

Solar Powered Automatic LED Lamp System with Power Optimization for Southern Expressway

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Abstract—The best solution for reducing power generation cost during peak hours is, shift some loads within peak hour to off peak hours. This solution cannot be subjected to light load. So ideal solution for removing light load from peak hours is to isolate those from grid during peak hours. Street lamps are having a considerable light load depend on grid. If we can remove some of this street light load from grid it would be a great advantage. In this paper we propose to convert all street lamps in Southern expressway to solar power LED lamps. Besides reducing daily peak load, this will provide several other advantages as well. The system is environmental friendly, cost effective with only installment cost, few or no maintenance, long life than existing system and high efficient. Solar electricity is free. Because of these notable advantages the proposed system can be used to replace existing street lamps. Proposed solar lamps can be installed in the extended part from Matara to Hambantota as well. **Keywords**—component; formatting; style; styling; insert (key words)

I. INTRODUCTION

Social life patterns and day to day activities of Sri Lankans exhibit two peak demand periods in daily load curve [1] as shown in Fig. 1. The first peak (Morning peak) occurs between 5.30 a.m. to 6.30 a.m. and the other occurs between 7:00 p.m. to 8.00 p.m. at night (Evening peak). Evening peak demand is the highest hence control engineers are much concerned about. To accommodate electricity demand during evening peak Ceylon Electricity Board (CEB) needs to operate gas turbines as well which



Fig. 1 Daily load profile [1].



Fig. 2 E01 lit up

requires a huge amount of money. Lighting load contributes significantly for evening peak as well as morning peak [2]. Therefore, cutting off some of the light loads during peak hours from the electrical grid will result in considerable savings to CEB and the country. One of these light loads is the street lighting in highways. This paper proposes energy free system for street lighting in Southern Expressway of Sri Lanka with no power demand impact from the grid.

Southern expressway from Kottawa to Matara is already completed and it is to be extended from Matara to Hambantota. In the completed part of expressway street lamps are used only at exits, bridges and service area. Existing system use 250W high pressure sodium lamps powered by the grid. Instead a standalone solar street light system with power optimization is proposed Fig. 3 in this paper.

II. ADVANTAGES OF SOLAR LIGHTING SYSTEM

Solar power is the conversion of the energy from the sun to usable electricity. Solar is indefinitely a renewable energy resource. Since Sri Lanka is in the equatorial belt, it receives a year-round supply of solar irradiation. Solar radiation varies from 4.5 – 2 kWh/m²/day [3]. The amount of solar energy available at any place of earth depends on date of the year, time and latitude of the collection place. Solar cells directly convert the solar radiation into electricity using photovoltaic effect without going through a thermal process. Solar cells are reliable, modular, durable and generally maintenance free and therefore, suitable even for isolated and remote areas. Solar

cells are quiet, benign, and compatible with almost all environments, respond instantaneously with solar radiation and have an expected life time of 20 years or more. Solar cells can be located at the place of use and hence no distribution network is required. Considering the merits of renewable energy, a solar powered street lighting system will provide unmatched reliability and convenience for the public. Unlike wired street lamps, solar powered street lights are easy to install at any location, have no daily operational or post-installation cost and can be functional even during load shedding.

III. EXISTING SOLUTIONS

Some other countries for example Ghana are planning to implement and integrate this kind of system as described in [4] while some others as Indonesia already have systems in function [5]. Methods of adding intelligent control to LED systems are proposed and experimented in number of researches [6], [7], [8], [9], [10] and [11]. [12] discusses how PV panel's mounting angle affects system parameters and performance.

IV. PROPOSED SYSTEM

Proposed system is elaborated in Fig. 3. It consists of a PhotoVoltaic (PV) panel, tracking system, storage system, LED lamp / light array, Real Time Clock (RTC) and a controller. PV panel converts the solar energy to electricity and characterization that needs attention while choosing a suitable panel is discussed in coming Section IV. Purpose of tracking system is to monitor the movement of sun throughout the day and adjust the PV panel to get optimum amount of sunlight as described in Section V. Storage system which is discussed in Section VIII is required to store energy generated during sunny weather to be used during night and in unfavorable weather conditions. Consideration for lamp is discussed in Section X. RTC provides timing information required for intelligent controlling and operation of the system. Controller block is the heart of the system which is responsible for optimization and expected functionality is described in Sections VI and VII.

