Hardware Implementation and Design of PV Off-Grid System for Street lighting at Thapar University, Patiala

S. Singh and S. Bhullar

***Abstract*— In this paper, comparison and analysis between High Pressure Sodium (HPS) Lamp and Light Emitting Diode (LED) are represented. Now-a-days, latest technology LED lamp is mostly used for outdoor lighting due to its low energy consumption, less maintenance and long life. At Thapar University, HPS lamps are used for street lighting. If HPS lamps will be replaced by LED lamps, a good amount of energy saving is possible i.e. if we replace HPS lamp of 250W with LED lamp of 120W. Also, PV Off-Grid system is designed for street lighting at Thapar University.**

***Index Terms*— – HPS, LED, Smart street lighting system.**

I. INTRODUCTION

THE purpose of street lighting is to make people, vehicles and objects on the road visible. Street lights are used for the safety of people, crime prevention, preventing night time personal injury accidents, promoting economic development by supporting a 24 hrs leisure economy, promoting 24-hr use of the existing road infrastructure, night time distribution, travel etc. Presently, High Pressure Sodium (HPS) lamps are widely used for the purpose of outdoor lighting. They produce yellow light but its Color rendering index is low that is near 40. So, the objects are not revealed clearly and they consume more power .Its life is also too short near 5000 hrs only. On the other hand, Light Emitting Diode (LED) lamps have long life up to 50.000 hrs, high CRI greater than 80 i.e. produce a white cool light and objects are revealed clearly and require less maintenance [1]. The main hindrance in the path of LED lamps is initial high cost. HPS lamps take near 15 min. for starting from initial state and has a lead toxic element [2] that pollute the air but LED lamps start with in a second and contain non lead element (reduce the energy consumption and also reduce Co_2 emissions per year). At, Thapar University, approx. 200 street lights are used at whole campus for providing lighting during night; So, we can replace HPS lamps of 250W which are currently used with new technology light emitting diode lamps 120W. The energy saving per year is calculated if above mentioned will be implemented. According to the load calculation of lighting lamps, a PV Off-Grid system for 200 LED street lights is proposed. With the help of PV panels, renewable energy sources for street lighting purposes can be used at Thapar University. The ratings of components which are required to design PV off-Grid system are calculated.

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II. ANALYSIS BETWEEN HPS AND LED LAMP

Fig. 1. Night time lighting view of the HPS and LED lamp of different rating

The Figure 1 shows the difference between the lighting view of High Pressure Sodium (HPS) Lamp (250W) and Light Emitting Diode (LED) (120W). The white LED street light seems brighter due to its higher CRI>80 (color rendering index) and objects illuminated could be identified clearly [3]. Objects are hard to be identified in case of HPS because of low CRI approximately 40, though HPS produces much more lumens. The specifications of HPS and LED lamps are as given below.

LED Lamp, 120W specification:

- Power = 120W
- Input voltage = AC 85-265V
- Working frequency = 50-60 Hz
- Working temperature = -45º to 50ºC
- Lamp efficiency: >95%
- Harmonic Distortion: <10%

- Power factor: >0.95
- LED luminous efficiency: 90-100 lm/W
- Luminous flux: >10200 lm [4]
- Colour (CRI): cool white / white: Ra>80, warm white: Ra>70
- Colour temperature: 6000-7000K, warm white: 3000-4000K
- Beam angle: 120^0, 90^0

HPS Lamp,, 250W specification:

- Power = 250W
- Colour temperature = 1900/2000K
- High CRI = 40
- Lamp voltage = 127/253V
- Luminous flux = 2800lm/3200lm
- Colour of light – Pink orange [5].

III. TOTAL INITIAL COST OF LED LAMP

At **Thapar University**, approximately 200 Street Light lamps are used which consist of 95% Sodium Vapour lamp (250W) and 5% Metal halide lamps. If these lamps get replaced by LED lamps, then large amount of input energy, electricity bills and also Co_2 emissions per year will be reduced.

The cost of one 120W LED lamp = Rs 12000

Cost of 200 pieces of 120W LED lamp = Rs 12000×200 = Rs 24, 00,000.

A. Calculations for energy saving annually

The energy saving per year is calculated if HPS 250W gets replaced by LED 120 W.

