A Comparative Study of Low Cost Solar Based Lighting System and Fuel Based Lighting System for Remote off Grid Location in India

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ABSTRACT: *A number of villages in India is yet to be electrified due to its location. At the same time it is also important to mention that grid connection to those areas is very expensive and time consuming. The source of lighting in those areas are conventional fuel based lighting system i.e. mainly kerosene based lantern. It has immense health hazard and environmental impact. To meet the energy demand of the off grid locations in India, solar energy can play vital role. The aim of the present study is to design an efficient and low cost solar based lighting system for the off grid location in India. The solar based lighting system was compared to the kerosene based lantern and found much efficient as far as lighting flux is concerned. The cost of the solar based system and payback period is also studied. The payback period definitely indicates the opportunity to utilize solar based lighting system for off grid locations in India.*

Keywords: *Energy Efficiency, LED Lighting, Payback Period, Single Diode Model, Solar Cell*

I. Introduction

Energy is the integral part of life. Energy demand increases day by day but it is a big challenge to distribute energy in usable form in all part of the country. It is found that, around 25,000 villages are located in remote and inaccessible areas and hence could not be electrified through conventional grid extension in India. But, it is essential to provide energy to those people who are living in off grid area. At the same time it is very much expensive to connect those areas though grid connection because of their inaccessible geographical location. The concept of mini grids is advantageous in some remote areas to provide sustainable, reliable electricity and cost effective electricity [1]. But this concept is also a long term process to meet the energy demand of the remote locations. To overcome this problem, it is beneficial to generate off grid power to meet the minimum energy requirement using available alternative sources of energy. The Ministry of New and Renewable Energy (MNRE) in India is implementing the 'Remote Village Electrification Program' (RVEP) to electrify such remote villages by installing solar photovoltaic (PV) home lighting systems in all the states. It is found that solar home lighting system in the remote village can influence the standard of living of people very significantly in the remote areas. It also reduces the expenditure on kerosene of the households of all income groups due to solar home lighting system [4]. A study in the household sector of Kanyakumari District of Tamil Nadu reveals that the consumption pattern of energy sources wholly depends upon the availability of the energy sources, and the level of income of the people [2]. It is found that decentralized energy planning (DEP) is one of the options for meeting the rural and small scale energy needs in a reliable, affordable and environmentally sustainable way. The main aspect of the energy planning at a decentralized level is to prepare an area based DEP to meet energy needs and development of alternate energy sources at least cost to the economy and environment [3]. In the rural area, domestic household sector accounts for nearly 75 percent of the energy use in rural areas [5]. In a study it is found that the employment of a solar lighting system of 3 W lamp and battery backup can successfully be used for small scale lighting applications in remote areas that are far away from the power grid. [6]. A study to quantify the energy saving potential possible with changing in illumination schemes, it found that the adoption of LED lighting scheme has huge energy saving potential, and reasonable payback period [8].

Hence conjugation of LED as a means of illumination with solar photovoltaic system will give a highly efficient system as alternative lighting for remote inaccessible areas in India. The scheme will definitely improve the lighting energy utilization pattern in the remote off grid location and hence the standard of living of the people.

II. Sources of lighting energy in off grid area in India

A huge no of remote villages are not connected yet with grid connection to meet the energy demand of that locations. This is mainly due to inaccessibility of the areas due to geographically backward location. The main means of lighting in those areas is burning fossil fuels. A very few number of people uses solar energy for lighting. In the present study it is found that solar energy is one of the important resources to meet the lighting energy demand of households with low initial investment and payback period. Our study is based on the solar energy utilization as highly efficient lighting system in a cost effective manner.

III. Sun as source of energy

Sun is the source of all energy in this universe. The energy received from the sun is in the form of radiation. The intensity of solar radiation available on the earth surface varies significantly with seasonal change. The intensity of solar radiation is measured in watt per square metre. The available energy from sun can be converted into usable energy by solar thermal application or by solar photovoltaic application. In the present study, concentration is given towards use of solar photovoltaic cell to directly convert the solar energy into usable electrical energy and hence to meet the lighting demand of remote off grid areas.

IV. Design of low cost domestic lighting system for off grid area

The schematic design for the domestic lighting system is shown in the figure. The main objective of the design is to provide lighting energy with very low cost as a large section of the people in remote areas belongs to economically backward section. It comprises of a solar cell array, solar charger, a battery backup system, LED as scheme of illumination.