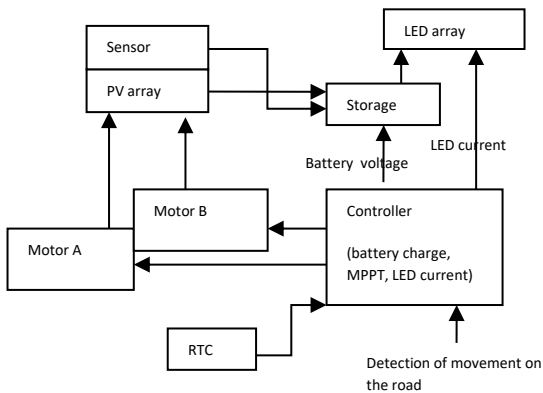


Fig. 3 General block diagram of the proposed system

V. OPTIMIZING SOLAR PHOTOVOLTAIC (PV) SYSTEMS

PV panels have a limited power output, and they work best over a narrow voltage range, or point, called the Maximum Power Point (MPP). Fig. 4 shows, in blue, the IV curve on which PV cells operate. At a PV panel's maximum voltage, Open Circuit Voltage (V_{oc}), it will produce no current. At a PV panel's maximum current, Short Circuit Current (I_{sc}), it will produce no voltage. Power is the product of voltage and current and we want a PV panel to operate at the point on the IV curve where it will produce its maximum power. This voltage level, Maximum Power Voltage (V_{mp}) is crucial when designing PV strings, especially for off-grid systems.

Inverters and charge controllers are available with a Maximum Power Point Tracking (MPPT) function. This forces the PV panels to operate at their MPP in any light condition. MPPT is most beneficial in off-grid systems because PV panels that are connected to a voltage source, like batteries, will operate at the voltage level of the source. If a PV string is not designed so that the V_{mp} is matched closely to the battery voltage much of the power that the panels could generate is wasted and it appears that the PV array does not work. And even then, the voltage of lead-acid batteries varies depending on their State-of-Charge (SoC). Fig. 5 shows the loss of power of a PV panel with a V_{mp} of 17V if it is connected to a 12V battery. Depending on the SoC of the battery the PV panel could be generating as little as 50% of its potential power. Panels connected in series, increasing the string voltage, will compound the problem.

VI. SOLAR TRACKING SYSTEM

One factor that greatly influences the energy collected by the panel is the angle at which the panel is mounted. This project proposes to operate a solar panel to constantly face sun at 90 degrees to produce maximum voltage. It will move the solar panel from east to west to correct for the durational movement of the Sun in the sky. We know the position of sun vary day by day. Therefore, to detect that variation we use another stepper motor as well. Literature related to solar tracking system describe in reference [14], [15] and [16]. Proposed tracking system used

