Street Lighting Design Solutions in the Efficient Lighting Program

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***Abstract*— This paper proposes some street lighting design solutions to reduce power consumption of lighting systems and adapt to the efficient lighting program. Proposed solutions will concern with luminaries, renewable energy and the operation of whole lighting system. Replacing traditional luminaries by light emitting diode luminaries and using dimmers in low density of vehicle is the first solution to reach the diminished purpose of power consumption. The second solution focuses on harnessing photovoltaic and wind power generations in isolated or grid-connected models to charge power to energy storage in daylight time. The third solution proposes a structure that combines expert system, artificial intelligence and communication technologies to have optimal operation for all lighting columns. A case study of isolated lighting column using photovoltaic power generation is concerned with more deeply and simulated in this paper. Simulation results carried out by MATLAB 2018a software showed the capability of harnessing maximum power point of photovoltaic power generation, power supply of battery and effect of dimmer in street lighting system.**

***Index Terms*— dimmer, dimming lamp, internet of things, LED, street lighting design, effective lighting program, renewable energy.**

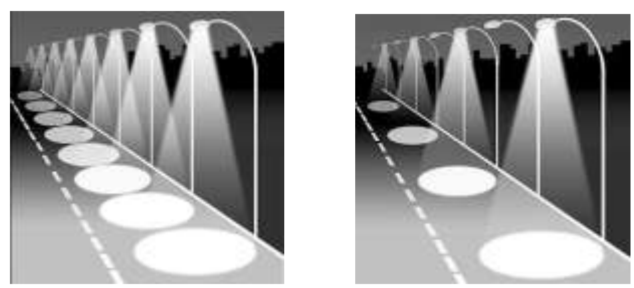
I. INTRODUCTION

Lighting system provides light for all human activities whenever having no natural light. Street lighting system is one of special architecture in capital to adapt high requirements about amount of light and power consumption. They can be solved by changing both hardware and software.

Lamp technology has undergone many developing stages from incandescent lamp, discharge lamps (fluorescent lamp, compact lamp, high-intensity discharge lamp) to light emitting diode (LED). They are improved lighting quality and duration very much. For example, incandescent lamps have been developed from the single twist incandescent to the double twist incandescent and there are many different fluorescent powder changed in discharge lamps to reduce power consumption and create many different colors. The special lamp, LED, has been developed recently and is considered as a potential solution to replace previous lamps. It is also combined a reflector to become the best luminary for street lighting system [1], [2].

Renewable energy is another solution that can be applied in street lighting system, where photovoltaic power generation (PVg) and wind generation (Wg) are considered as the most potential and suitable generations to replace electric grid at lighting columns. These generations have harnessed in many different structures such as using energy storage (ES) or no ES, coupling at DCbus or ACbus, isolated or grid-connected. Their power can be harnessed by using a controller with a maximum power point tracker (MPPT) through power converters [3]. Lighting columns can be used ES such as battery and operated as an isolated system to have power supply by themselves.

To operate street lighting systems, luminaries can be programmed by using on-off control, timers, multilevel ballasts or dimmers. In the way of on-off control and timers, luminaries can be switched on or of a power transmission line in phase A (or B, C) in time range from 6 o'clock pm to 10 o'clock pm or from 10 o'clock pm on this day to 5 o'clock am on next day as described in Fig. 1. This operating method can help to cut off 1/3 or 2/3 of the number of luminaries that helps to reduce 1/3 or 2/3 total rated power for whole lighting system but it makes lighting ladder effect (alternately dark and light zones) and bad visibility for drivers [4], [5].



a. Full luminaries b. Not full luminaries

Fig. 1 On-off control or timer for luminaries

Almost multilevel ballasts or dimmers were applied in some lighting systems but they has not been synchronized with other technologies to adapt to real conditions. It is the factor that forces intelligent lighting systems basing on internet of things (IoT) to ensure requirements of light and efficient energy. Moreover, artificial intelligence (AI) such as fuzzy logic or neural network with multi input and multi output to train control system and create a suitable decision corresponding to detailed contexts. Expert systems also must be used to have experience from leading experts to make more accurate regulation for whole lighting systems [6], [7].

