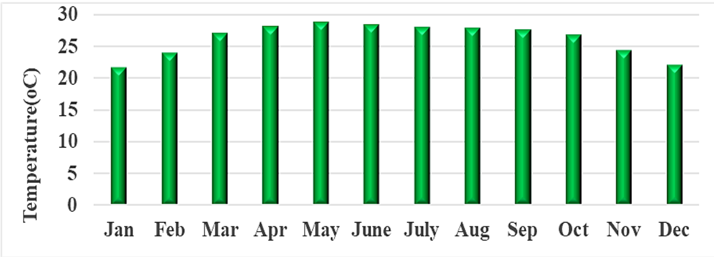


Figure 2. Monthly Temperature profile of Chittagong.

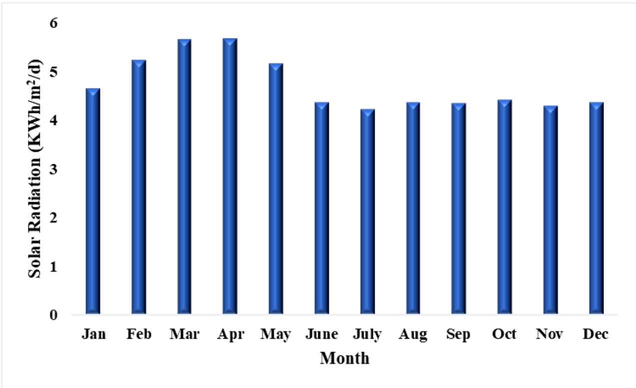


Figure 3. Monthly radiation profile of Chittagong.

2.2. Information and Load Estimation of the Proposed Site

Shahid Mohammad Shah Hall is one of the residential halls where approximately 400 students live. This building is a "Z" shaped building have a lot of potential for solar energy. Figures 4 and 5 show the location and the dimension of this hall, respectively. The total space available in roof top is calculated as $1319.15m^2$. Figure 6 represents the annual load profile of the selected building at CUET. Furthermore, Figure 7 represents an average hourly load profile of the selected hall. Considering the load profile, the average load is found 25.475 KW.

Figure 4. The Location of Shaheed Mohammad Shah Hall, CUET. [32]

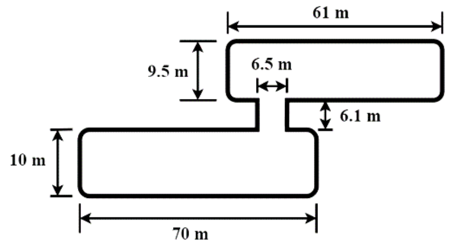


Figure 5. The dimension of Shaheed Mohammad Shah Hall, CUET.

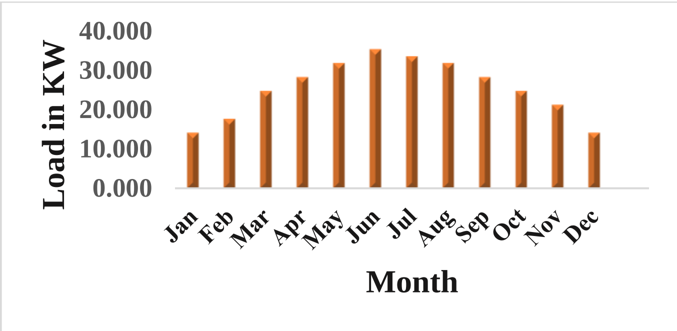


Figure 6. The annual load profile and solar radiation profile of CUET.

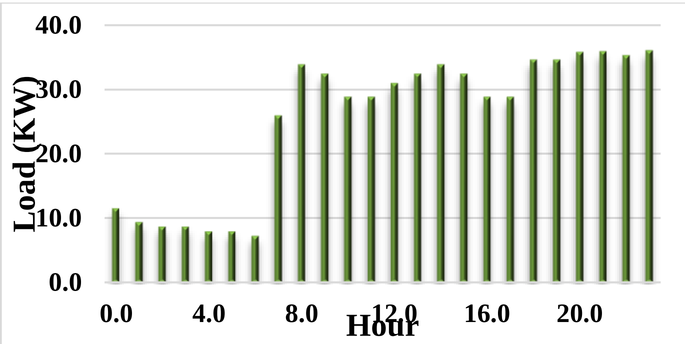


Figure 7. The hourly load profile of Shaheed Mohammad Shah Hall, CUET.

