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A CASE STUDY OF USING PHOTOVOLTAIC SOLAR MODULES WITH LUMINARIES

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ABSTRACT*—This paper presents a systematic approach to solar photovoltaic (PV) system design for energizing constant profile luminary loads. Energy optimization is undertaken first, followed by system design. Experimental results for system evaluation are presented.*

Key Words: Alternate renewable energy; Photovoltaic solar modules; LED lighting; Illumination

1. INTRODUCTION

Photovoltaic system design presents various challenges. For example: solar radiation levels vary with time and place and has to be accommodated as an important design variable. Also, the direction and placement of solar collectors affects the amount of energy they effectively harvest.

Firoz Ahmed [1] has highlighted the bright prospects of solar energy for PV and water heating applications whilst presenting useful data on direct and diffused solar radiation patterns throughout the year. J.A. del. Cueto [2] describes the seasonal fluctuations in output of flat plate collectors of different cell materials.

To envisage a complete and true picture of the prospective photovoltaic system, it is essential to predict the actual performance of PV modules being used in prevalent conditions. Energy storage is a major challenge in the renewable industry as battery packs have voltage, current flow and discharge depth limits of their own. Energy optimization is a practiced approach to renewable systems design. Costs incurred may largely be reduced by optimizing target loads than spending extra on larger solar systems. Incandescent and fluorescent luminaries, specifically, are investigated with this view in Narendra. B. Soni's work on transition to led illumination. [3]

M. A. Javed, et al., [4] have experimented with commercially available inverters working with PV systems and recorded the varying levels of efficiency of these achieved.

Keeping in view all of the stated variables, the designed system has to be adequately placed in a fail-safe region of operation such that it can serve minor disturbances without tripping.

2. PROCEDURE ADOPTED

This section presents the details of the proposed methodology adopted for achieving an energy optimized solar PV renewable system.

2.1 TARGET LOAD INVESTIGATION

The first step is to perform an analysis of the existing target load for energy optimization. In this lieu, luminous flux values produced by Compact Fluorescent Lamps (CFLs) installed as recorded at various points almost 8ft from the luminaries at table top height.

The area to be illuminated is shown in Fig.1 and consists of office table-sets and limited seating. The luminaries already installed in the ceiling are as detailed in Table.1.

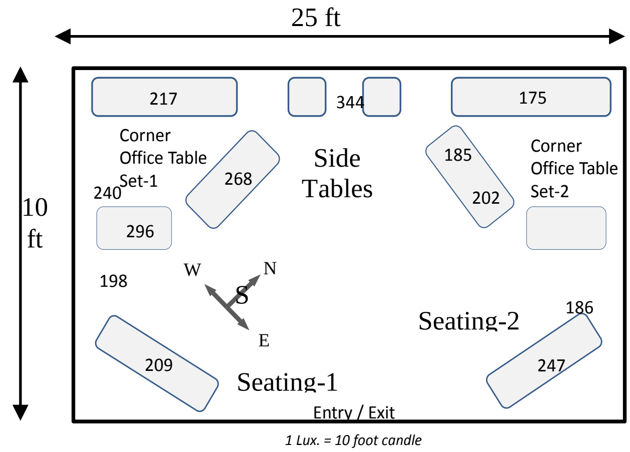

Fig. 1: Luminous flux values (in Lux) received at 8ft from Compact fluorescent lamps

Table. 1: Already Installed CFL Wattage

CFLs (Rated Wattage)			
	Wattage	**Quantity**	**Total watts**
fitting-1	18	20	360
fitting-2	11	36	396
Total:			**756**

2.2 FINDING EQUIVALENTLY LUMINOUS LED LAMPS

The goal is to find energy-efficient replacements for CFLs and bring down the overall energy consumption.

Figure 2 presents a comparison between the luminance produced by LED lamps and CFLs as obtained through experiments. It may be noted that using LEDs the same levels of luminance can be achieved with effectively half to one third of CFL wattage.