This paper concentrates on the efficient lighting program that helps to reduce power consumption. Section II proposes three solutions gathers some solutions that can be applied overall in each street lighting system and focused on improving luminaries, using renewable energy and changing methods to operate whole lighting systems. Section III designs and simulates an isolated system at a lighting column harnessing PVg. The last section represents some conclusions and contributions of this paper.

II. OVERALL SOME STREET LIGHTING DESIGN SOLUTIONS IN THE EFFICIENT LIGHTING PROGRAM

2.1 Luminaries

A. Replacing traditional luminaries

A luminary in street lighting is a combination of a lamp and a reflector, where a reflector must be improved to change the direction of lights and focus them into a desired area by using high quality of silver coating. Lamps hold an important role to consume power in luminaries. Two popular lamps in street lighting system are mercury vapor lamp and high pressure sodium vapor lamp as described in Fig 2 [1].

a. Mercury vapor lamp b. High pressure sodium vapor lamp

Fig. 2 Two popular lamps in street lighting system

These lamps can generate yellow lights and have high capability to penetrate lights into much fog or rain areas. However these lamps have the same disadvantage that is much power consumption.

LED lamps, described in Fig. 3 and manufactured from semiconductors, have been used for some years recently. LED lamps consume less power and have higher working life than above lamps. Moreover, they can be designed to operate well with DC or AC power supply in any weather condition [1].

Fig. 3 LED lamp

Some characterized parameters of above lamps in street lighting system are represented in Table 1 [8], [9], [10].

Table 1. Some characterized parameters of above lamps

Parameter / Type	Rated power [W]	Luminous flux [lumen]	Working life [hour]	Color temperature [^{0}K]
LED	120	13200	50000	5000
High pressure sodium vapor lamp	150	13200	15000	2000
Mercury vapor lamp	250	12750	16000	4100

We can see that all lamps have different values of color temperature and can adapt to high requirements of lighting systems. They also have the same value of lighting power but rated power consumption of LED lamp is lower 25% than high pressure sodium vapor lamp and 108.3% than mercury vapor lamp. In additionally, working life of LED lamp is three times longer than working life of both high pressure sodium vapor lamp and than mercury vapor lamp. It means that LED lamp is one of the best solution to reduce power consumption and bring economic benefit for street lighting systems in the efficient lighting program.

B. Regulating lighting levels for luminaries

The relation between consumed power and current of LED lamp is shown in Fig. 4 [11], [12].

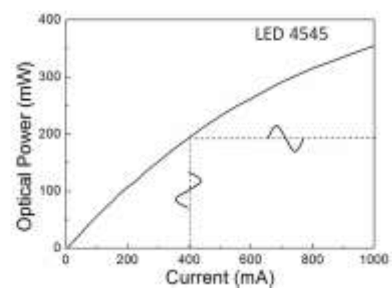


Fig. 4 Power - current characteristic of LED lamp

We can see the consumed power of LED lamp is directly proportional to input current. This relation is the principle to control lighting level that helps to reduce power consumption of LED lamps. In the time range having low density of vehicle, lamps can be dimmed in lighting levels as described in Fig. 5.

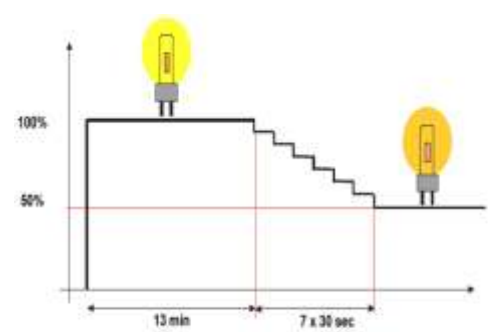
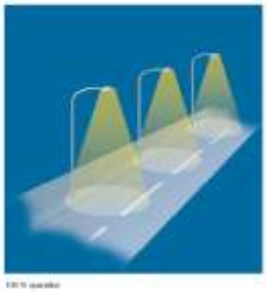
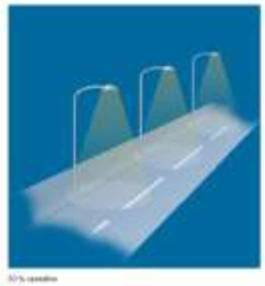


