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Analysis of Solar Power Plant Dynamics and Reliability

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Abstract—*After hydro and wind, the third most growing energy sector is solar photovoltaic which converts sun light directly into electricity. An initiative is taken by the university authorities to install solar power plant to support the Indian government's national solar mission. This paper is based on the analysis conducted to seek the opportunities to improve energy efficiency and to find issues related to the extension of power plant capacity of campus. The data for analysis is collected manually and with the help of measuring instruments from in house solar power plant. The power plant dynamics is understood to find the constraints in its extension and discussions are done on this to find the appropriate solutions. The paper is divided into various sections highlighting the parameters related to plant. In order to increase the plant capacity continuous monitoring of the plant has been done to find plant efficiency and reliability. Due to the increasing demand of power in expanding campus, the recommendations are given to reduce the electricity consumption.*

Keywords*: PV System, Energy Efficiency, Reliability, Load Distribution, Rooftop Power Plant.*

1. INTRODUCTION

The legacy of the Chiranjiv Charitable Trust in the realm of higher education goes back to 1989, when the foundation of the Sushant School of Art and Architecture was laid by Mr. Sushil Ansal, to address the gap in Indian architectural education. The School was conceived with the objective of combining traditional Indian aesthetics and modes of urban planning with the needs of a modern cityscape. As the School made a mark in the field of architectural education under the guiding force of late Fellow of the Frank Lloyd Wright Foundation, Padma Shri MM Rana, the Trust further expanded to establish the Ansal Institute of Technology in the year 2000 that received international recognition in the field of research, extension and global collaborations. The Sushant School of Design was instituted a decade later and in 2012 the 'Sushant Group of Institutions' came under the Ansal University, established through the legislation of the State of Haryana under Haryana Private Universities Act 2006. The various schools under the University, located in a sprawling campus in the heart of Gurgaon, have carved a niche by offering the required educational programs and providing the best faculty and facilities to promote academic excellence.

The university has introduced innovation center to promote the multi-disciplinary education programs. In order to attain excellence in the techno oriented society and developing an integrated personality of a well adjusted human being. This paper is to focus on the power needs of expanding campus. It is divided into various sections where the first section is introduction, the second section explains the power flow scenario in the campus i.e. power plant dynamics, the third section is about the energy efficiency and reliability analysis and the methodology used to complete the process of analysis. The fourth section gives deep understanding in to the solar power production from the in house plant, its parameters and discussions are done based on its expected expansion, whereas in the last section recommendations are given to further improve the solar power plant performance to achieve the energy efficient environment in the campus.

2. POWER FLOW SCENARIO

Ansal University has taken a remarkable step to build its own renewable energy system in year 2014, to reinforce its commitments towards green and clean energy, environment safety, energy efficiency and reliability. The campus is currently powered by four distributed locations in campus with roof top standalone power plant having 100 KW capacity of producing DC power to meet the energy requirement of campus and 1000lb thermal plant installed in campus hostels to meet hot water requirements in winters. The layout of the campus installed standalone power plant of various locations which includes block-A, block-B, block-C, block-D, hostels and School of Law as shown in Fig. 1. While the flat plate fixed tilt solar modules are located at the rooftops of block- B, block-D and hostels respectively.

According to the areas on the rooftop of the building blocks the flat plate solar modules are installed in series and parallel combinations called solar arrays to obtain the required amount of power. The series and parallel connections of solar modules are decided based on the connected load and peak power demand. The DC power obtained from the solar arrays of different locations is converted into consumable AC power with the help of string inverters. The approximate conversion is obtained by multiplying DC output power with 0.8 as multiplication factor, keeping in mind the performance of system being optimal with respect to the environment conditions such as cloudy/rainy days. The consumable AC power produced from a plant is nearly 80KW and the details related to power production from each distributed location is summarized in Table1.The calculations shown are done with the data obtained manually with the help of digital measuring instruments and from the system monitoring software installed in the facility department of university. Assumptions are made where the data obtained is insufficient. The monitoring software shows the daily based energy production data, which is obtained from the string inverters of solar photo voltaic power plant. Sometimes due to very common problems like ware and tear in wiring the data is collected manually. There are six string inverters in the campus at various locations for solar power conversion. The string inverters are used because of lower maintenance cost (e.g. no fans of air filters), simpler design and modularity although these are costlier than central inverters, If in case one string inverter fails its impact is limited to few number of arrays compare to the central inverters which can affect the whole plant, in short it is always advantageous to use the sting inverters for power production of more than 5KW [1, 2]. Research in the field of solar inverter efficiency improvement is still going.