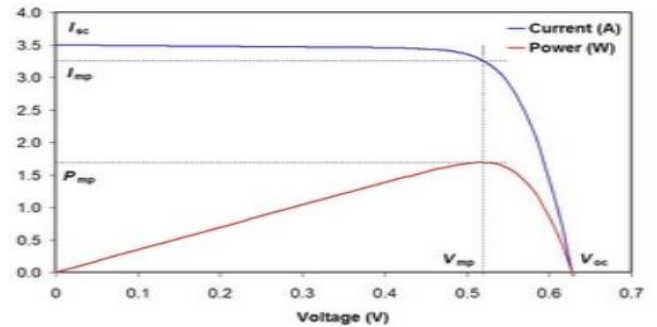


Fig. 4 IV curve of PV panel

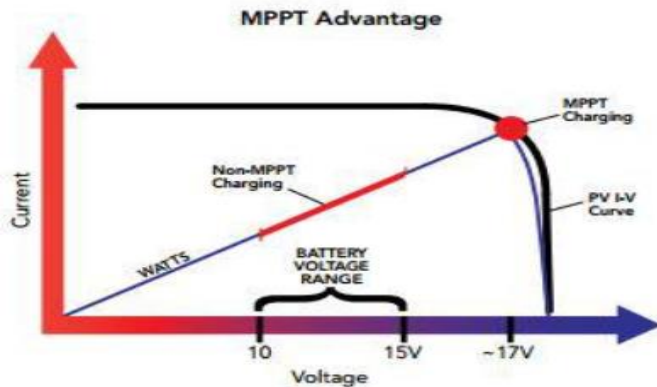


Fig. 5 PV panel with a V_{mp} of 17V if it is connected to a 12V battery

LDRs, stepper motors and PIR sensors. But for the design convenience single stepper motor moving East to West is sufficient. Much easier way and stable solution is to fix the solar panel to the tower.

VII. INTELLIGENT CONTROL OF ILLUMINATION

The proposed system considers the intelligent control of illumination of the streets during the off-peak hours in night (from 11.30pm to 5.30am say) based on detection of movement on the road caused by vehicles. Detection of traffic density, thereby operating the lamps at different intensity levels as per requirements. This will save energy wastage in time of low or no traffic and will further relax the requirement on system size. The system will increase the battery usage duration. A traffic sensor can be easily implemented using an ultrasonic or radio-frequency sensor, but use of the plenty of CCTV cameras already in operating in expressway would be an easy option. Real time image processing of frames captured by those can be used to detect movement on the road, allowing straight forward and cost-effective implementation. Alternative approach to increase efficiency incorporates dimming of LED street lights at midnight and brightening before dawn. But it may cause inconvenience to late night travelers on expressway. Off peak time can be detected by RTC. This can be also used to switch on and off the street lamp as well.

VIII. AUTOMATIC ON/OFF

During the bad weather conditions, the street lamp can be early the RTC setting. So, this type of situation can be avoided by measuring the current and voltage of PV panel. If voltage lowers than the minimum voltage, panel controller can send signal to switch on the light. Also, the amount of voltage greater than that value during the morning the lamp can automatically switch off.

IX. BATTERY PROTECTION CIRCUIT FOR CHARGE AND DISCHARGE

In the proposed system battery backup is very important. Batteries used in renewable energy (RE) systems are specially design for deep cycling. It is sufficient to light the lamp continuously at least for four days, if the weather is such that the PV cannot recharge the battery. With proper care batteries use in such system has a lifetime of ten to fifteen years. Protection of the battery is also an important factor. Completely discharging or over your battery decreases its longevity. Therefore, battery voltage should be always measured and when it reaches the lower limit, the lamp should be off to protect the battery. During charging also, battery voltage should be measured to prevent over charging. Sealed lead acid batteries can be used in this system.

X. LED STREET LAMP

Proposed system consists of LED street lamp and it gives notable advantages. This type of lamp reduces the amount of CO₂ emissions and eliminate hazardous disposal to environment. Further they are having an extremely long life of 100,000 hours, and most importantly these are high efficient. LEDs are good light sources; their efficiency is 160 Lm/W. So, using this type of lamps reduce more than 50 % of the total energy used by HID lamps; that by its order reduces the required PV arrays. Therefore, applying the proposed system, streets can be illuminated with lower power lamps, no operating costs, no CO₂ emissions and environmental friendly. [17] and [18].

The standard EN 13201 - part 2 "road lighting - performance requirements" specifies the different definitions with the requirements for each street type. The major requirements to look for are luminance, illuminance, uniformity (mean to min), limitation of glare, surround ratio and colour rendering. LEDs can fulfill the standards. Various types of LEDs are available in the market. To obtain high brightness, high power LEDs are better option. sle-080nw40-1w-cg (cool white) type has 90 w/lm. We can increase luminous flux by increasing number of lights. Average forward current of one unit is 350mA. Therefore while designing we have to maximize illuminance and minimize the current consumption. LED arrangement of the lamp can be as shown in Fig. 6.