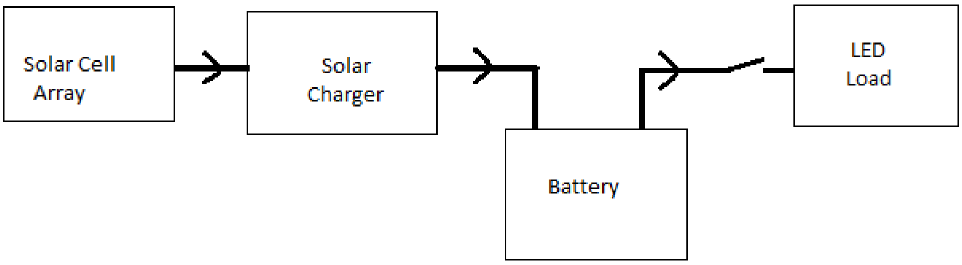

Figure 1: Schematic diagram of the system designed

4.1 Solar cell array

PV cells are grouped in larger units called PV panels which are further interconnected in a parallel-series configuration to form PV arrays. Each of these cells is basically a p-n junction capable of converting solar energy into electrical energy. The conventional technique to model solar cell is to establish mathematical expressions based on the equivalent circuits of the cell. Circuit of a single diode model of solar cell is shown in Fig 2 [9]. In single diode model, there is a current source parallel to a diode. The current source represents light generated current, which varies linearly with solar irradiation. This is the simplest and most widely used model as it offers a good compromise between simplicity and accuracy.

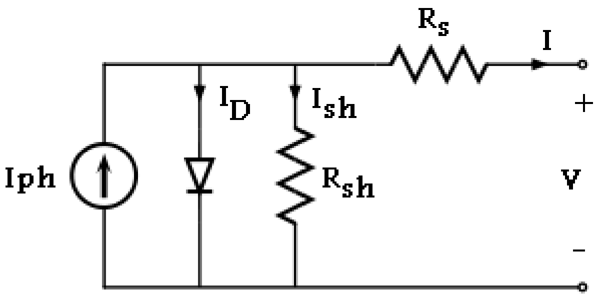

Figure 2: single diode model of solar cell

From the Fig.2 the following equations can be written to mathematically describe the model of the solar cell:

$$I = I_{ph} - I_D - I_{sh} \quad (1)$$

$$I_D = I_s\left(exp\frac{q(V_D + R_s I)}{NKT} - 1\right) \quad (2)$$

$$I_{sh} = \frac{(V + R_s I)}{R_{sh}} \quad (3)$$

$$I = I_{ph} - I_s\left(exp\frac{q(V_D + R_s I)}{NKT} - 1\right) - \frac{(V + R_s I)}{R_{sh}} \quad (4)$$

In these equations, I_{ph} is the photo current, I_s is the reverse saturation current of the diode, q is the electron charge, V_D is the voltage across the diode, K is the Boltzmann's constant, T is the junction temperature, N is the ideality factor of the diode, and R_s and R_{sh} are the series and shunt resistors of the cell, respectively. In the present work a solar cell specifications are mentioned in Table 1.

Table 1: Solar cell parameters

Parameters	Values
Maximum Power (P_{max})	5W
Voltage at max. Power (V_{max})	8.8 V
Current at max. Power (I_{max})	0.57 A
Short circuit current (I_{sc})	0.61 A
Open circuit voltage (V_{oc})	10 V

4.2 Solar charger

A solar charger is designed to charge a sealed and maintenance fee (SMF) battery during the presence of day light. It will also limit the current and protect the battery to discharge through the solar cell in absence of day light.

4.3 Battery

The battery is used here to store energy generated in the solar cell and use the same in absence of sunlight i.e. mainly during the night time. The battery used is a sealed and maintenance free battery of 4 Ah capacities.

4.4 LED as lighting source

LED is a semiconductor device which emits light when connected to power source. Basically it is a PN junction diode. In forward biased condition it emits energy in the form of light. The collour of the emitted light depends on the material used to develop the LED. The efficacy of light source is measured in lumens/watt. The efficacy of LED is compatible with the present light source but the efficiency of LED lighting is very high. As there is no heat developed in LEDs hence power towards heat will be reduced. The losses taking place will be in driver circuits which account for 10-15% losses, thus a higher efficiency in the range of 85-90 % can be obtained. It makes LED as an energy efficient source of lighting of coming days [8]. Power consumption of the designed light system is 3w.

