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A PROPOSED DESIGN OF SOLAR ON-GRID PV POWER PLANT FOR AN ACADEMIC INSTITUTION WITH CONSERVATION MEASURES THROUGH ENERGY AUDIT PROCESS

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Keywords:

Energy Audit;
Energy Conservation;
On-Grid Solar PV Plant;
Payback Period;
Thermography.

Abstract

Economic development of any country depends on energy consumption and conservation. Within the commercial sector of India, the educational institutions are significant consumers of energy. Energy consumption depends on the type of the load associated with it, within the educational institution lighting load is a major load. It has been concentrated on how energy consumption can be reduced for the illumination by using energy efficient LED lamps. Energy conservation measures by energy audit has to be performed prior to the design of solar PV power plant as of to reduce the capacity and cost of the plant to be installed. Hence this paper first focuses on the energy conservation measures carried out in University Visvesvaraya College of Engineering, Bengaluru. Later the energy demand has been estimated based on previous electricity bills and 120kW On-Grid Solar PV power plant in the area of 0.35 acres land has been proposed to meet the energy requirements within the college campus.

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1. Introduction

India is the fourth highest energy consumer in the world with 17% of the overall population residing in the country, however per capita energy consumption is much lesser compared to other developed countries [Sanjay kumar et al. (2013) and Shukla et al. (2017)]. Government of India has taken many innovative measures to promote renewable/ non-conventional energy resources like solar, wind etc to cope up with the energy crisis

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[India Solar PV Advisor (2011)]. India's power consumption pattern is divided into various sectors where industrial sector plays a major role with 44.8% of total consumption whereas the domestic, agricultural and commercial sectors consume 21.8%, 17.95% and 8.33% respectively. Educational institutions, shopping malls, hospitals etc. lies under commercial sector and hence one can concentrate on this stream to improve the efficiency by reducing the losses.

In the year 1917, Sir. M. Visvesvaraya established University Visvesvaraya College of Engineering (UVCE) which is the fifth engineering college in India [14]. The energy audit has been conducted in the facility as 100 years has been passed for the infrastructure and interior lighting systems seems to be not modified and has very old fixtures of the lighting system. Energy consumption and scope of energy conservation was effectively evaluated by an energy audit process in order to reduce the power bills which was about Rs 16.84 lakhs during the fiscal year 2016-2017 and thereby conservation of energy.

There are numerous ways to reduce energy consumption. Jayesh R et al. (2014) focus on how monthly electricity bill can be reduced by reduction in maximum power demand. In paper [R Hari Bhaskar et al.(2014) and Gousia et al. (2015)], a case study has been performed to lessen the energy consumption and therefore the electricity bill by suggesting cost-effective measures. Lighting gives majority of contribution towards energy consumption under commercial sector. Moreover the electricity consumption by lighting lies between to 25 to 50% of the total consumption [Deepti Jain et al. (2013)]. Due to above factors, it is motivated to proceed with an energy audit in order to improve the interior lighting system and to reduce the energy consumption that would result from standard retrofit activities [Chikku Abraham et al. (2015)].

In this paper, energy audit and conservation measures are taken prior to the design of solar PV power plant as of to reduce the installed capacity and cost of the plant. Energy audit was conducted in the institution with various approaches using a variety of measuring instruments including thermography which can identify thermally consequential defects [Elena Lucchi (2017)]. Then a detailed analysis was carried out on obtained data. This further led to opportunities towards energy conservation and a systematic approach have been followed to determine the annual energy savings and payback period. Later a grid connected solar PV power plant is designed for the institution with net metering system which can export excess power to the grid such that electricity bill is reduced as the college works for intermittent hours.

2. AUDIT PHASES

There involved 2 phases of the audit and are discussed in detailed manner below [Moncef Krati (2011)]:

- Phase I : Surveying of building
- Phase II : Detail Analysis

2.1 Phase-I Surveying of Building

As of first to do the audit one has to be familiar with the layout of the facility. Scope of energy conservation is identified by taking surveys. And Survey is classified in to two as below,

1. Preliminary survey
2. Walk through

2.1.1 Preliminary survey:

One has to have the thorough knowledge of the infrastructure before starting walk through activity. The information can be obtained from the layout of the building and single line diagram of the power supply.

2.1.1.1 Architectural blue print of UVCE college:

Blueprint of the UVCE college building collected is shown in Figure 1.