On clear day in winters; the whole campus can be powered by solar power plant with power saving measures but eventually it is not. Even on normal sun shine days, the campus is self sufficient in delivering power at peak load demand and not affected by the frequent power outages. Other than energy from solar, the campus is also facilitated with the power from state distribution power grid and with a popular backup resource diesel generator set. The diesel generator when excessively used causes air pollution and consumes high cost fuel. Thus we are planning to enhance the solar power plant capacity, so that we do not require power from other means and the power demand can be fulfilled with available green and clean solar energy.

Therefore the main objective of this analysis is to investigate the energy consumption and identifying the possible energy saving methods, due to the fact that the electricity bill has been increasing extensively compared to load added in the last year. The challenge now is to study the system and find the methods to make the system energy efficient, reliable and economically viable in the face of dynamic loading conditions [3].

The uninterrupted AC power supply for the campus utilization is obtained from three sources i.e. from substation, standalone off grid rooftop solar photovoltaic system and diesel generator set. These sources are connected to common AC Bus with the help of power flow controlling panels kept at the power house in the campus as shown in Fig. 2. The power flow is unidirectional, because the power produced from the solar photovoltaic power plant is not fed to the Grid. The power house contains monitoring and controlling units which are used to collect the data related to plant and also detects the faults in the power flow system whereas the flow of power can be controlled with the help of controlling units. The important parameter to monitor is power factor of the system because of different units connected together to supply the same load. All these power provider works at different power factor either low or high, generally the power factor of solar power plant is near 0.9 and the power factor of diesel generator set is nearly0.85, therefore with the help of controlling units the power factor is controlled or matched with respect to the power factor of load to get uninterrupted power supply in the campus.

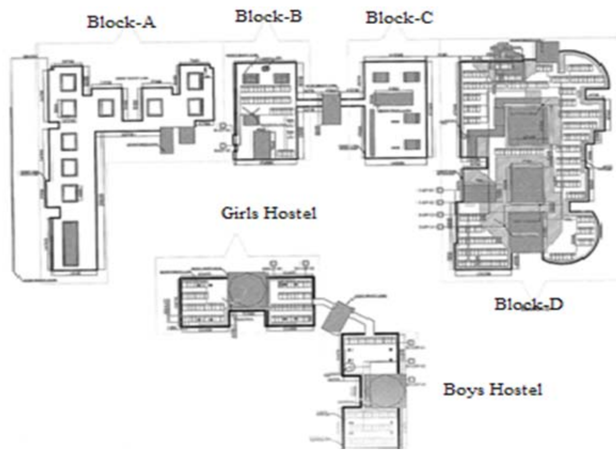

Fig. 1: Layout of Ansal University Solar PV system

Table 1: Location Wise Solar Power Generation

Building Blocks wise Plant Location	Number of Photo Voltaic Modules	SPV Capacity (KW)	DC Power Generated (KW)	AC Power output (KW)
Block-B	42	15	11.76	9.41
Block-D part-1	80	20	22.40	17.92
Block-D part-2	80	20	22.40	17.92
Block-D part-3	44	15	12.32	9.85
Girls Hostel	66	20	18.48	14.78
Boys Hostel	46	15	12.88	10.30
Total	358	105	100.24	80.18

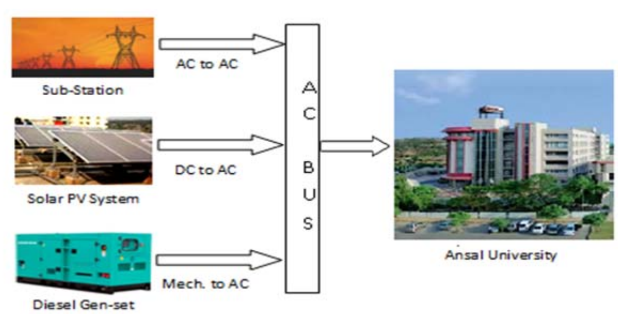

Fig. 2: Power Flow Diagram

3. ENERGY EFFICIENCY AND RELIABILITY ANALYSIS

The methodology adopted for this analysis was three step processes

Data Collection: In this first phase, where data is collected using different methods from different resources such as observations, measurements and sometimes approximations and generalizations were done. The data such as building layout, electricity bills, load distribution data, data of non-operational equipments etc is collected from the staff of facility department. Data sheets are prepared by using secured information for the analysis of power plant dynamics and reliability.