V. Results

From the study it is found that the developed system can deliver power for four hours per day when the battery is charged during the day time on a sunny day. The available solar radiation profile for a particular sunny day during 5:00 a.m. to 5:00 p.m. is shown in Fig.3. From the Fig.3 it is seen that the duration of effective day light is around seven hours to charge the battery.

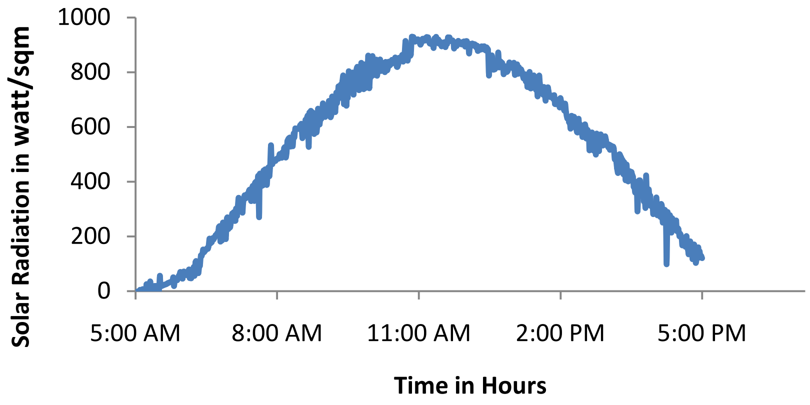

Figure 3: Variation of solar radiation on a sunny day

The scheme of measurement of output LUX of the lighting source has been shown in Figure 4. Lighting source is placed on different vertical height and measurement of light flux has been taken in two positions namely A and B in the Figure 4. Position A indicates the lighting flux on the working plane just under the lighting source. It is obvious that this position will be the maximum LUX point on the working plane. Position B is the point on working plane at some defined horizontal distances from the maximum LUX point. The vertical distance from source to working plane and horizontal distance between position A and B on the working plane are 1, 2 and 3 feet respectively.

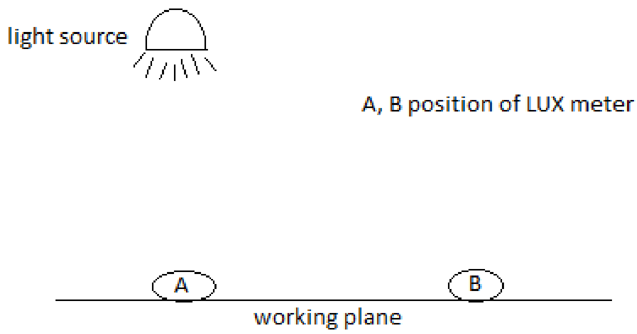

Figure 4: Illumination measurement in working plane

The output light flux for the designed system at different distances is shown in Table 2. The conventional lighting system i.e. kerosene based lamp for the remote off grid area is also studied and shown in Table 3. Kerosene lantern is placed on the working plane to quantify the available lighting flux. The measurement has been taken at 1, 2 and 3 feet distance with LUX meter facing towards source and LUX meter placed on the working plane. From the comparative study it is clear that the designed system is much better as far as lighting flux is concern. It is also important to mention that it can avoid the health hazard on the occupants caused due to burning of fossil fuel.

Table 2: Illumination level on the working plane with the designed system

Sl. No.	Distance (in feet)	Illumination level when LUX meter at position A (in LUX)	Illumination level when LUX meter at position B (in LUX)
1	1	125	30
2	2	33	7
3	3	13	3

Table 3: Illumination level on the working plane with the conventional kerosene lantern

Sl. No.	Distance (in feet)	Illumination level when LUX meter at position faced towards the source (in LUX)	Illumination level when LUX meter is placed in working plane (in LUX)
1	1	10	5
2	2	5	2
3	3	2	1

VI. Calculation

Cost of the system designed is around Rs. 700. Now the cost of kerosene based hurricane lantern used in the rural area for lighting is around Rs. 100. On an average the fuel consumption per household to run a lantern round the year is around 40 litres. Now the yearly cost of fuel i.e. kerosene in this case is Rs.15X40 = Rs.600 assuming the cost of kerosene per litre with Government subsidy as Rs. 15. Hence the replacement of kerosene based lantern with solar photovoltaic based lighting system will demand a reasonable initial investment with payback period of 700/600 = 1.16 year i.e. one year two months.

VII. Conclusion

From the present study it can be concluded that the developed lighting system will eliminate the health hazard of using low intensity kerosene based lighting system in the remote villages in India. At the same time, the study shows the amount of savings kerosene and the initial investment of the system which reflects a reasonable payback period.

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