Design and analysis of a rooftop PV system for a University Building in Pakistan

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***Abstract*-In this paper, the hourly load profile of a university building in Pakistan based on electricity bills is presented. Using the load profile, a rooftop PV system has been designed. Homer Pro software has been used for steady-state modeling and analysis of the system. The designed system comprises of 126kW PV, including 200, 12V, 205 Ah batteries and a 43kW inverter. Analysis shows that the designed system can fulfill all electricity requirements of the building. The dynamic simulation and analysis are carried out using MATLAB/Simulink. For maximum power output of PV, a perturbation and observation-based algorithm with a DC-DC boost converter have been selected for the system. Results show the designed system can provide stable voltage and frequency for a full load of that university academic building**.

I. INTRODUCTION

Currently, researchers and consumers are mainly focusing on renewable energy, as there is a massive demand for energy, and there are environmental concerns as well. Talking about Pakistan the difference between electricity demand and supply lead towards unavoidable load-shedding of 14-18 hour per day[1].

As an underdeveloped country, Pakistan needs a vast amount of energy to keep its economy and growth on track. Despite this, Pakistan is struggling hard to assure uninterrupted power supply and is currently in the most severe energy crisis of its history [4]. The use of energy in Pakistan has risen significantly in the past ten years following the trend of other developing countries [5].

II. SOLAR PHOTOVOLTAIC POTENTIAL IN PAKISTAN

Pakistan has plentiful renewable energy resources because of its strategic location. Many researchers observed RE resource availability in the country[1, 2-3]. The primary focus was on solar energy [2,3].
The United States National Renewable Energy Laboratory (NERL), together with the Alternative Energy Development Board of Pakistan (AEDB), has quantified the solar energy potential in Pakistan [9]. Pakistan is receiving 15.5_1014kWh of solar radiations yearly, receiving 8–10 hours of daylight in most of the areas, on average [9].

The first 178.08 kW solar PV system was operational at Pakistan Engineering Council (PEC) building and Planning Commission building in 2010 selling excess energy to Islamabad Electric Supply Company (IESCO). Fig. 1(a) shows the project site. A solar PV system of 2 MW was installed on National Assembly (NA) of Pakistan, this project also feeds excess energy to the national grid after fulfilling its own energy needs. The site is shown in Fig. 1(d). National Assembly of Pakistan is now the first parliament in the world, which is fulfilling all its energy needs from solar PV systems [5].

During the year 2015-16, Quaid-e-Azam Solar Park (QASP) was commissioned, which is having a generating capacity of 100 MW and has produced 25 GWh. On the other hand, three solar projects having capacity100 MW are in developing stage at QASP [4,5]. Fig. 1(b) shows the site of QASP.

Pakistan Council of Renewable Energy Technologies (PCRET) is also organizing trainings on maintenance and use of RE equipment [6]. Fig. 1(c) shows the solar cooker made by PCRET.

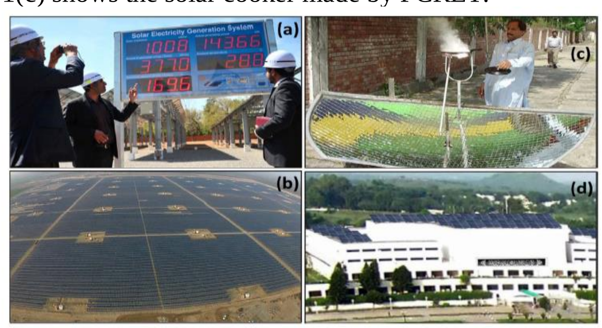


Figure 1. (a) Pakistan Engineering Council solar PV system. (b) Quaid-e-Azam solar park. (c) Solar cooker prepared by PCRET. (d) Solar PV installed at Parliament house [5].

In 2014–2015 budget, the GOP exempted taxes and duties on solar technology imports [10].