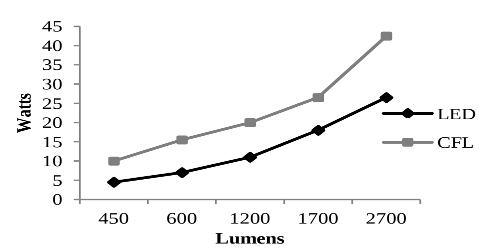

Fig. 2: Comparison of Lumens Produced by LEDs and CFLs

Spotlight / down light LED lamps have been tested, Luminous flux measured at 8 ft from the luminaries. The selection criteria is maximum flux / watt ratio for each unit. The following two types in Table-3 were selected to be installed.

Table. 1: Specifications of LED down Lights Installed

Color	Rated Power	Luminance at 8ft	Lux / Watt	Power Rating of CFL to be replaced	No of units installed
	Watts	Lux		Watt	
Warm White	6	97.6	16.3	11	36
Warm White	9	116.7	13	18	20

2.3 SIZING THE SOLAR ARRAY

The sizing of a photovoltaic (PV) solar array requires a study of the solar radiation profile of the area where the system is to be installed. National Renewable Energy Labs (NREL) USA have collected a great deal of data on "solar mapping" of all major regions of the world. This data has been used to predict output of a solar array in Lahore (Punjab, Pakistan) region [5], [6].

To energize the 400 Watt load, 100 Watt Multi - crystalline solar modules are used. Choice between mono and multi crystalline modules largely comes down to covered area as for the same per watt peak output larger cell area is required for multi crystalline. Factors included in this calculation were:

- Seasonal solar radiation data (NREL)
- Solar cell energy conversion efficiency (Refer to Appendix. Table.5)
- Temperature coefficient of the solar modules (Refer to Appendix. Table.5)
- Assumed inverter DC-AC conversion efficiency (max70 % of DC input) deduced from [4]

A spread sheet model takes all the above factors into account, calculating the output of a solar module of the given specifications. Gradually increasing number of modules used to predict output such that the array generates enough output to service the load.

3. TRACING THE COMPLETE OUTPUT CURVE

An experiment has been carried out to verify the Power output of a Class-A 100 Watt Multi-crystalline solar modules in given solar irradiance and ambient temperature prevalent.

(Refer to Appendix. for detail module specifications)

The solar module is placed facing true south. Angular tilt with horizontal is varied from 10 to 50 degrees. Module output connected to battery charge controller, charging a 4.5 AH, 12 volts battery and servicing variable resistive loads as shown in Fig.3 and Fig.4. Load is varied from 5 ohms to 10 k ohms in 20 Watt resistors and (voltage * current) values indicated on the on device amp / voltmeter have been recorded.

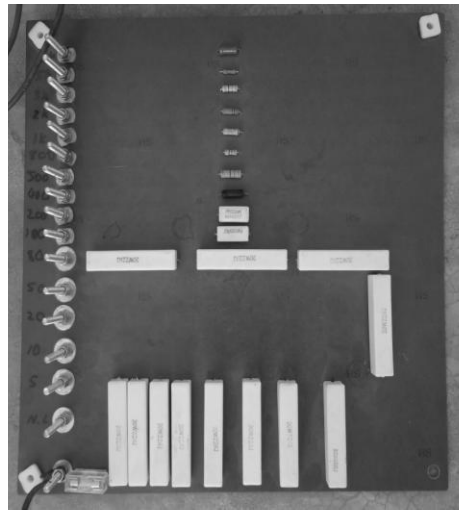

Fig. 3- Resistive load used during the test

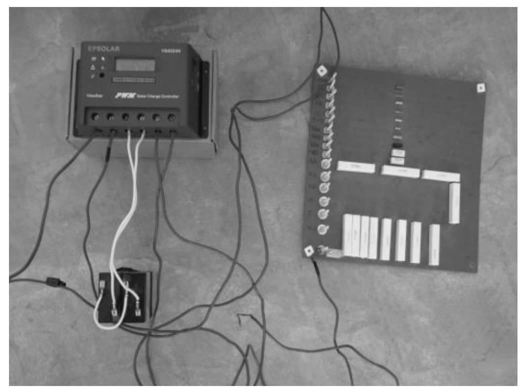

Fig. 4- Arrangement showing the 40A 24volt charge controller with resistive loads and 4.5 AH battery set

4. RESULTS

Following main results are presented.