3. THE DESIGN, SIZING AND OPTIMIZATION OF THE PROPOSED SYSTEM

3.1. Design and Sizing of the Proposed System

For this system, considering the availability and cost 300W 30V solar panel is selected. For the storage system 12V 100 Ah batteries are selected. Table 1 shows the detail calculations and estimation of the amount of required solar panels. Furthermore, Table 2 presents the estimation of no. of required batteries. The DC bus voltage is selected at 360V considering the load, panel voltage and battery voltages.

Table 1. The estimation of the amount of required solar panels

Daily load:	25.475 KW
Daily Consumed Energy:	611.4 KWh
Monthly Consumed Energy:	18342 KWh
Average solar radiation:	4.71KWh/m2/day
Size of over all system (Daily Consumed Energy/ Average solar radiation):	129.8 ≈ 130 KW
Rated power of one panel:	0.3 KW
Derate factor:	0.77

Total no. of panel required (Size of over all system/(Rated power of one panel * Derate factor)):	562.77 ≈ 563
Total panel Space required:	1095 m^2

Table 2. The estimation of the no. of required batteries

Energy required at night:	305.7KWh= 25475 Ah at 12V
Total No. of battery required (required Ah/rated Ah):	254.75 ≈ 255

From the calculation we can conclude that the roof top has enough space to accommodate these number of panels as its total space is 1319.15 m^2. For the selected bus voltage, total no of solar panel required to be connected in series is 12 and the no. of parallel string required is 47. Consequently, the total system incorporates 564 no. of solar panels, which is approximately same of total no. of required panel. Similarly, for storage system 9 strings of batteries are required where, each string contains 30 batteries. As a result, the total system has 270 no. of batteries, which is the closest approximation of the total no. of required batteries. Furthermore, considering approximately 20% more than the rated system size, two inverters of 80 KW rating are selected for the system. The solar strings are divided into two halves and connected to each inverter. Consequently, one inverter incorporates 24 no. of parallel solar strings and other one has 23 strings. Similarly, for batteries one inverter has 5 parallel strings of batteries and another has 4 strings. Figure 8 shows the details connection layout of a subsystem which includes one inverter. The total single line diagram of the system is presented in Figure 9.

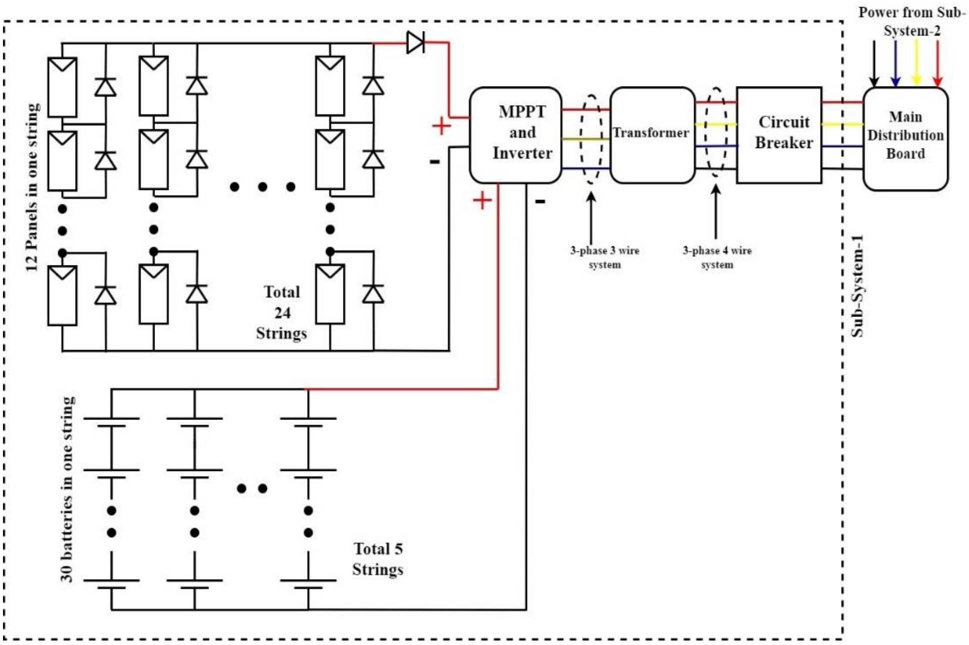


Figure 8. Detail connection diagram of the proposed system.