HPS Lamp:

Rating of HPS lamp = 250W
Burning hrs = 10
Life time = 12000-24000 hrs
Starting time = 15min.
Environment pollution = contains Lead element [6].
Power consumed by 250W 200 fixtures per day if burning time is 10 hrs
= (watts of lamp/1000) ×200
= (250/1000) ×200
= 500 kWh = 500 units
Total Co_2 emissions per year = 182 tones

LED Lamp:

Rating of LED Lamp = 120W
Burning hrs = 10
Life time = 50,000-100, 000 hrs [7].
Starting time = quite high (within seconds)
Environment pollution = less as compared to HPS [7].
Power consumed by 120W 200 fixtures per day if burning time is 10 hrs
= (watts of lamp/1000) ×200
= (120/1000) ×200
= 240 kWh = 240 units
Total Co_2 emissions per year = 87.36 tons

B. Power saving:

- Per day power saving with 200 LED fixtures = 500-240 = 260 kwh = 260 units
- Per month power saving with 200 LED fixtures = 260×30 = 7800 units
- Per year saving = 7800×12 = 93,600 units

C. Money saving:

- Total money saving per year = Total no. of units × unit cost per kwh
- Unit cost per kwh for public lighting = Rs 6.10 (according to Punjab power regulatory commission, year 2014)
- Total Saving = Rs 6.10×93,600 = Rs 570.960

D. Co_2 reduction

- Co_2 emissions reduction per year = 182-87.6 tons = 94.64 tons per year

From the above calculations, it is found find that nearly 260 units per day or 93.600 units per annum can be saved. Also, approximately 95 tons carbon-dioxide per year will be reduced while implementing 120W LED lamps at Thapar University. Energy consumption graph is given in Figure 2. Given the graph carbon emissions and energy consumption can be clearly seen.

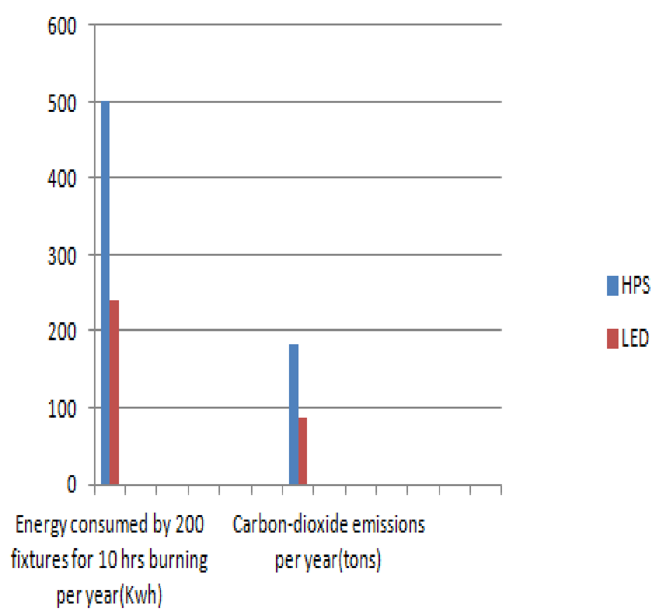

Fig. 2. Energy consumed by HPS and LED

High Pressure Sodium (HPS) Lamp and Light Emitting Diode (LED) when compared in terms of efficiency, LEDs can be seen to be more efficient. High Pressure Sodium (HPS) Lamp s carbon emissions are rather high [8].

IV. DESIGN OF PV OFF-GRID SYSTEM FOR 200 LED STREET LIGHTING SYSTEM IN THAPAR UNIVERSITY

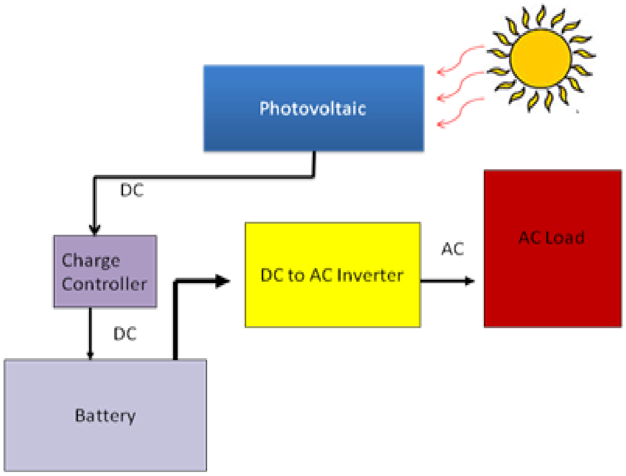

Fig. 3. PV Off-Grid System

Off-grid PV System's fundamental operating principle is shown in Fig. 3. The following system components are used in PV off-Grid System.