2.1.1.2 Single Line Diagram of electric power supply:

Single line diagram of the power supply is shown in the Figure 2. Electric power supply to the college is fed through the 11kV feeder. The 11kV is step down to 433V by 250kVA transformer installed at the college premises. The 3 phase 433V has been fed to the three blocks - Mechanical Engineering Sciences block, Electrical Engineering Sciences block and Computer Engineering Sciences block; further which is distributed to the different loads of the respective blocks.

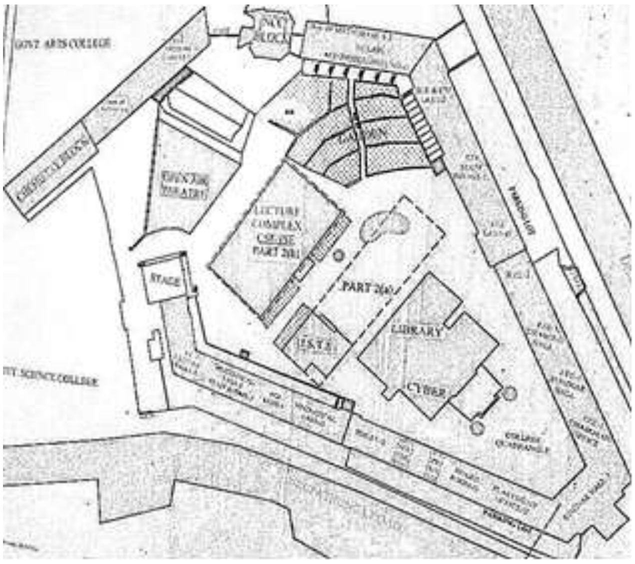

Figure 1. *Architectural blueprint of UVCE College.*

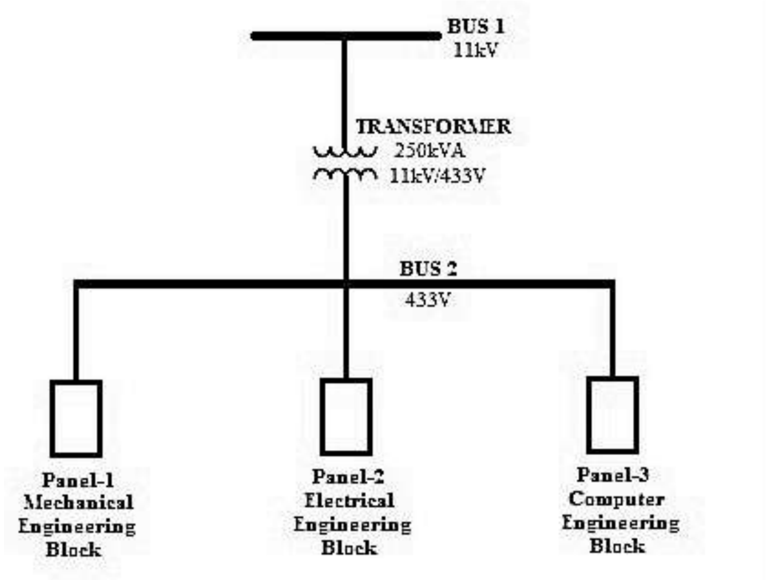

Figure 2. *Single Line Diagram*

2.1.2 Walk through:

Preliminary survey acquaints one with the infrastructure and thus it eases up the walk-through activity. The building envelope has to be examined during the process to ensure it is strong and in good condition [Iyyanki V et al. (2017) and Barney L et al. (2003)]. Total number of rooms were found to be 126 excluding a library block. Only few classrooms and labs were found to be bright and cross ventilated, and others were lighted during daytime and the rooms did not cross ventilated. All these made a path for many energy conservation opportunities.

Operating schedule of the college is not fixed at different departments have different working hours and in fact few departments runs evening college too. Hence, college has an intermittent operating schedule, and for the purpose of calculations, it has been assumed as an average of 6 hours of operation per day for energy consumption study and the whole campus is divided into different zones accordingly.

2.2 PHASE-II Detail audit

Detail audit is carried out for the entire campus and it includes:

- Field visit and measurements
- Energy charges
- Energy bill analysis
- Quantification of loads

2.2.1 Field visit and measurements:

Different measurements are taken and the readings are consolidated in a sheet which includes:

1. Inventory measurements: The number of connected loads at each room of the campus was counted.
2. Lumens measurement at each room

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3. Power measurements at all the panels
4. Temperature measurement in AC rooms
5. Thermography measurement at the incomer and panels

2.2.2 Energy Charges:

The Karnataka Electricity Regulatory Commission (KERC) revises the tariff rates every year [15]. Section HT-2(c) under BESCOM electricity board comprises hospitals, educational institutions and hostels [16]. Hence the tariff applicable for UVCE is fetched from the tariff order 2016-17 under HT-2(c) section which in details is shown in Table 1.