A. Different PV system installed in other universities in world

Study shows the installation of the 50kW rooftop PV system at Wyoming University campus, USA [6]. Feasibility study for the installation of photovoltaic (PV) system on shady parking area and roof of main campus buildings in Shaqra University, Saudi Arabia, has also been conducted [7].

The Study in [8] shows simulation and analysis at the University of Surabaya, Indonesia, of PV installation to cope with its energy demand. The study in [6,8] addresses that PV rooftop installations are significant to cope with the rising electricity demand.

III. BUILDING LOAD ANALYSIS AND MONTHLY AVERAGE GLOBAL HORIZONTAL IRRADIANCE DATA

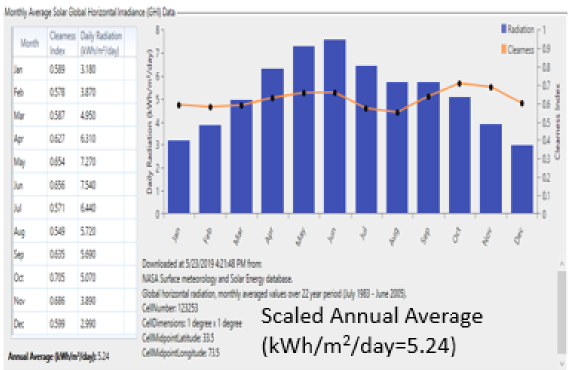


Figure 2. Solar energy potential for the selected location.

*TABLE 1. Monthly energy needs of the proposed building

Sr. No.	Month-2018	KWH Consumed
1	January	13000
2	February	6000
3	March	3000
4	April	3440
5	May	5000
6	June	7080
7	July	8300
8	August	8540
9	September	11200
10	October	15000
11	November	8500
12	December	9000

Solar energy potential for the selected location is explained in fig.2, and the monthly energy utilization of the proposed building for the year 2018 is shown in table 1 which 98060 kW/hr/year. Fig. 3 represents the front view of the proposed building, while fig. 4 shows the aerial view of the building depicting enough space for the PV installation on the rooftop to fulfill the energy needs.