A. Solar panels:

A number of photovoltaic modules are connected in parallel or series which give a DC output of the incident irradiance. [9] The important design parameters of PV modules are orientation and tilt as well as shading from surroundings obstructions.

Different types of solar panel are:

i. **Monocrystalline Cells:** These are made using cells cut from a single cylindrical crystal of silicon. It offers the highest efficiency (18%) and complex manufacturing process makes it slightly more expensive [10]. Monocrystalline silicons are used in the production of high-performance solar cell. But solar cells, structural defects, Monocrystal solar grade as concerns frequently used in microelectronics circuits is less demanding.

ii. **Polycrystalline Cells:** These are made by cutting micro-fine wafers from ingots of molten and recrystallized silicon [11]. These are cheaper to produce, but there is a slight compromise on efficiency (14%) [10].

B. Solar charger controller:

It is also called brain of the system. It is responsible for performance, durability and functions. Another name is also known as solar regulator. It controls the flow of current to and from batteries to protect it from overcharging after reaching the required voltage within the battery [11]. It also protects again over charging when the load causes critical/min. voltage within the battery.

C. Batteries:

The batteries which are used in off-Grid system connected in series-parallel depending upon the requirement of voltage and current. The power produced by PV modules saves in batteries and discharge it at the time of need. The electrical power stored in the batteries is used for lighting during night [12]. The unit of batteries is in Ah. The rating 1Ah means, battery delivered 1 amp load for one hour.

D. Pure sine wave inverter:

A Pure sine wave inverter also known as power converter which is used to converts the dc power produced by solar modules into ac power. The characteristics of output signal should match the voltage, frequency and power quality limits in the network [13]. The rating of inverter is in watt or kilowatt.

V. DESIGN OF PV OFF-GRID SYSTEM

A. Determine power consumption demands:

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

Total lighting load = 120W×200 = 24.000W
Lamps used 10 hrs per day = 24.000×10hrs = 2, 40,000 Wh/day
Total PV panels energy needed = 2, 40,000×1.25 = 300.000 Wh/day (+25% reserves energy and losses)

B. Sizing the PV generator:

Total W_p of PV panel capacity needed = 300.000/7 = 42.857 W_p
Factor **7** = Avg. daily solar exposure in hrs in Patiala during summer but in winter it may be 4-5 hrs.
No. of PV panels needed = 42.857/180W_p = 238 module of 180W_p.

This system should be powered by at least 238 modules of 180W_p PV module which when connected in series-parallel connection.

C. Sizing the inverter:

Total watt of load = 24000W
For safety, the inverter should be considered 25-30% bigger size [3].
The inverter size should be about,
24000×1.3 = 31,200W = 32000W (32kW) or greater.

D. Sizing the battery:

Total load = 24000W×10hrs
Nominal battery voltage = 24V
Days of autonomy = 3 days
Battery loss = 0.85
Depth of discharge = 0.5

Battery Capacity (Ah) = total watt-hrs used by load× days of autonomy/ (battery loss× depth of discharge× nominal voltage)
Battery Capacity = (24000W×10hrs) × 3/ (0.85×0.5×24)
Total Amperes-hrs required= 70.588Ah

So, the battery rating should be 24V and near 70,588Ah for 3 day autonomy.

E. Sizing the charge controller:

Technical specifications of 180W_p module are as given below:
Power = 180W
Voltage = 24V
Current = 5A
Type – Polycrystalline
Module efficiency = 14.3%
Temperature = 25^o C
Dimension = 1593×790×50
Area of single panel = 1258470 mm or 1.259 m^2
Tilt angle (slope) of PV module = 30^o 7'
Mounting – fixed type

Current (A): The rated current for solar charge controller = (238×5A) × 1.25 = 1487A (25% safety buffer)

Solar charge controller should be rated at 1487A or greater.

Voltage (V): The PV voltage (V_{oc}) of 238×180W_p panels, connected parallel will be 24×1.2 = 28.8V (20% safety buffer).

The maximum allowed voltage within a 24V PWM controller is 52V and it should not exceed 28.8V.

According to above calculation (238×180W_p), a 1487A PWM charger controller for 24V system should be chosen.

VI. Graphical Representation of Calculations

The following graph represents the Power consumed by 200 fixtures per day by High Sodium Vapour Lamp and LED Lamp.