Table 1. Rate Schedule [16].

Demand Charges	Rs. 180/kVA of billing demand/month
Energy Charges	
For the first one lakh units	600 paise per unit
For the balance units	650 paise per unit

2.2.3 Energy Bill Analysis

As of April 2008 the contract demand sanctioned for the college was 200kVA. Figure 3 shows the recorded monthly peak demand for the year 2016-17. The maximum demand recorded by the meter was 95.2kVA in the month of June-2016 with 0.94 power factor. The total energy bill for the year 2016-17 can be obtained by summing the monthly bill from the Table 2 and is found to be Rs. 16.84 lakhs.

Table 2. One year month wise electricity bill.

Sl. No.	Month	Maximum Demand (kVA)	Energy Consumption (kWh)	Power Factor	Total Amount (Rupees)
1	Apr-16	84.4	16986	0.95	148315.2
2	May-16	90.2	19158	0.96	163271.9
3	Jun-16	95.2	14252	0.94	129488.7
4	Jul-16	65.0	13466	0.96	124076.7
5	Aug-16	70.2	16278	0.95	143440.1
6	Sep-16	73.4	14966	0.95	134240.7
7	Oct-16	84.8	15732	0.95	139507.5
8	Nov-16	90.6	15836	0.95	140222.5
9	Dec-16	80.0	13420	0.94	124498.1
10	Jan-17	58.0	14576	0.95	132521.4
11	Feb-17	50.0	12904	0.94	120916.4
12	Mar-17	51.2	21880	0.96	183219.3

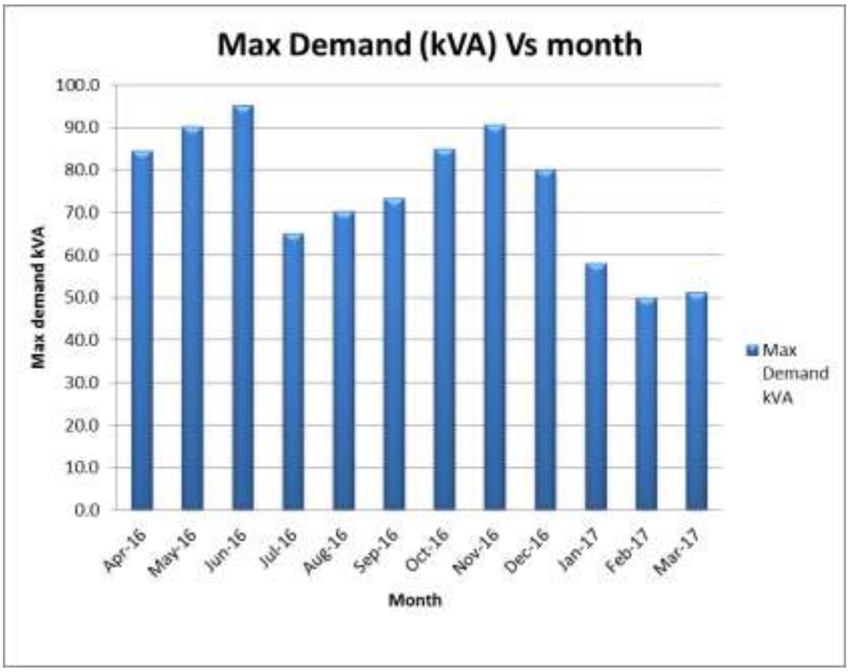

Figure 3. *Recorded monthly peak demand at UVCE during the year 2016-17.*

2.2.4 Quantification of Load

The electrical loads are classified as lighting load, fan loads, air conditioning, computer monitors & water pumps. The institute has about 140kW of total connected load in different departments, office, library and laboratories. Out of total connected load, lighting load was calculated to be 65kW whilst the fan load was 9.64kW. The corresponding computer, pump and Air conditioner loads are 9kW, 7.5kW and 37.5kW respectively. The details are as shown in Figure

4.