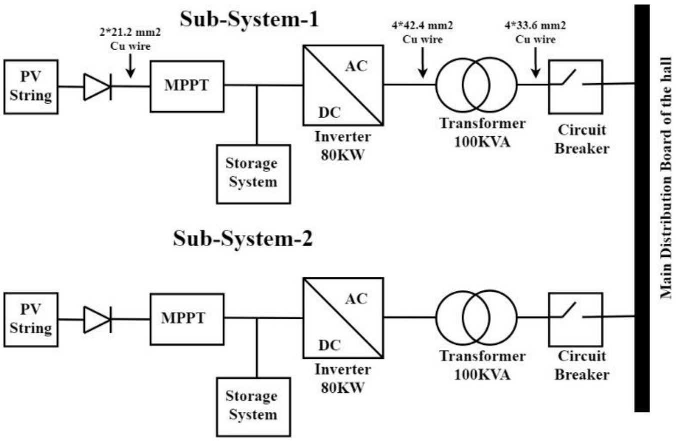


Figure 9. Single line connection diagram of the proposed system.

3.2. Optimization of the Proposed System Using Homer

The proposed system is also analyzed using homer software. The optimum generation and size of each components are achieved from the analysis using HOMER. Figure 10 shows the proposed system construction in HOMER software. The optimized result of the system suggested by HOMER is illustrated in Figure 11. Additionally, the electrical energy details of the proposed system is presented in Figure 12. It is observed that, the optimized system suggested by homer also contains very few extra energies. So, we can conclude our system can support the load effectively.

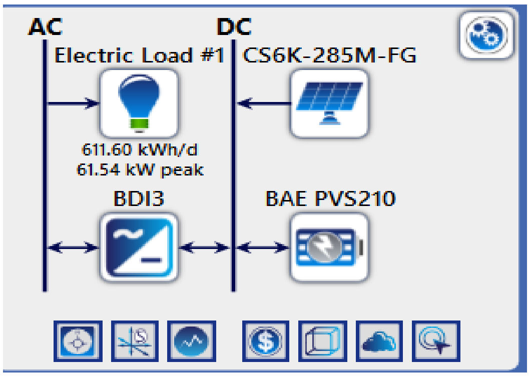
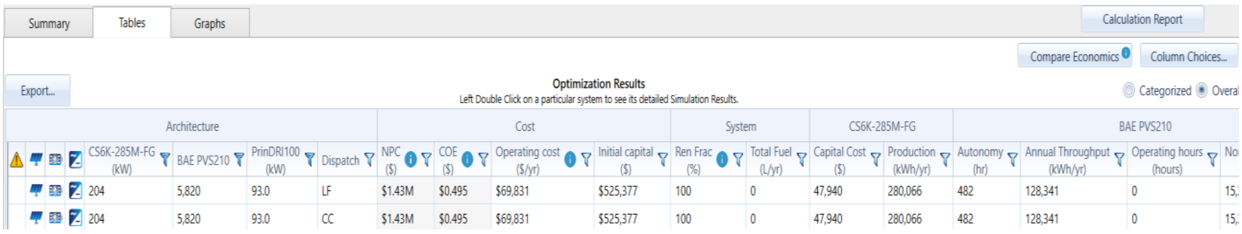


Figure 10. Construction of the proposed system in HOMER



Architecture				Cost				System		CS6K-285M-FG		BAE PVS210			
CS6K-285M-FG (kW)	BAE PVS210	PrinDRI100 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)	Operating hours (hours)	No
204	5,820	93.0	LF	$1.43M	$0.495	$69,831	$525,377	100	0	47,940	280,066	482	128,341	0	15,
204	5,820	93.0	CC	$1.43M	$0.495	$69,831	$525,377	100	0	47,940	280,066	482	128,341	0	15,

Figure 11. Optimized results obtained from HOMER.