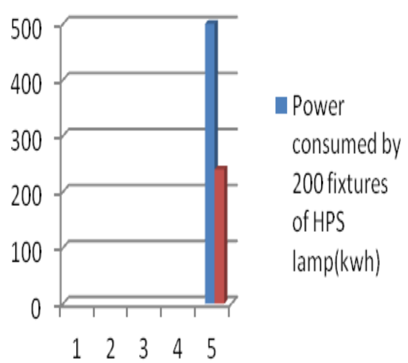

Fig. 4. Power consumed by HPS Lamp and LED Lamp

The following graph (Fig.5.) represents the life time hrs of HPS and LED Lamp. Graphs show that LED lighting systems are very efficient and long life compared to other lighting fixtures (Fig.6 and Fig.7). When considering the energy-saving LED lighting systems it is becoming the most preferable. Despite today's LED lighting production costs it is higher than expected [14].
Light Emitting Diodes with their electricity performances have proved to be the most appropriate solution for street lighting implementations. Todays, a topic of interest in the subject is the project for driver in to take the advantage of LEDs performances. Although, needs as high power factor, long life, exact current control and high efficiency pose challenges to the project of LED circuits [15].

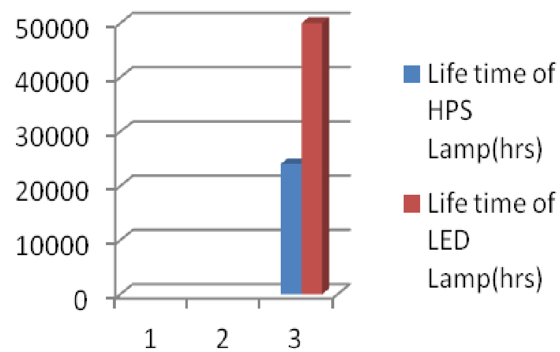

Fig. 5. Life time hrs of HPS and LED Lamp

The following Fig.6. represents the power saving per month and year by 200 fixtures if HPS Lamps get replaced by LED.

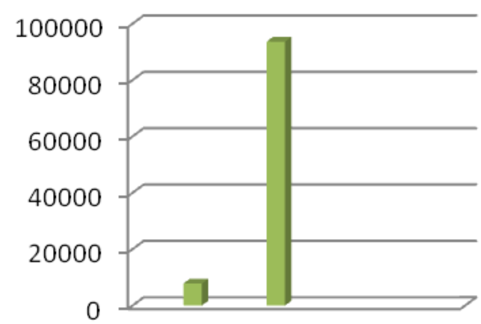

Fig. 6. Annually Power saving

The Fig.7. represents the money saving in a year.

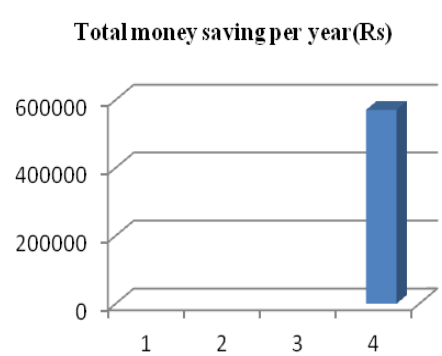

Fig. 7. Money saving annually

The following graph (Fig.8) represents the usable power of HPS and LED.

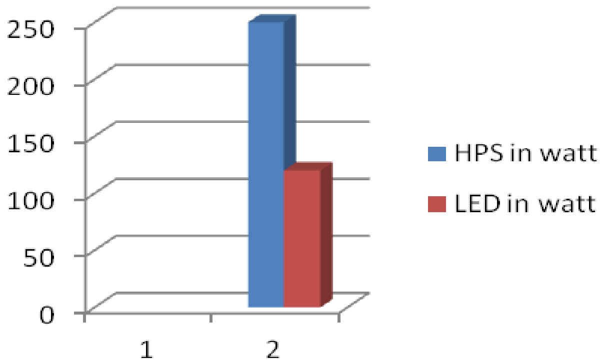

Fig. 8. Usable Power by HPS and LED

Fig. 9. Complete Hardware Setup

VII. CONCLUSIONS

From the observations, it is proposed that for street lighting LED lamps are superior as compared to HPS lamps. In this paper, HPS lamp of 200W is to be replaced by LED lamp of 200W because lumens emitted by HPS of 200W are almost equal to lumens emitted by LED lamp of 120W. Also, in order to promote renewable sources, a PV off grid system is designed for street lighting at Thapar University.

VIII. ACKNOWLEDGEMENT

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BIOGRAPHIES

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