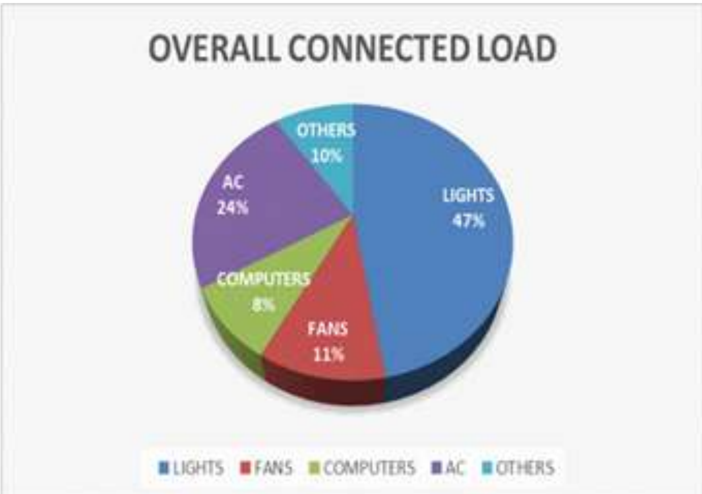

Figure 4. *Overall Connected Load at UVCE campus.*

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3. ENERGY CONSERVATION

3.1 Standard retrofits used:

Here the Fluorescent Tube Lights (FTL), Mirror Optic Reflector-Fluorescent Tube Lights (MOR-FTL), General Lighting Service (GLS), Compact Fluorescent Lamps (CFL), Halogen lamps and High Pressure Sodium Vapor Lamps (HPSV) are replaced by energy efficient Light Emitting Diode (LED) lamps. Also the existing old fans are replaced by energy efficient fans and Cathode Ray Tube (CRT) monitors by LED display monitors as listed in Table 3.

Table 3. List of proposed fixtures replacing the existing fixtures.

EXISTING FIXTURE	PROPOSED FIXTURE
1 x 36W FTL	1 x 18W LED
1 x 40W FTL	1 x 18W LED
2 x 36W FTL	2 x 18W LED
2 x 40W FTL	2 x 18W LED
2 x 36W MOR-FTL	2 x 18W LED
1 x 60W GLS	1 x 10W LED
1 x 200W GLS	1 x 45W LED DOWN LIGHT
1 x 8W CFL	1 x 5W LED
1 x 65W CFL	1 x 30W LED
1 x 500W HALOGEN	1 x 100W LED FLOOD LIGHT
1 x 150W HPSV	1 x 35W LED STREET LIGHT
1 x 100W FAN	1 x 35W ENERGY EFFICIENT FAN
1 x 60W FAN	1 x 35W ENERGY EFFICIENT FAN
CRT MONITOR (80W)	LED MONITOR (30W)

3.2 Saving calculations:

Systematic approach have been adopted to determine the annual energy, cost savings, payback period as well as return on investment. The calculations are made for replacement of each existing fixture by the proposed fixture as mentioned in Table 3. For annual energy consumption calculations, it has been assumed an average of 6 hours of operation per day with 300 working days in a year. The calculations for the replacement of 1 x 36W FTL by 1 x 18W LED is shown in section 3.2.1. Similarly the calculations have been made for the replacement of other fixtures too, and the results obtained are listed in Table 4.

3.2.1 Replacing 1 × 36W FTL By 1 × 18W LED:

1. Total number of fixtures = 397
2. Power consumption of 1 x 36W FTL (including ballast) = (36W+10W) = 46W
3. Power consumption of 1 x 18W LED (including driver circuit) = (18W+2W) = 20W
4. Power saving by LED replacement = 26W
5. Power saving by entire fixture = (397 x 26)/1000 = 10.322kW

6. Annual energy consumption of existing fixture = (397 x 46 x 6 x300)/1000 = 32,871.6kWh
7. Annual energy consumption of proposed fixture = (397 x 20 x 6 x 300)/1000 = 14,292kWh
8. Annual energy savings = 32,871.6 - 14,292 = 18,579.6kWh
9. Annual cost savings = 18,579.6kWh x 8.89 Rs/kWh = Rs 1.65 lakhs
10. Investment cost (including labor) = 397 x Rs 1050 = Rs 4.169 lakhs
11. Simple payback period = Investment cost / savings = 4.169/1.65 = 2.52 years
12. Return on investment = 1/ (spbp x 12) = 1/ (2.52 x 12) = 0.033

4. DESIGN OF SOLAR PV POWER PLANT

The peak load estimated as per the energy audit report is 95kVA and with the expected rise of power consumption in the near future, a 120kW On-Grid Solar PV power plant has been proposed for the college. Solar PV power plant is designed by considering module circuit, inverter sizing and PV module sizing. An On-Grid solar PV power plant is shown in Figure 5. As the college lies in the heart of the city which is highly a commercial area, the frequency of power-cuts are very less, in fact Nil. Hence the On-Grid system is found to be the best as it decreases the cost and space occupied by the installation of battery banks.