Fig. 5 Dimming in level of dimmers

After dimming, the brightness of luminaries decreases corresponding to a desired value as represented in Fig. 6.



a. 100%



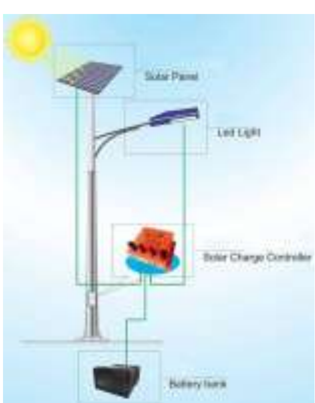
b. 50%

Fig. 6 Decrease the brightness of luminaries using dimmers

This solution brings a big benefit because it makes an unique illuminance and ensures a good ability to drive vehicle in the night. A difficult problem in this solution is the dimming time. To decrease operating and investing cost, almost lighting systems only uses automatical timers to close switches or breakers at fixed hours such as from 6 pm o'clock to 9 pm o'clock, from 9 pm o'clock to 12 pm o'clock or 0 pm o'clock to 5 pm o'clock. This method has a main disadvantage that is not able to distinguish density of vehicles on roads between different days. The best solution to solve this problem is that places impulse sensors on the ground or image cameras to have instantaneous information about the density of vehicle although it makes high cost for investing cost.

2.2 Using renewable energy

Renewable energy can be used in lighting systems to limit power that must be bought from electric grid. Photovoltaic power and wind generations are the most potential to implement on lighting columns, where only photovoltaic panels can be installed at locations having much solar irradiance and less wind and only small wind turbine - generators can be installed at locations having much wind and less solar irradiance. Both generations can be used in hybrid structures at each lighting column at coastal terrain with lots of solar irradiance and wind. Models to harness these generations in lighting systems is described in Fig. 7.



a. Only PVg

b. Only Wg

c. Hybrid generations

Fig. 7 Lighting column using renewable energy

Disadvantages of this solution is high cost, quite complex and not stable. Power generating from renewable energy often varies in a wide range (from 0 to rated power) and oscillates in a short time, so it can not be enough to provide power for the requirement of luminaries in some time range. Because of this reason, electric grid should be used as a reserved way to ensure power for luminaries.

The hybrid structure system harnessing PVg and Wg on a lighting column is shown in Fig. 8. In this structure, a AC/DC converter is used in series with Wg and a DC/DC converter is used in series with PVg to converter photovoltaic and wind energy to electric to charge ES [3], [13], [14].

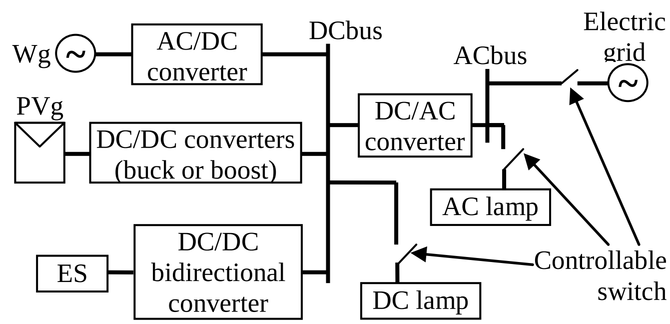


Fig. 8 Hybrid structure harnessing PVg and Wg

In this system, electric grid is a reserved generation to supplement power when renewable energy and ES are not enough to supply power. Controllable switch must be used in this structure to regulate light from luminaries or turn on (or off) them as requirements. DC/DC bidirectional converter (optional) regulates voltage at DCbus as a constant and conduct power flow from DCbus to ES (charging ES) or from ES to DCbus to supply power to load (discharging ES). DC/AC converter also works as a bidirectional converter to conduct power flow from electric grid to DCbus or from DCbus to ACbus. Moreover, lighting systems prefer DC lamp to AC lamp because it can help to reduce power loss in DC/AC converter and DC/DC bidirectional converter could not be able to be used.