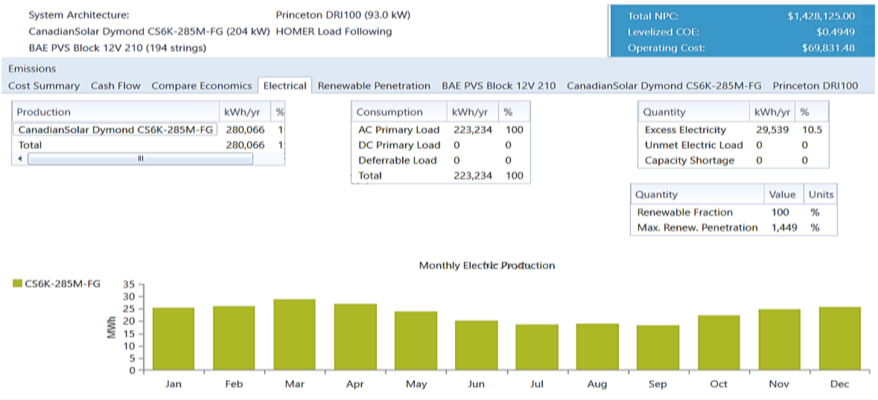


Figure 12. The electrical quantities details obtained from HOMER.

4. DYNAMIC SIMULATION AND DESIGN OF CONTROL & PROTECTION SCHEMES

4.1. Dynamic Simulation and Analysis

The proposed system is simulated in MATLAB R2017a. Figure 13 shows the model for simulation. Here the output of solar panels is connected to the MPPT (Maximum Power Point Tracking) converter. For this simulation Fractional Open Circuit Voltage MPPT Method is used [32-34]. A standard 360V bus is selected for connecting battery. The output of 360V bus is given to a DC-AC inverter. IGBTs are selected for switching purposes at a frequency of 20 KHz. Figures 14 to 16 represent the voltage at MPPT output, the load voltage, the load power.

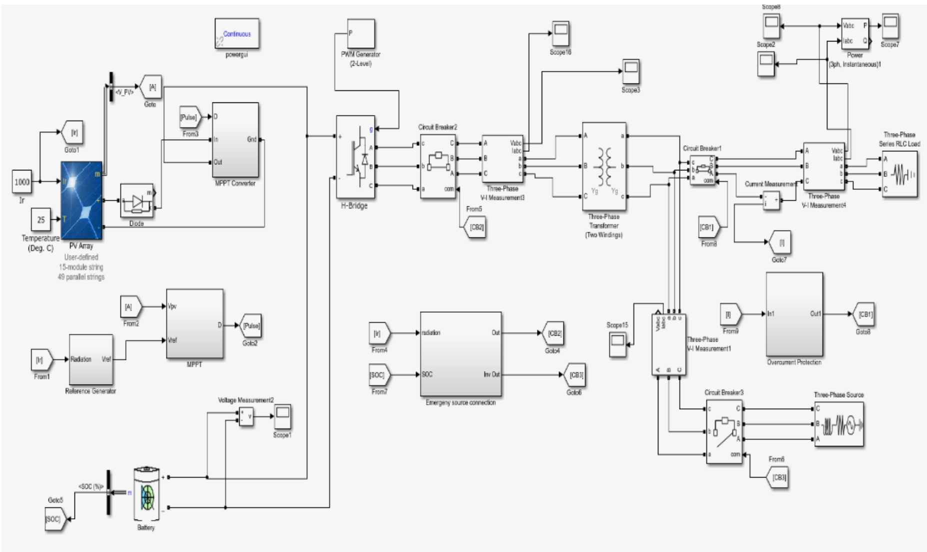


Figure 13. The complete Simulink model of the proposed system.

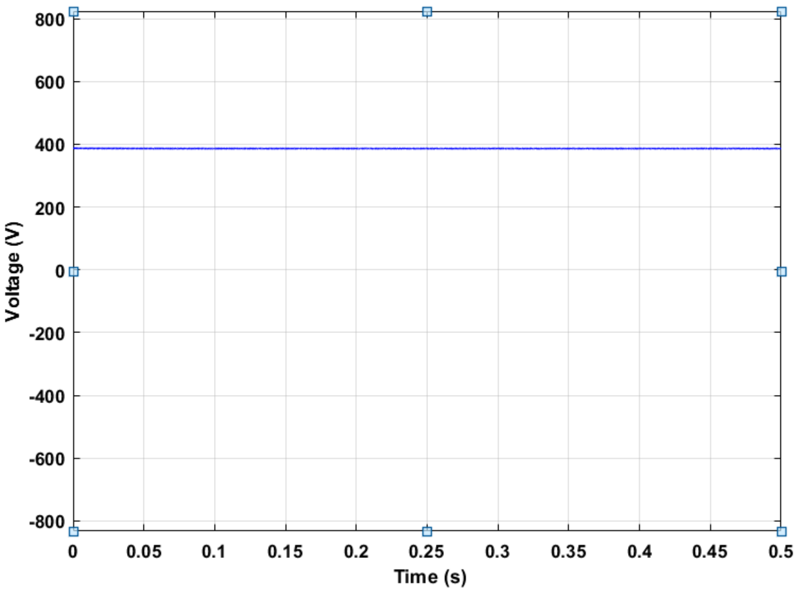


Figure 14. The Voltage at MPPT Output.