Data Analysis: The analysis of data is done building block wise connected distributed load and taking in to account the power flow diagram shown in Fig. 2. The evaluation of the data is done keeping the basic parameters in mind and representation of it is done using tables and other graphical methods. It helps in identifying the areas where electrical energy conservation is possible [4-6].

Recommendations: Based on the results obtained from the observations and calculations, some measures are to be taken to save the energy consumption, without affecting the working of solar plant. While considering the limitations of existing system and further expandability limit of the solar photovoltaic system and reliability of plant in the campus various recommendations are given, which are based on the cost, product life, saving in energy bills, replacement of inefficient appliances and expected addition of load [7].

The system design depends on the energy requirement and maximum peak load demand by the consumer. In our campus total 358 flat plate solar collectors/PV modules are used, each module having following specifications as shown in Table 2a are installed south facing at an optimum fixed tilt of 20 degree and the six string inverters used with the specifications shown in Table 2b.

Table 2a: PV Module Specifications

Maximum power P_{max}	280W
Open Circuit Voltage V_{oc}	43V
Short Circuit Current I_{sc}	8.68A
Peak Voltage V_{mp}	35V
Peak Current I_{mp}	8A
Max. System Voltage in DC	1000V

Table 2b: String PV Inverter Specifications

Max. Power Point Tracking (MPPT) Voltage Range	35.5-820V
Max. Voltage V_{max}	$1000V_{dc}$
Max. Current I_{max}	44A
Fill Factor	0.75

The DC power produced from the solar arrays and converted into deliverable AC with the help of string inverters installed at all the six different locations in the campus. The monitoring of these inverters is done with the help of software and data is collected. Thus the solar power produced from all the six plants per month in KWh taken at Indian Standard Time (IST) 17:30 is shown below in Table 3. The pie chart personify in Figure.3 gives insight into the maximum power consumed from the PV system is in the month of May and minimum in the month of December and the data obtained from the energy meter shows the consumption of electricity.

Table 3: Average Monthly Power Production

Months	Solar Power Production in MWh	Months	Solar Power Production in MWh
Oct'14	10.151	Apr'15	13.859
Nov'14	8.217	May'15	14.453
Dec'14	6.828	Jun'15	12.171
Jan'15	6.997	Jul'15	10.639
Feb'15	8.901	Aug'15	11.272
Mar'15	13.098	Sep'15	13.579

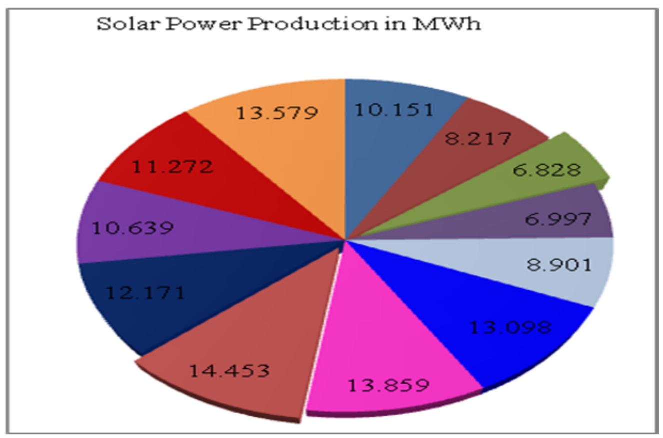

Fig. 3: Monthly power production

The power consumed is paramount in the month of May'15 as shown above and the weather data at which the solar power production obtained at the campus location is maximum shown in the Table 4 below.

Table 4: Weather Data of May Month

Date	Avg. Temp.	Avg. Solar Radiations	Wind Speed
2-May	38.6	5.4	3.2
4-May	36.1	7.9	2.2
6-May	37	5.7	3.2
8-May	38.4	5.6	1.9
10-May	37.6	5.1	2.2
12-May	38.5	3.2	3.2
14-May	39.8	6	2
16-May	41.5	6.3	2.6

18-May	38.9	5.6	2.8
20-May	39.2	5.6	3.6
22-May	38.8	5.6	5.3
24-May	38.8	5.8	4.2
26-May	38.8	5.9	3.2
28-May	41.3	5.7	2.9
30-May	37.6	6.2	2.1

The handheld wind speed meter with wheel sensor is used to collect the wind speed data, the temperature sensors are used to collect the average temperature of the day and the average solar radiation data, which is highly dependent on the geographical location, is collected using pyranometer. The geographical location of our rooftop plant in Gurgaon is at 28.5 degree north, 77.02 degree east coordinates. The assessment of energy consumed by whole campus in kilowatts load wise in descending order is shown in the Table 5 and graphically it is shown in the Fig. 4. It also shows that the maximum electricity used in the campus is by air conditioners, which are generally operative for six to seven months in a year as per the geographic location of Gurgaon [8, 9]. Thus the electricity bill in summer during these months of the year is comparatively higher than the remaining months.