2.3 Changing methods to operate whole lighting systems

To execute this solution, big data in lighting systems must have a modern architecture with high speed connections for all devices (called IoT technologies), sensor and camera networks to observe traffic density and other sensors to collect weather information about humidity, temperature, light from the sun, pollution,... Big data can help to decide and give out optimal commands in real time to operate all street lighting columns [6], [7].

It is easy to see that wire and wireless communication is very important to regulate street lighting systems. The wire communication includes DALI (Digital Addressable Lighting Interface), Ethernet, BACnet (Building Automation and Control networks), where DALI is the most popular in current street lighting systems. The wireless communication includes ZigBee (using in short distances, low speed and low power consumption), Bluetooth (connecting all devices in short distances), Wireless fidelity (wifi - using radio wave) [15]. General model to regulate street lighting systems using wireless communication is represented in Fig. 7.

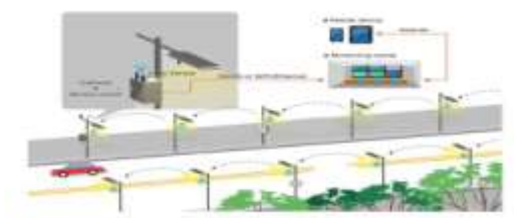


Fig. 7 General model using wireless communication

IoT technologies must be applied and synchronized overall with modern street lighting systems through a center of dispatch, data operating acquisition and management. There are some kind of software that help dispatchers create database about the operating and controlling process at each lighting column in desired zones. The address of each street lighting column is defined and identified by the global positioning system to track more easily. Because of using these method, it is easy to find the location of non-working street lighting column and make an optimal maintenance plan for whole street lighting system. It also helps to reduce useless energy and maintenance frequency for all equipments. Architecture of control and data acquisition applied in street lighting systems basing on IoT background is represented in Fig. 8.

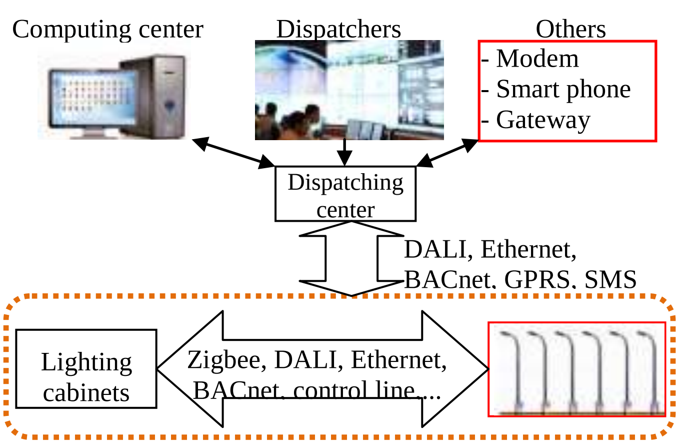
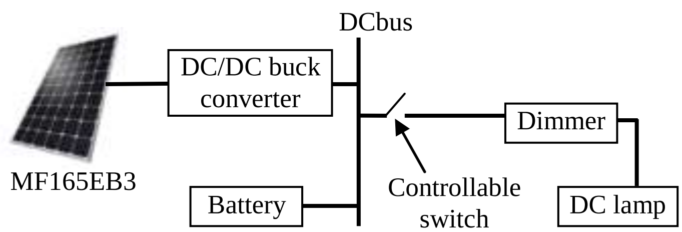


Fig. 8 Architecture of control and data acquisition applied in street lighting systems

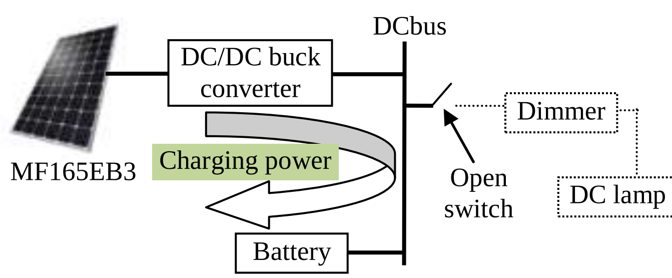
This architecture allows to transfer control information from dispatch center to each street lighting column, smart phones, modems... and receive information from them to the dispatch center. Dispatchers use knowledge of expert system and AI to have real-time decision about instantaneous working state of each luminary that is suitable to real operating conditions and ensure the best viewing comfort while saving power consumption.