4.1 LED LUMINANCE

To evaluate the performance of installed LED luminaries, luminous flux values were recorded at 8ft from the installed down lights these are presented in the Fig.5 whereas the total wattage of the same is summed up in Table. 4.

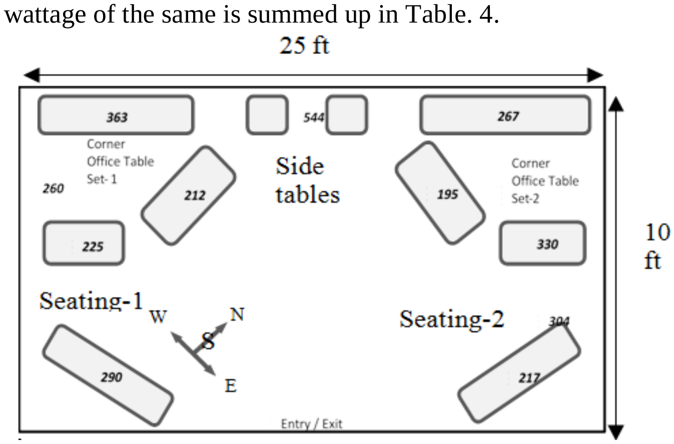

Fig. 5: Luminous flux values (in Lux) produced by LED down lights at various points 8ft from the ceiling

Table. 4: Total Rated Wattage Of Led Down Light Units Installed

LED Lights	Rated Wattage	Number of Units Installed	Total watts
down light-I	9	20	180
down light-II	6	36	216
Total :			**396**

4.2 PREDICTED OUTPUT AT OPTIMUM SEASONAL INCLINATION

Figure 6 and Fig. 7 show the results generated by the spread sheet model, predicting the performance of a solar array when it is sized at 800 watts and 1000 watts respectively Located in Lahore, Punjab with modules placed at seasonal optimum tilt angles through-out the year.

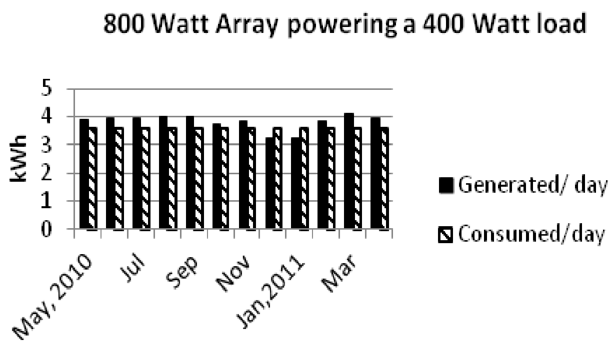

Fig. 6: Predicted results of an 800 Watt array energizing a 400 Watt constant profile load plotted for an average day each month

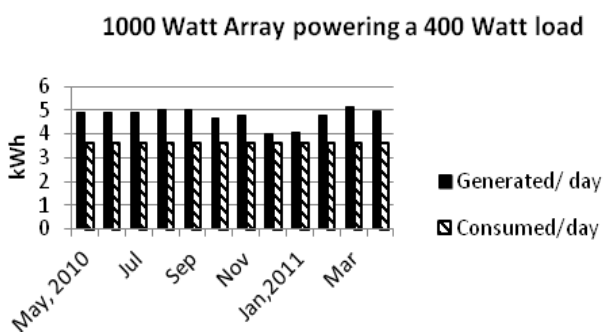

Fig. 7: Predicted results of a 1 k Watt array energizing a 400 Watt constant profile load plotted for an average day each month

4.3 OUTPUT AT VARYING TILT WITH HORIZONTAL

Fig.8 – Fig.12 present the actual maximum values of solar energy collected on one 100 watt Multi crystalline solar module at three different angles of inclination with horizontal that translate into watt hours.