Table 5: Load Distribution in Kilowatts

Type of Load	Load (KW)
Air Conditioners	1477.3
Internal and External Lights	233.13
Fridge and Geyser/Heater	232.8
Fire and Water Pumps	217.45
Kitchen and ventilation Load	57.8
Lifts	55.95
Ceiling and Exhaust Fans	51.56
Computer Load	40.5
Water Coolers/Water purifier	27.4
Mechanical Workshop	26.3
Electrical and Mechanical Machine Lab.	25.4

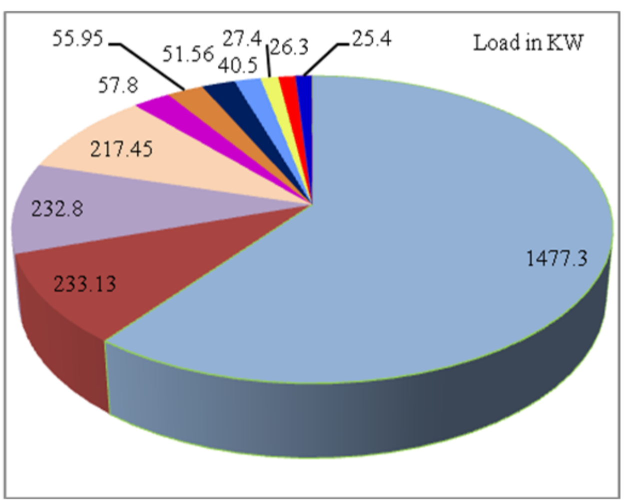

Fig. 4: Load wise power consumption

Whereas block wise energy consumption by the distributed loads in killowatts is given below in Table 6. Whereas the block-D has the highest demand for electrical energy and canteen is equiped with minimum load having lowest electricity demand as shown in Fig. 5.

Table 6: Building Block wise Load Distribution

Sr. No.	Building Block wise load distribution	Load (KW)
1	Block-A	352.8
2	Block-B	68.8
3	Block-C	195.54
4	Block-D	840.3
5	School of Law	145.72
6	Mechanical Workshop	26.3
7	Hostel	545
8	Sports Complex	48.96
9	Pump House	217.45
10	Canteen	4.72