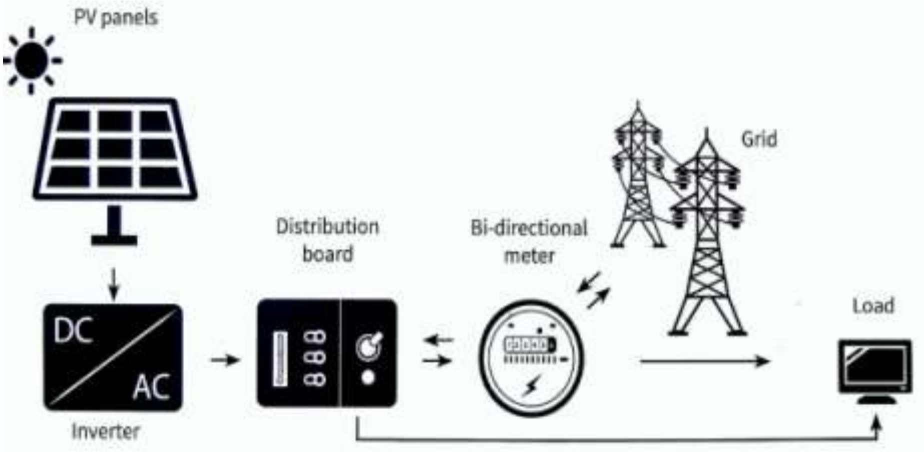

Figure 5. *On-Grid Solar PV power plant.*

4.1. Sizing of PV plant and Inverter

Based on solar intensity and sunshine hours one can calculate the Panel generation factor (PGF) to determine the size of solar PV cells required [Mevin Chandel et al. (2014)]. At Bengaluru the solar irradiance is 556 with an average 9 hours of sunshine a day. Hence PGF can be obtained as

Panel generation factor = (Solar irradiance × sunshine hours)/ (Standard test conditions irradiance) = (556 × 9)/1000 = 5.004

From the audit report, the peak energy requirement of the institute per day is 565kWh/day.

Considering the energy loss in the SPV system as 35%, the expected energy from PV modules = 1.35 × 565 = 763kWh/day

Total Watt peak rating for PV modules = (Energy required from PV modules)/ (Panel generation factor) = (763)/5.004 = 153Kw

Selected PV modules for the plant is TP260 (60 cell multi-crystalline) of Tata product with the maximum power (P_{max}) = 260W. Specification table of the PV module is given in Appendix [17].

Number of PV modules required = (Total watt peak rating)/ (PV module peak rated output) = 153kW/260W = 588 modules.

Number of modules to be connected in series = Maximum open circuit voltage/ Open circuit voltage (V_{OC}) of each PV module = 780/37.9 = 21

Maximum power voltage (V_{mpp}) of each PV module = 30.6V_{dc}

Maximum power voltage (V_{mpp}) at inverter input = Number of modules to be connected in series × Maximum power voltage (V_{mpp}) of each PV module = 21 × 30.6= 643V_{dc}
Total number of PV arrays to be used for producing 643V_{dc} = 588/21 = 28 arrays.

Total wattage required in the college is 90kW. In order to handle the peak wattage during sudden requirement, the size of the inverter should be 25% larger than the actual requirement.

Size of the inverter = 1.25 × 90kW = 112.5kW
Hence, high efficiency Helios Systems HS 120kW central inverter with built-in MPPT is chosen for the plant [18].

4.2. Land required:

Number of PV modules required = 588
Dimension of one PV module = 1.66m × 1m
Series of modules connected in an array = 21
Total width of each PV array = 21 × 1 = 21m
Length of one PV module = 1.66m
Number of arrays in PV field = 28
Let the number of arrays in a row = 7
Width of the solar field = 21 × 7 = 147m
Number of rows in solar field = 28/7 = 4
Pitch distance between two arrays = 2.5m (including module length of 1.66 m)
Length of the solar field = 3×2.5 +1.66 = 9.16m
Land required for PV field= 147×9.16 = 1,347m^2 = 0.35 acres. [1 acre= 4047m^2].
Solar PV array arrangement consisting of 21 panels is shown in Figure 6.