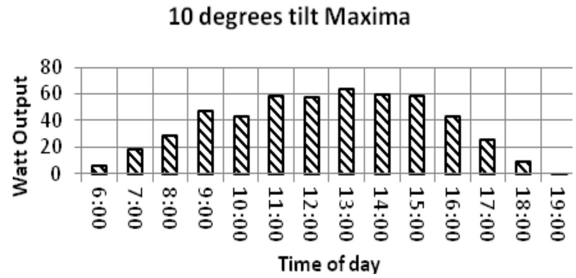

Fig. 8: Hourly collected energy through a 100 Watt Class-A solar multi-crystalline module making a 10 degrees angle with the horizontal

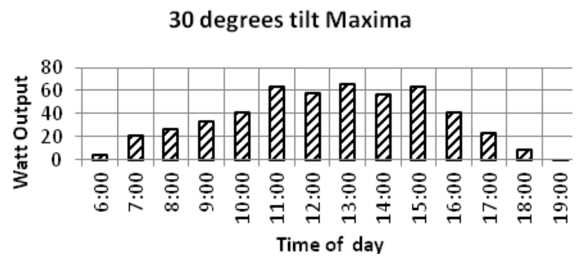

Fig. 9: Hourly collected energy through a 100 Watt Class - A solar multi-crystalline module making a 30 degrees angle with the horizontal

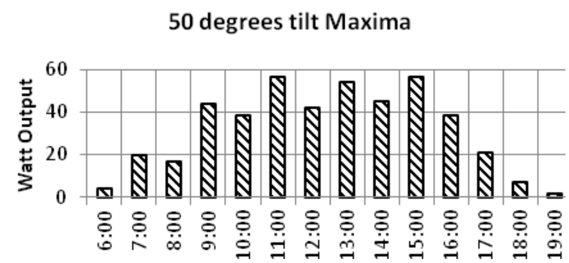

Fig. 10: Hourly collected energy through a 100 Watt Class - A solar multi-crystalline module making a 50 degrees angle with the horizontal

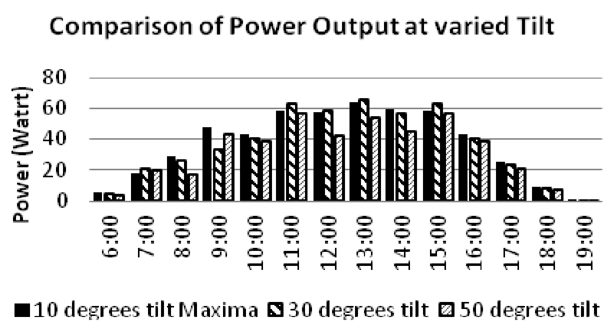

Fig. 11: Hourly comparison of power collected in watts by a 100 Watt multi crystalline module at three different angles of inclination with the horizontal

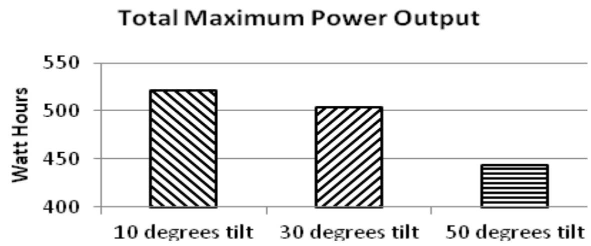

Fig. 12: A comparison of the Total Watt-hours collected through a 100 Watt multi crystalline solar module at three different angles of inclination with the horizontal

4.4 HOURLY GENERATION AND DEMAND DIFFERENCE BASED ON RESULTS OF SOLAR MODULE TESTS

Fig.13 – Fig.16 present an hourly comparison of expected power collected in watts to the hourly energy demand of the system for an 800 Watts and 1000 Watts solar array respectively.