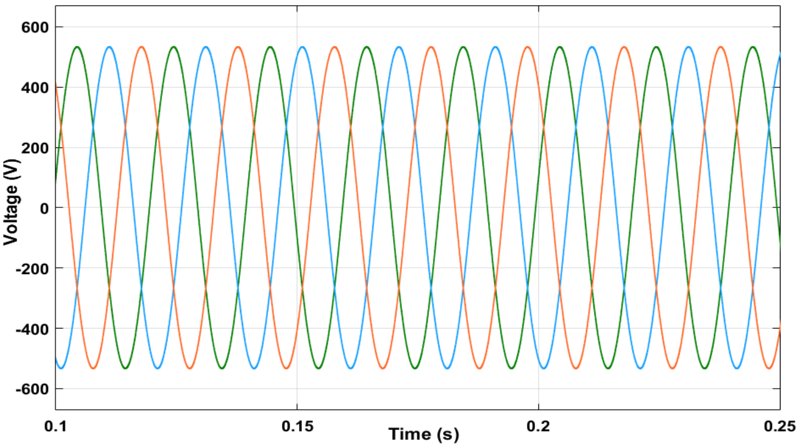


Figure 15. The Load Voltage.

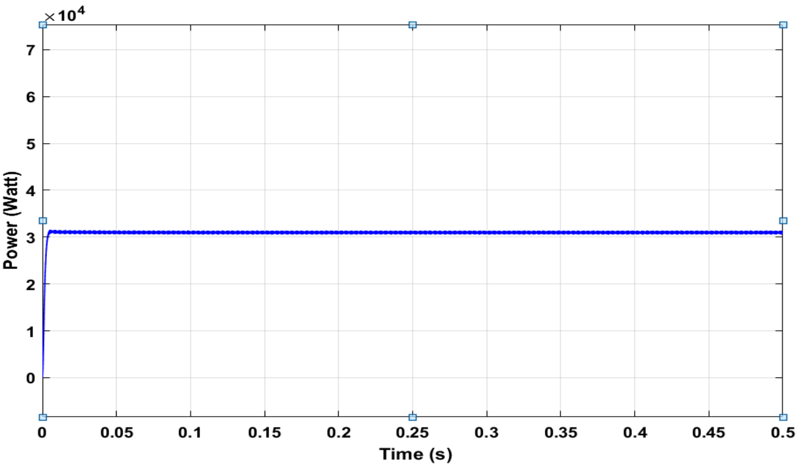


Figure 16. The Load Power.

4.2. Design of Control and Protection Scheme

4.2.1. MPPT Control Scheme

The output of solar panels is connected to the MPPT (Maximum Power Point Tracking) converter. For this simulation Fractional Open Circuit Voltage MPPT Method is used [33]–[35]. According to this algorithm the MPPT voltage is assumed to be a linear fraction of open circuit voltage. A close loop control system is designed to maintain the output at desired level. Figure 17 shows the MPPT voltage of the string which is achieved from the output of the MPPT converter.

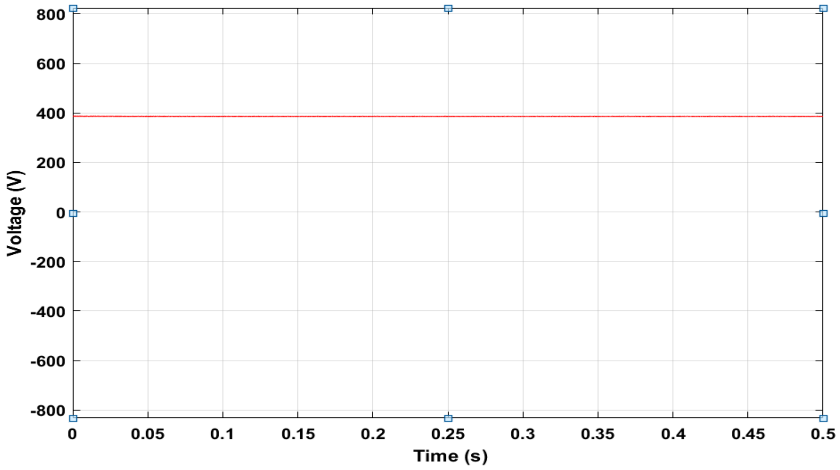


Figure 17. The MPPT voltage.