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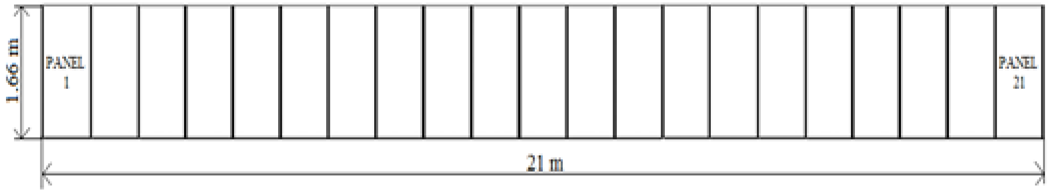

Figure 6. *Solar PV array arrangement consisting of 21 panels.*

5. RESULTS AND DISCUSSIONS

5.1. Implementation Measures:

The implementation measures are listed in Table 4. The total annual energy savings obtained after the replacement of existing fixture is obtained as 82,615.50kWh. The simple payback period is 3.1 years. Comparison between total annual energy consumption of existing and proposed fixtures is shown in Figure 7. It can be noted that the annual energy consumption of existing system is 1,42,140.9kWh, which can be reduced to 59,525.4kWh by implementing the proposed ones. The data obtained from Table 4 for the simple payback period of various retrofits (in years) is plotted in Figure 8.

Table 4. Implementation Measures.

Sl. No	Proposal title	Annual energy consumption of existing fixture (kWh)	Annual energy consumption of proposed fixture (kWh)	Annual energy savings (kWh)	Annual cost savings (Rs)	Investment cost (Rs)	Simple payback period (years)	Return on investment
1	Replacing 1×36W FTL by 1×18W LED	32,871.60	14,292	18,579.60	1.65 lakhs	4.16 lakhs	2.521	0.033
2	Replacing 1×40W FTL by 1×18W LED	11,250	4,500	6,750	60,007.50	1.31 lakhs	2.187	0.038
3	Replacing 2×36W FTL by 2×18W LED	36,763.20	15,984	20,779.20	1.84 lakhs	4.66 lakhs	2.524	0.033
4	Replacing 2×40W FTL by 2×18W LED	21,780	8,712	13,068	1.16 lakhs	2.54 lakhs	2.187	0.038
5	Replacing 2×36W	5,133.60	2.232	2,901.60	25,795.22	65,100	2.524	0.033

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	MOR-FTL by 2×18W LED							
6	Replacing 1×60W GLS by 1×10W LED	2,916	486	2,430	21,602.70	8,100	0.375	0.222
7	Replacing 1×200W GLS by 1×45W LED down light	720	180	540	4,800.60	4,500	0.932	0.088
8	Replacing 1×8W CFL by 1×5W LED	198	99	99	880.11	2,750	3.12	0.026
9	Replacing 1×65W CFL by 1×30W LED	252	122.4	129.6	1,152.14	900	0.78	0.01
10	Replacing 1×500W Halogen by 1×100W LED flood light	3,600	792	2,808	24,963.12	39,000	1.562	0.053
11	Replacing 1×150W HPSV by 1×35W LED street light:	3,832.50	876	2,956.50	26,283.28	37,500	1.426	0.058
12	Replacing 100W fans by 35W EE fans	3,960	1,386	2,574	22,882.86	99,000	4.326	0.019

13	Replacing 60W fans by 35W EE fans	13,392	7,812	5,580	49,606.20	5.58 lakhs	11.248	0.0074
14	Replacing CRT by LED monitors	5,472	2,052	3,420	30,403.80	2.09 lakhs	6.874	0.0121
15	**TOTAL**	**1,42,140.90**	**59,525**	**82,615.50**	**7,34,451.70**	**22,92,250**	**3.1**	**0.027**

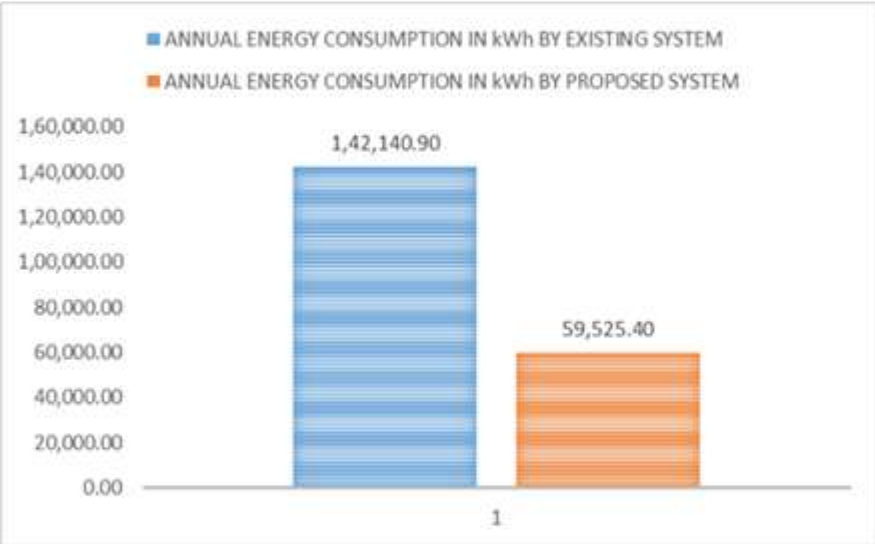

Figure 7. *Comparison of total annual energy consumption of existing and proposed fixtures.*