III. SIMULATION RESULTS

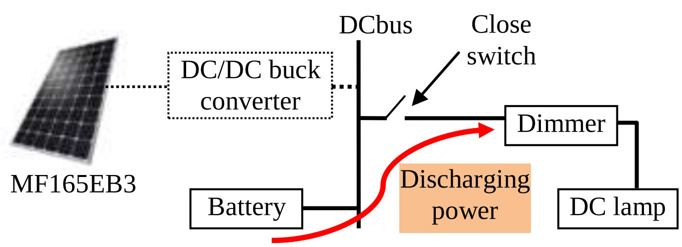
Simulate an isolated system at a street lighting column using PVg (type MF165EB3, a production of Mitsubishi) with a structure is described in Fig. 9a.



a. Simulation structure



b. Daytime power flow



c. Night-time power flow

Fig. 9 Structure and power flow in simulation system

In this system, power from PVg charges to a battery in daytime and the battery discharges to supply power to luminaries in night time with the distribution as described in Fig. 9b and Fig. 9c.

A DC lamp (rated power is 120 Watts) is used in this structure to consume power corresponding to battery voltage that helps to reduce power loss in power converters.

Parameters of converter, DCbus, and switching frequency are represented in TABLE I. Parameters of MF165EB3 are represented in TABLE II.

TABLE I. PARAMETERS OF CONVERTER, DCbus AND SWITCHING FREQUENCY

	Symbol	Value
DC/DC buck converter	R (Ω)	0.01
	L (H)	5.10^{-3}
	C (F)	10^{-3}
Voltage at DCbus	V_{dc} (V)	12
Switching frequency	f_S (kHz)	50

TABLE II. PARAMETERS OF MF165EB3 AT STC

Name of parameter	**Value**
Short-circuit current I_{SC} (A)	7.36
Open-circuit voltage V_{OC} (V)	30.4
Rated power (W)	165
Voltage coefficient of voltage C_{TV} (mV/^{0}C)	-0.346

The process of harnessing from PVg to charge power to the battery is represented in Fig. 10, where 13.8 V is the working safety threshold for the battery. Information about voltage at maximum power point is determined by a MPPT using temperature technique and sensor [16].

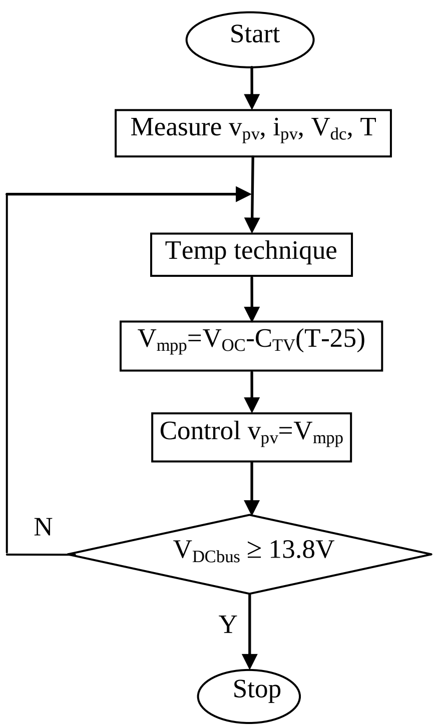


Fig. 10 Algorithm to harness energy from PVg and charge energy to battery

A simulation scenario about power of solar irradiance is represented in Fig. 11.