Minimize current consumption is very important to the RE system, as it increases battery power usage. To reduce battery charge usage, micro-controller based control circuit utilizing PWM dimming control to control the LED light

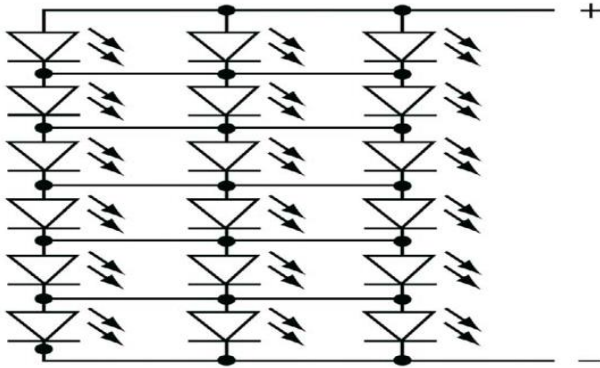


Fig. 6 schematic of LED lamp

output can be implemented. To increase brightness, we can introduce optical for the lamp. Literature related the optical is in reference [19]. Better heat management of the lamp is another important factor and discussion about heat sink design is on reference [20].

XI. CURRENT STATE OF STREET LIGHTING IN SOUTHERN EXPRESSWAY

The street lighting system already employed in Southern expressway is the cobra head type, which employs the use of high pressure sodium lamps for its illumination. The operating voltage is 230V and lamps used have wattages rating 250W. The main issue of these lamps is high power consumption from the grid during peak hours. There is no luminous control according to road vehicle in off peak. Switching on / off lamps are done automatically. Luminous flux of a lamp is approximately 25000lm. Mean service life of lamp is 25000h and nowadays some of lamps are not functioning.

The main purpose of street lighting is to ensure road safety, flow of traffic and public safety. The standard EN 13201- part 1 “road lighting - selection of lighting classes” classifies the streets in different lighting classes. Classes ME1-ME6 for motorized vehicles on main roads separated in medium driving speeds (30-60 km/h) or high driving speeds (above 60 km/h). For the highways the required total flux is too high.

XII. PRACTICAL MEASUREMENT OF LAMP

After the final design it is required to check whether the design complies specifications of EN 13201 1-5. Different kinds of measurements can be carried for the light. The cheap and easy way to measure light output of a system is by using a lux meter. A lux meter measures the luminous intensity on a surface. Within Sri Lanka SLS 1231: Part 1:2002 also used for light measurement. To properly measure luminous flux, an integrating sphere must be used [21]. These test facilities

are already available in Sri Lanka. So, we can produce good quality high standard LED lamp within our country.

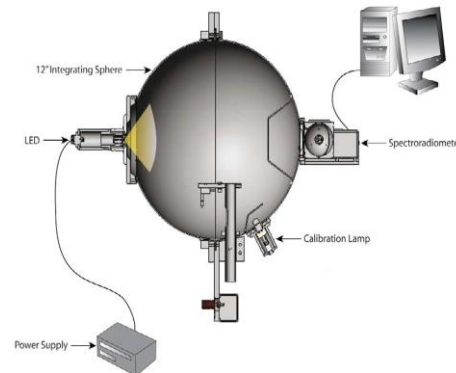


Fig. 7 luminous flux measurements using integrating sphere

XIII. CONCLUSION/SUMMARY

Today renewable energy technologies have drawn tremendous interest worldwide to find solutions for world energy crises. Solar power is a power source which is recognized as being an environmentally “clean” from the energy production of view. Further location of Southern Expressway gets adequate bright sunshine. If we can reduce the load from grid during peak hours, that would be one of the best investment for our nation and environment. Replace the traditional lamps to LED is a measure for reducing amount of energy required. Proposed system introduced number of power optimization including automatic ON/OFF and intelligence controlling of illuminance. We have test facilities with high quality equipment as well as knowledgeable researchers locally to take forward this kind of initiative. Considering all above points, the proposed system can be implemented as one of the promising solution for the energy challenges.

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