IV. SYSTEM SIZING

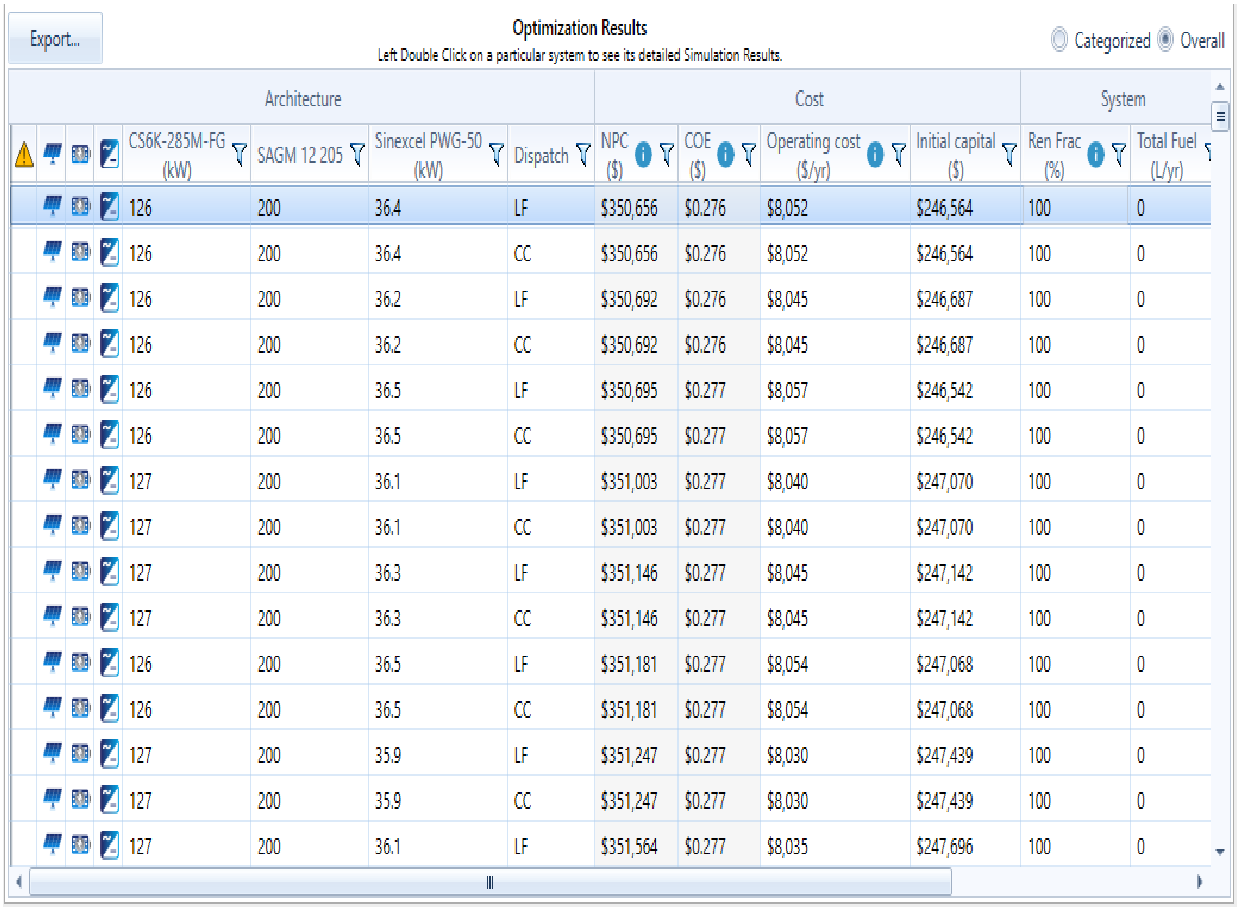
The proposed university building is in Azad Jammu & Kashmir, located towards the north of district Jhelum of Punjab province of Pakistan. The coordinates of the location are 33°8.9′ N 73°45.2′E. The load of the building is 269 kWh/day, which is calculated from the monthly electricity bills by the local utility company.

Figure 3 . Front view of the proposed university building.

Figure 4. Aerial view of the proposed university building.

The peak month is July, and there is meager energy consumption at night and on weekends, i.e., almost 1kW utilized by very few LED

Lights inside the building. The space available on the roof of the building is 1298 m^2. The design of a solar photovoltaic system for the required building is set up using HOMER Pro, and the data for solar irradiance is obtained from NASA database.



Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

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Architecture				Cost				System	
CS6K-285M-FG (kW)	SAGM 12 205	Sinexcel PWG-50 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
126	200	36.4	LF	$350,656	$0.276	$8,052	$246,564	100	0
126	200	36.4	CC	$350,656	$0.276	$8,052	$246,564	100	0
126	200	36.2	LF	$350,692	$0.276	$8,045	$246,687	100	0
126	200	36.2	CC	$350,692	$0.276	$8,045	$246,687	100	0
126	200	36.5	LF	$350,695	$0.277	$8,057	$246,542	100	0
126	200	36.5	CC	$350,695	$0.277	$8,057	$246,542	100	0
127	200	36.1	LF	$351,003	$0.277	$8,040	$247,070	100	0
127	200	36.1	CC	$351,003	$0.277	$8,040	$247,070	100	0
127	200	36.3	LF	$351,146	$0.277	$8,045	$247,142	100	0
127	200	36.3	CC	$351,146	$0.277	$8,045	$247,142	100	0
126	200	36.5	LF	$351,181	$0.277	$8,054	$247,068	100	0
126	200	36.5	CC	$351,181	$0.277	$8,054	$247,068	100	0
127	200	35.9	LF	$351,247	$0.277	$8,030	$247,439	100	0
127	200	35.9	CC	$351,247	$0.277	$8,030	$247,439	100	0
127	200	36.1	LF	$351,564	$0.277	$8,035	$247,696	100	0

Figure 5: HOMER Pro sizing and optimization results.