4.2.2 Overcurrent Protection

A circuit breaker1 (CB1) is used to provide protection against overcurrent. Figure 18 represents the overcurrent protection scheme used in the system. Figure 19 shows the functionality of this scheme after introducing a three-phase fault at 0.2s.

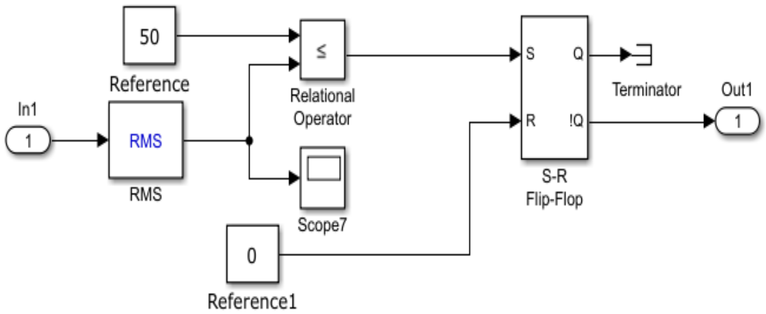


Figure 18. The overcurrent protection scheme.

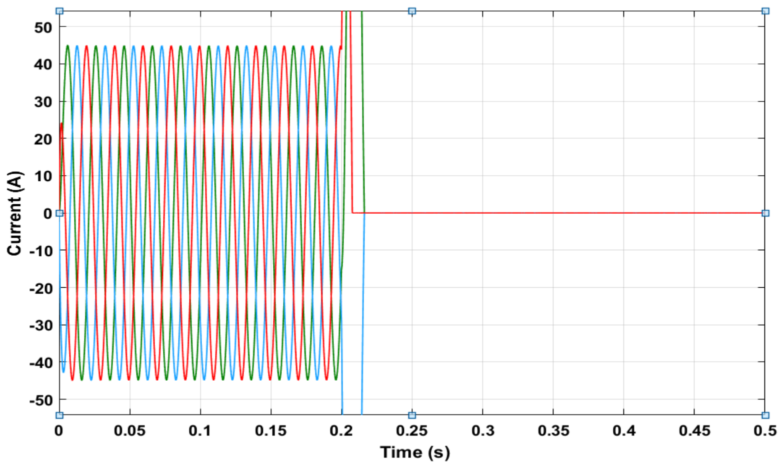


Figure 19. The Load current waveform after introducing fault at T=0.2s.

4.2.3 Emergency Source Connection

If at night, the battery charge level will be gone below 50% then an emergency source is automatically connected using circuit breaker3 (CB3) to avoid blackout. At this time, the CB2 will be automatically disconnected. The emergency source can be an embedded generator or grid. Figure 20 shows the emergency source connection scheme for the system. However, the waveform of grid current for such condition is presented in Figure 21.

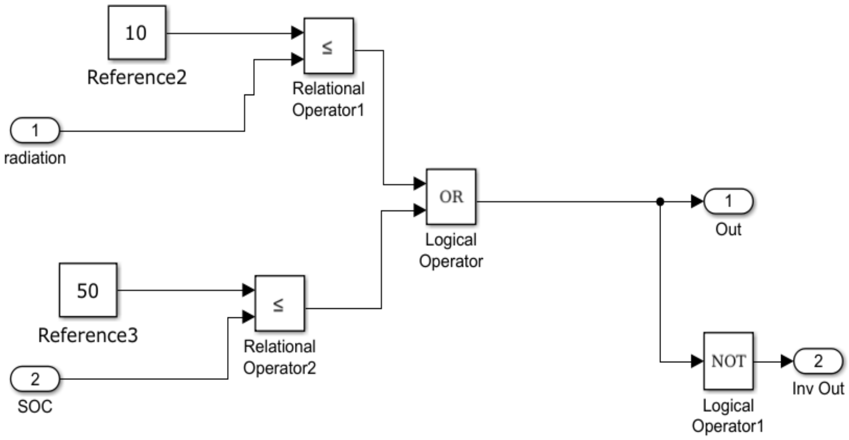


Figure 20. Emergency source connection scheme.