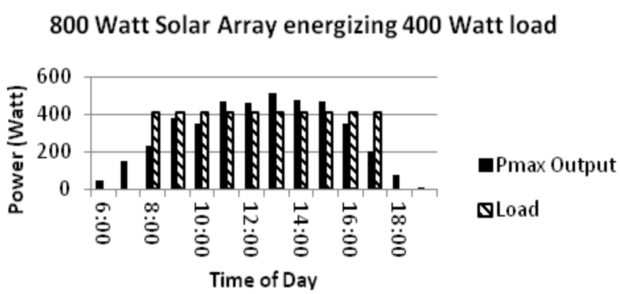

Fig. 13: Comparison of energy collected by 800 watt solar array with un-varied load demand

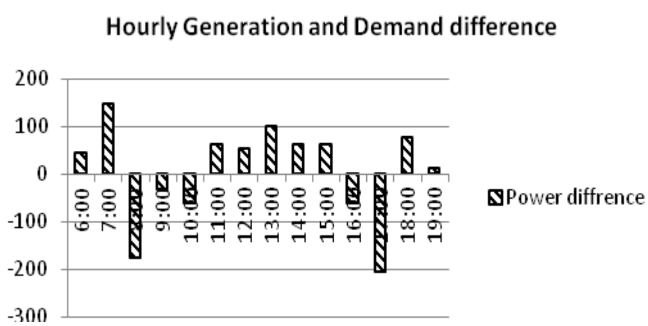

Fig. 14: Hourly generation and demand difference in Watts

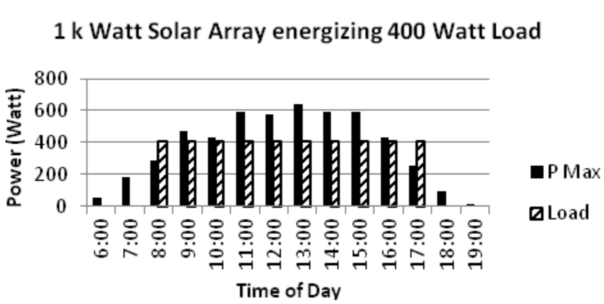

Fig. 15: Comparison of energy collected by 1 k Watt solar array with un-varied load demand

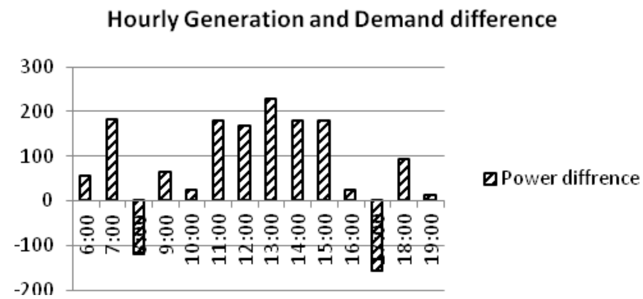

Fig. 16: Hourly generation and demand difference in Watts

4.5 HOURLY AMBIENT TEMPERATURE

Fig.17 gives hourly values of ambient temperature recorded by charge controller mounted temperature sensor while the experiment was being performed.