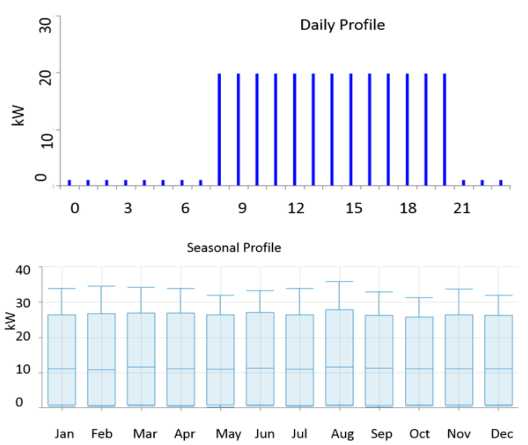
HOMER Pro optimization results are shown in Figure 6. In results, up to 332 combinations were optimized in the HOMER Pro optimizer. HOMER Pro optimization results are considering different number of PV panels with different ratings. Also, a different number of battery banks are considered in HOMER Pro optimization. Results show that PV panels of Canadian Solar Dymond CS6K-285M-FG (with the efficiency of 17.33%) 141kW capacity, 200 batteries Trojan SAGM 12V, 205 Ah (5 strings of 480V) and a convertor of 43.4kW can supply the load demand of the proposed building. The HOMER Pro optimization results also show that the system will give the backup for 32.8 hours that will be almost enough three days during adverse weather conditions. The power inverter is sized considering the A.C. peak load demand which is not more than 35.81 kW. Figure 5 shows the optimization results for the sizing of the proposed building.

The load profile and the battery state of charge have been shown in Fig. 6(a) and 6(b), respectively. Figure 6(a) shows a daily load profile with peak hours. Figure 6(b) the storage state of charge and the depth of discharge, which is 30%. The optimization results also show that the cost of the system is $350,656. Energy expenditure occurred by the proposed building during the year 2018 is $12334, which shows a payback period of 28 years.

The schematic diagram of the system is shown in Figure 7. Table 2 shows the information about the rating and price of different components for installation of the proposed PV system. To build up a 126-kW rooftop PV system, 442 solar panels of 285W capacity each have been utilized. According to [11] the total area required for the installation of these panels is 752 m^2 out of the entire 1298 m^2 available space. The excess energy of the system can feed to the surrounding buildings to meet their partial requirements.

V. SYSTEM DYNAMIC MODELING

Dynamic simulation of the proposed building has been carried out using MATLAB/Simulink. Fig. 8 shows the arrangement of PV array, battery bank, Dc-Dc boost convertor, Dc-Ac converter, and load. In fig.8, the output of the solar panels (20 in series



Metric	Baseline	Scaled
Average(kW/day)	268.4	269
Average(kW)	11.18	11.21
Peak(kW)	35.73	35.81
Load Factor	.31	.31

Load Type: AC DC

Figure 6: (a) Hourly load profile for a typical day and average demand of each month.

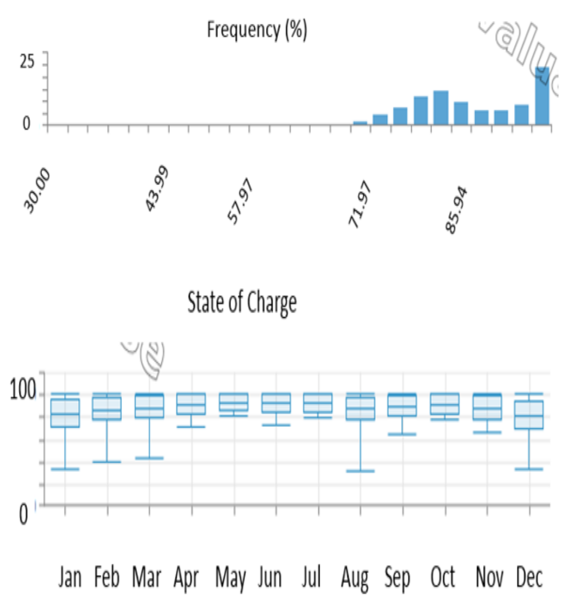


Figure 6: (b) Battery bank discharge frequency and the depth of discharge.

and 22 parallel strings each of 24 volts) is connected to the dc-dc boost converter through a charge controller. The perturbation and observation-based algorithm of maximum power point tracker is implemented to control the duty cycle of the converter.