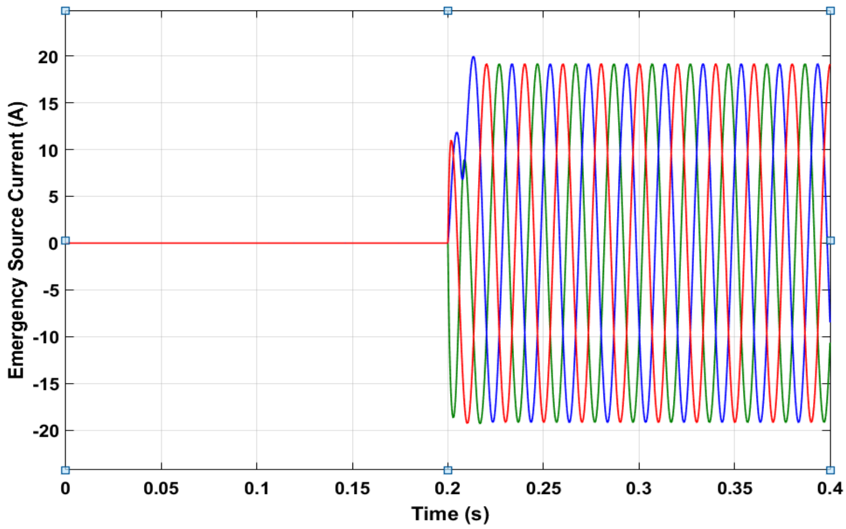


Figure 21. The waveform of source current, which shows that the emergency source is connected at T=0.2s.

4.2.4 The grounding System

The total system requires proper grounding system to be protected against any faulty situation. There are two types of grounding like DC and AC grounding is provided and both types of grounding wires are interconnected with each other. This type of grounding system is single point grounding, which meets the requirement of National Electrical Code (NEC). Without grounding system, the system may be damaged at the time of lighting or other faulty situations. Figure 22 shows the overall grounding system, which is indicated by green wires.

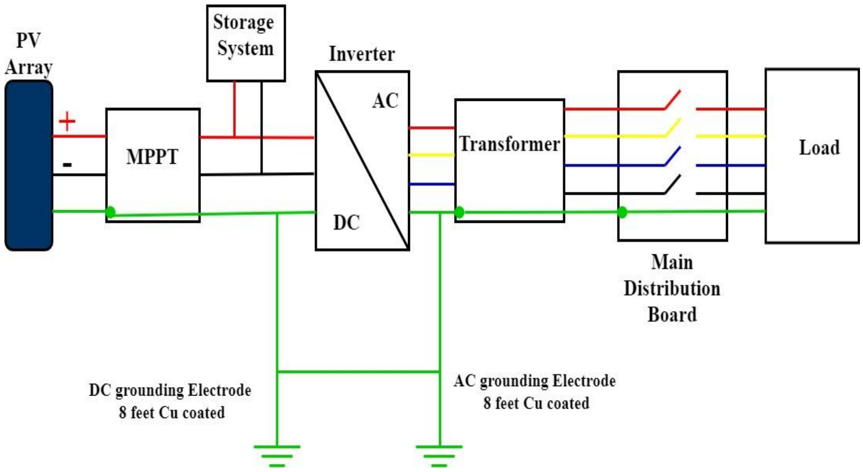


Figure 22. The grounding system layout.

5. CONCLUSION

A Complete Load Analysis of Shahid Mohammad Shah Hall, a residential hall of CUET in Bangladesh is performed in this project. After that, a Roof Top PV System is designed. At first the load is calculated, and the daily load profile is developed. Then the feasibility of the roof top solar panel system is analyzed using HOMER. After that, the total system is designed in Simulink, MATLAB to observe the dynamic response of the proposed system. The dynamic response of such system is found quite satisfactory. Different types of control and protection scheme is developed to make the system robust against any abnormal or changing situations. Form this study we can say that this system is completely feasible. The future works may include:

- This proposed system is an isolated system with having solar PV and battery storage. However, it produces some extra energy. For this reason, to design and analysis of a grid connected net metering system for such a building is a good future work.
- Some analysis can be performed using some other renewable resources like wind-based generation.
- The feasibility of roof top solar panel can be studied for academic and administrative buildings of CUET.
- The size of the proposed system depends on several issues. So, dependency of the sizing on different factors can be studied both theoretically and analytically.

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