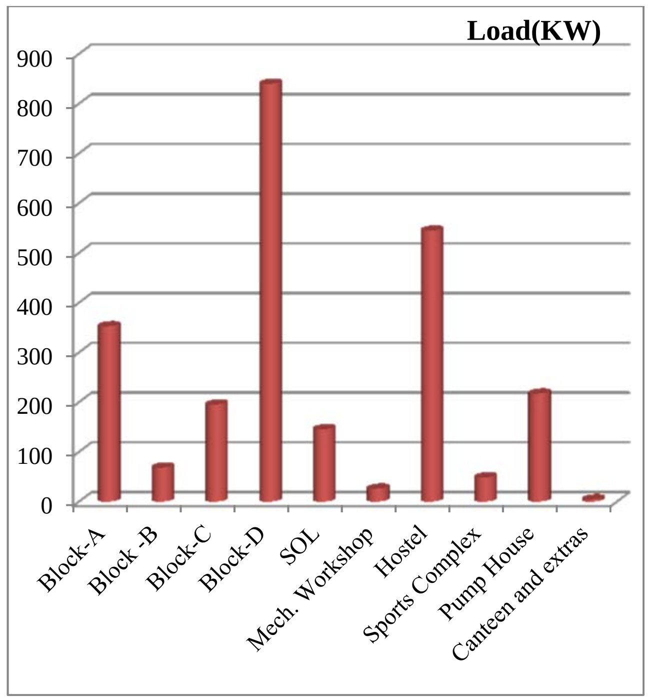

Fig. 5: Block wise load distribution

4. PLANT COST AND RELIABILITY

The initial cost of setting up the solar PV system was Rupees: Sixty three lakhs inclusive all taxes, duties, supply, installation, testing, commissioning and five year comprehensive annual maintenance of Rooftop Solar Power Plant. The power flow in campus is measured with the help of a common energy meter, which has a sanctioned load capacity of 1000KW at 0.94 power factor, whereas the accuracy of the meter is within the permissible limits. While considering the tariffs, the power obtained from DHBVN, Gurgaon is charged at the rate of Indian rupees 6.50 under two part variable tariff scheme and the electricity produced from solar is charged at rupees 8.62 that is under fixed rate tariff scheme, whereas the backup diesel generator set consumes approximate yearly diesel (as fuel) of 47,000 liters charged at rupees 49 is used to deliver power to the seven different locations in the campus [8]. The cumulative monthly electricity bill of all electricity resources is calculated and the bill calculations are shown in the Table 7 and also represented in the form of chart in Fig. 6. Certain steps already have been taken to reduce the electricity bill. Further the facts and statics collected in this paper expressing the plant dynamic and reliability. While appropriate measures to improve it are discussed in the last section of the paper.

Table 7: Monthly expenses on electricity

Months	Total (Rs. in Lakhs)	Months	Total (Rs. in Lakhs)
Oct'14	15.8	Apr'15	23.7
Nov'14	10.9	May'15	29.1
Dec'14	9.9	Jun'15	11.8
Jan'15	10.7	Jul'15	19.6
Feb'15	10	Aug'15	25.5
Mar'15	10.6	Sep'15	25.7

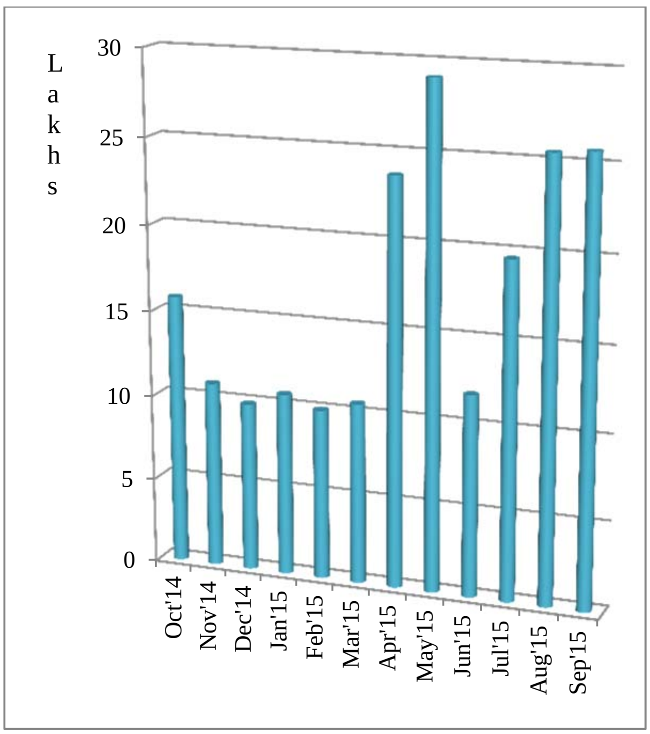

Fig. 6: Cost Analysis (in Rupees (Lakhs)

5. RECOMMENDATIONS FOR ENERGY EFFICIENCY

Based on the above data analysis the conclusions obtained are discussed one by one. A major drawback of the plant is that there is common energy meter for the whole campus. Therefore placing the dual operated sub-meters in all the blocks would help in calculating exact power consumption per block. There should be master switch at each floor of the block so that the power consumed per floor per room can be calculated. Accordingly the equipments consuming maximum power can be identified and their working can be controlled by providing maintenance as per the requirement or appropriate measures can be taken to reduce the power consumption by replacing the equipments.

For the standalone solar PV system storage batteries can be used so that the power backup can be provided from solar system itself. All the building blocks of campus should be centrally connected so that monitoring of the peak load demand can be done. As the campus is expanding and the electricity load is likely to increase up to 600KW by next year, energy efficient building can be design in such a way so that maximum sun light can be used for lighting purpose. The motion sensors can be used in the laboratories where lights used are more in number as compare to other places in the campus. Maintenance of machines should be done annually to avoid excessive power consumption by heavy machines in workshop and other mechanical laboratories such as computerized numerical control machine, three dimensional printers and motor operated lath machines. As per the calculations load because of air conditioners is maximum thus the timings for its operation should matched with the classes to be held and serious actions should be taken to avoid the unwanted use of it.

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