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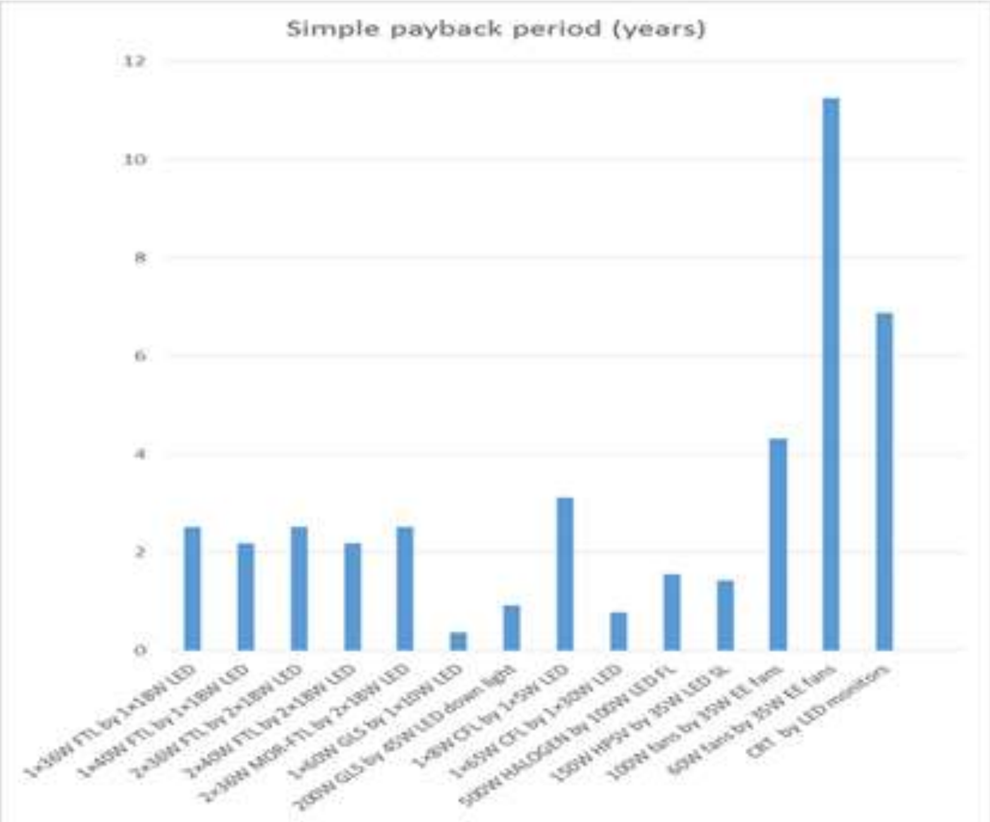

Figure 8. *Simple payback period of various retrofits (in years).*

5.2. Thermography Analysis:

Thermography images were taken to detect the hotspots at the incomer and in the panel boards. Only those panels with intense hotspots are discussed in the following section.

5.2.1 Thermography at pump house panel

The thermography image with respect to actual image captured at the pump house panel is shown in Figure 9. The details of the detected hotspots are given in Table 5.

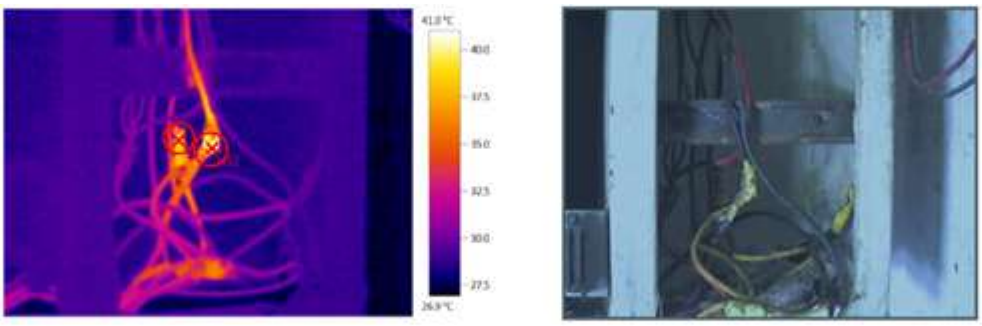

Figure 9. *Hotspots detected at pump house panel.*

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Table 5. Thermography observations at pump house panel.