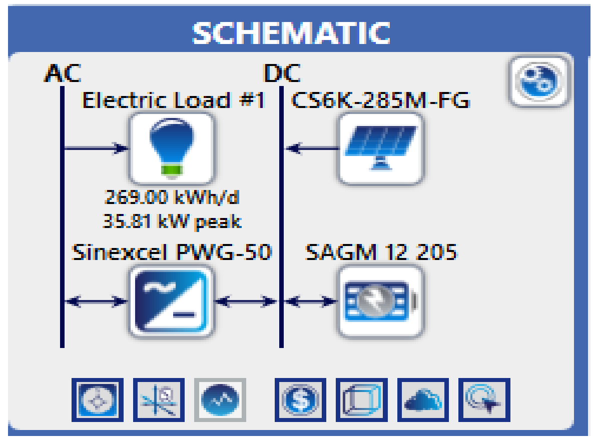


Figure 7: Schematic integration of the system.

TABLE 2:Cost for each component [11]-[13].
Idealistic conditions for solar irradiance and lousy weather are considered.

Components	PV	Convertor	Battery
Rating of each component	0.285kW	43kW	SAGM 12V, 205Ah
Required No of components	442	1	200
Final rating	126KW	43kW	480V,1025Ah
Cost/unit	$ 253	$ 7475	$412.45
Total cost	$111826	$ 7475	$ 82490

In this way maintains the dc output voltage to 480 volts and feeds the battery bank. Under normal operating conditions, the battery bank will be fully charged. Battery bank characteristics are shown in fig.10. A three-phase inverter is also connected with the battery bank. The switching frequency of the inverter is 40 kHz. PI controller with a PWM is used to control the inverter output. Its output AC waveform with a 50Hz rate, which is the standard frequency in Pakistan.
For single-phase, the Voltage level of the output is 212V RMS and 300 peak voltage. To reduce the harmonics, a low pass filter is also attached. Output voltage waveform is shown in Fig.9. Fig.11 above shows the complete protection scheme of the system.