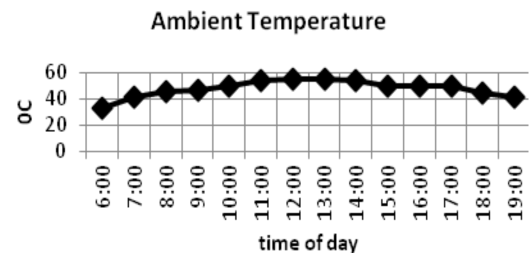

Fig. 17: Hourly ambient temperature recorded by charge controller mounted temperature sensor

5. DISCUSSION

5.1DOWN LIGHT / SPOTLIGHT LIMITATIONS

Comparing the measured luminance levels in Fig.1 and. Fig.5 achieved using CFLs and LED Down lights respectively, it may be noticed that at a few spots the luminance levels slightly fall below the previous. Whereas, towards the upper right and upper left part of the figure luminance levels have actually increased. The former phenomenon is largely due to the spotlight output being blocked by decorations. Spotlights are designed throw an outwardly spreading beam of light, illuminating a given area. For good results the path of this beam should not be blocked by impeding objects. Furthermore, light hues and reflective surfaces aid such LED illumination schemes.

5.2 COMPARISON OF ENERGY COLLECTED AT VARIOUS ANGLES OF INCLINATION

Fig. 11 and Fig.12 compare the actual watt hours collected by a 100 Watt solar module at three different angles of inclination with horizontal. Since this experiment was carried out near the end of the month of June, the 10 degrees angle is closer to the optimum seasonal angle for summer and thus collects the greatest energy in comparison.

5.3 ENERGY COLLECTED ON FLAT PLATE COLLECTORS TILTED AT SEASONAL OPTIMUM

The optimum angle of inclination solar modules should make with the horizontal plane has been calculated such that the angle of sunlight incident on module surface is as near to normal as possible. This optimum angle varies throughout the year with notable change in tilt angles for summer and winter. Tilt angles have been calculated for each month and season. The collected solar radiation data is based on the assumption that flat plate collector modules are inclined at the seasonal optimum angles.

5.4 EFFECT OF AMBIENT TEMPERATURE

An increase in the temperature of a solar cell has a negative coefficient on output power. This is usually stated at a standard of 25 degree Celsius, above which the output falls by the stated co-efficient and below which it increases by the stated co-efficient, provided the Solar incidence remains constant. In true terms the Actual temperature of the Solar Module has to be considered. In these calculations, however, this has been approximated with the temperature ambient (under shade).

(Refer to Appendix Table.8 for temperature coefficients)

5.5 HOURLY GENERATION VS. DEMAND AND CORRESPONDING CONSIDERATIONS IN SIZING THE BATTERY BANK

The hourly generation vs. hourly demand differences presented in Fig.12 and Fig.14 are both positive and negative. System design aims at storing the positive (excess) regions in battery banks and reproducing these where negative (demand) regions appear. All this has to be done maintaining depth of discharge (DOD) constraints. Usually, it is better not to exhaust the batteries beyond 40 to 50% of charging capacity in ordinary circumstances. This along with a stated efficiency of most Lead acid batteries around 75% has to be considered in arriving at a convenient battery bank size.

6. CONCLUSIONS

Following the systematic procedure stated in this paper, luminary loads comprised of Incandescent and fluorescent lamps can be replaced with LED lights whilst maintaining equivalent levels of ambient luminescence. Furthermore, A properly sized Solar PV system can be arrived at which can energize constant profile loads.

In this way, input from PV modules can be made to contribute into already existing systems, thereby, yielding cost savings in the longer run.

7. FUTURE WORK

A thorough analysis of the economic viability of moving towards PV energy in Pakistan, may be undertaken. Economic analyses with and without battery banks. Important questions as the comparison of the price of a kWh of electricity produced by solar energy with that produced through conventional means; the payback period of solar systems and how break even can be achieved sooner should be dealt with in the context of prevailing financial trends.

Appendix [7]-[8]

Table. 5: Operational Limits of Solar Module

System voltage (max):	50V DC Max.
Series rating of fuse:	10 A DC
Reverse current (limiting):	not for voltages > Voc
Oper. range of Temperature:	-40 to 194°F (-40 to 85°C) 115
Max. static load, front (e.g., snow and wind):	113 psf (2400 Pa)
Max. static load, back (e.g., wind):	50 psf (2400 Pa)
Hailstone impact:	1 in (25mm) at 51 mph (23m/s)

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