Measurement Objects	Temp.[°C]	Emissivity	Refl. temp.[°C]
Hot spot 1	41.0	0.95	20.0
Hot spot 2	39.8	0.95	20.0

Remarks:

Observation: Hot spot observed at R & Y-Phase of cable joints.

Suggestion: It is suggested to use end to end cable connectors for connecting the cable.

5.2.2Thermography at DG Room panel

The thermography image along with actual image recorded at the DG room panel is shown in Figure 10. The details of the detected hotspots are given in Table 6.

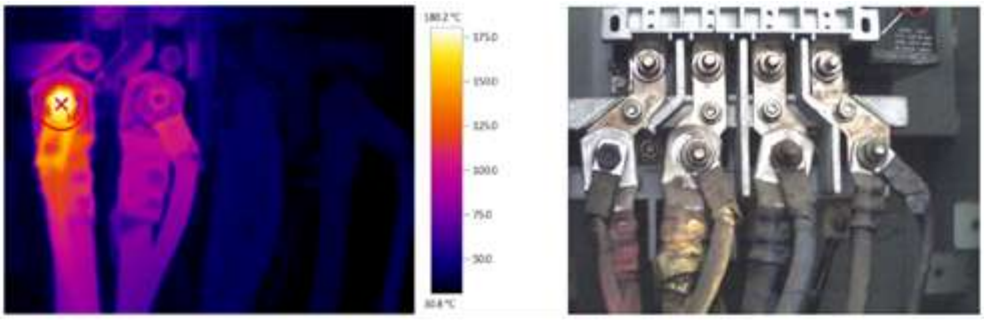

Figure 10. *Detection of hotspot at DG room panel.*

Table 6. Thermography observations at DG room panel.

Measurement Objects	Temp.[°C]	Emissivity	Refl. temp.[°C]
Hot spot 1	180.2	0.95	20.0

Remarks:

Observation: Hot spot observed at R-Phase cable terminal.

Suggestion: Crimp the cable lug and tighten the terminal bolt & nut.

5.3. Recommendations:

After analyzing all the calculations and graphs and by keen observations during audit phases, it has been revealed many energy conservation opportunities.

1. As the lighting system is 47% of the end use connected load, energy conservation methods can be implemented such as:

- Replacement of old wirings and the lighting fixtures by new retrofitting scheme of lighting system.
- Replacing fluorescent lamps with energy efficient LED lamps.

2. Efficient wiring diagram, proper location of the power layouts/ distribution boards and timely maintenance is a good practice.
3. CRT monitors shall be replaced by LED monitors.
4. Air conditioners must be maintained regularly as of it is not done properly till now.
5. Creating awareness among the students and staffs of the college about the smart usage of electricity.
6. Penalties can be avoided by paying the bills on or before the due date.
7. Installation of on-grid solar PV power plant for the institution can reduce the energy charges payable to the electricity board.
8. Thermography results yields that the cables in distribution panels must be crimped, the terminal bolts & nuts must be tightened and end to end cable connectors must be used for cable connections.

6. CONCLUSION

Energy audit has been carried out and recommendations are given accordingly as per the observations made. The energy audit infers the broad insight of energy conservation and the measures to be taken to address the energy crisis. Exploring the possible usage of renewable energy resources can considerably bring down the energy expenses, thereby high flexibility of further expansion and reduced environmental impacts. A study has been carried out to determine the capacity of On-Grid solar PV power plant and is found that 588 PV modules have to be installed in the area of 0.35 acres of land to produce 120kW of power with an inverter to meet the energy requirement of the college.

APPENDIX

Electrical parameters of Tata Power TP260 (60 cell multi-crystalline) PV module at standard test condition: Irradiance of 1000W/m^2, spectrum AM of 1.5 and cell temperature of 25^{o}C is given in Table A.1.

Table A.1. Electrical parameters of Tata Power TP260 PV module [17].

Sl.No.	Parameter	Units	Values
1.	Nominal Power Output (P_{max})	W	260
2.	Power Tolerance	W	0 ~ +5
3.	Module efficiency (ŋ%)	%	15.60
4.	Voltage at P_{MAX} V_{MPP}	V	30.6
5.	Current at P_{MAX} I_{MPP}	A	8.49
6.	Open-Circuit Voltage (V_{oc})	V	37.9
7.	Short Circuit Current (I_{sc})	A	8.80

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