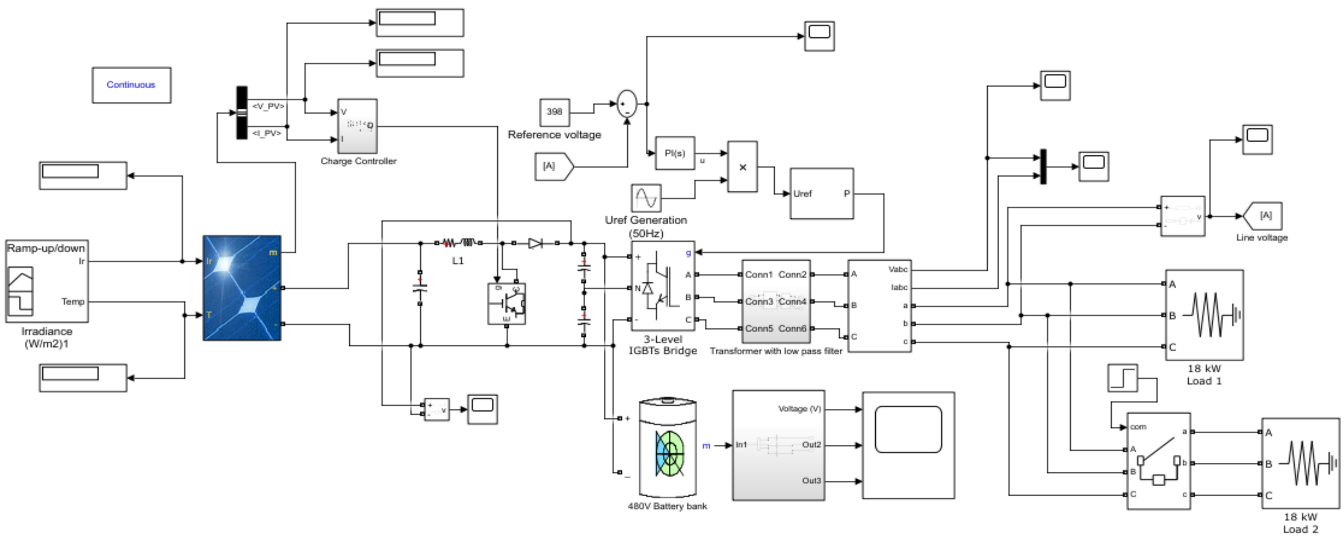


Figure 8: Simulation of the system using MATLAB/Simulink

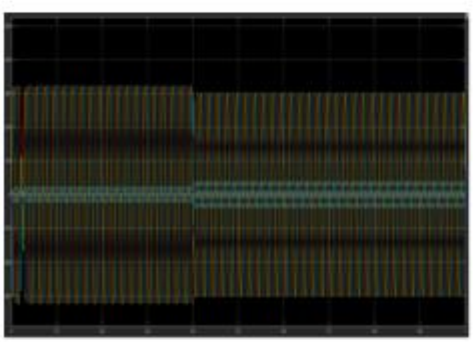


Figure 9: Output AC voltage waveform.

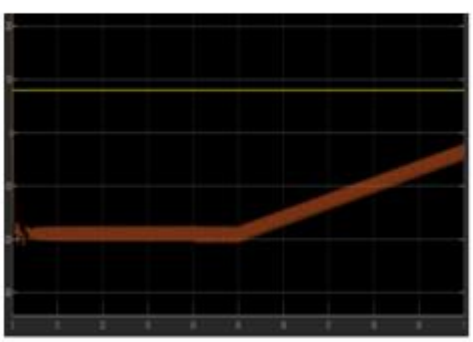


Figure 10: Battery bank charecteristics

Disconnect switches, fuses, and lightning arrestor are used to protect the system. All the components of the system are also grounded.

VI. PROTECTION SCHEME FOR THE SYSTEM

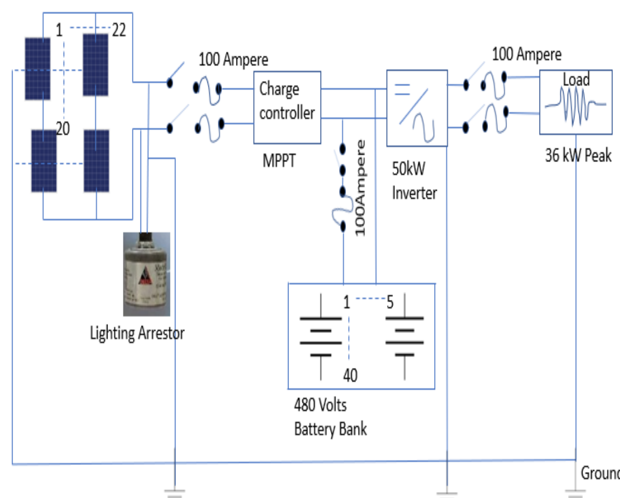


Figure 11: Complete protection scheme of the system.

VII. CONCLUSION

Energy is the backbone of every nation and economy. The current energy requirements of Pakistan and the electricity crisis require such concrete steps. After the design of the rooftop PV system for the proposed university building, the building will have a sufficient amount of energy, which will help in the smooth running of academic activities. Although the cost of the project is high, but keeping in mind the current energy situation of Pakistan and the geographical location of the site, the proposed solar PV system is the only solution.

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