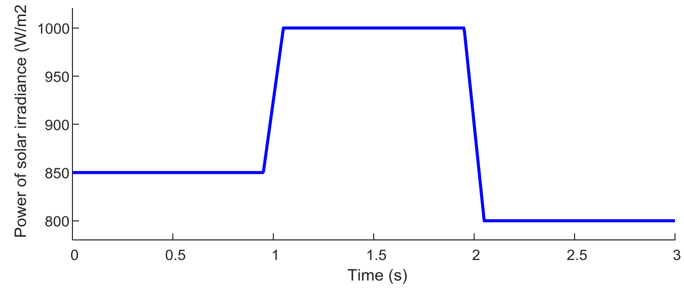


Fig. 11 Power of solar irradiance

Simulation results corresponding to the above scenario and 40^{0}C for temperature are shown in Fig. 12. In three seconds, we can see that power generating from PVg changes corresponding to the variation of power of solar irradiance and the energy also increases corresponding to the time.

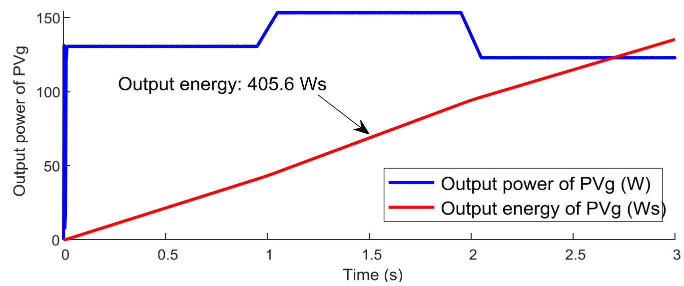


Fig. 12 Output power and energy of PVg

Simulation results about received power and energy at DCbus are represented in Fig. 13.

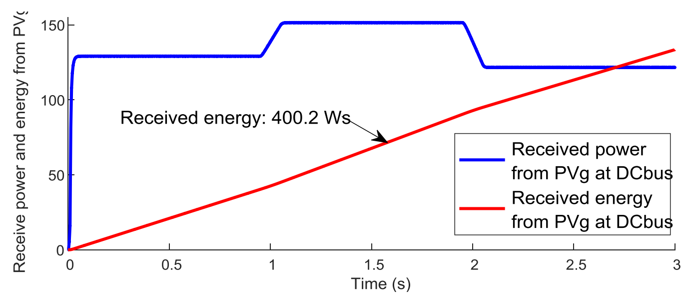


Fig. 13 Power and energy received at DCbus

We can see that power and energy received at DCbus also varies corresponding to power of solar irradiance and are smaller than output power and energy of PVg. It can be explained by power loss in the DC/DC buck converter. The efficiency of the DC/DC buck converter is calculated by (1):

$$\eta_{DC/DC} = \frac{\text{Received energy at DCbus}}{\text{Output energy from PVg}} = \frac{400.2}{405.6} \times 100\% = 98.7\% \quad (1)$$

In night time (with no solar irradiance), power consumed by the lamp can be supplied completely by the battery. Simulation results in Fig. 14 describe the system response when closing the DC lamp at 0.5s with no dimmer. We can see that power consumption increases to rated power of the DC lamp immediately after closing the switch and hold power consumption at that value during happening lighting process.

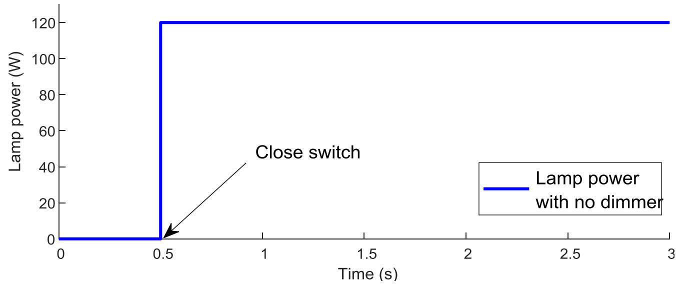


Fig. 14 Power consumed by DC lamp with no dimmer

When using the dimmer, power consumption of the DC lamp can be decreased and held at a fixed value corresponding to the requirement of dispatch center as shown in Fig. 15.

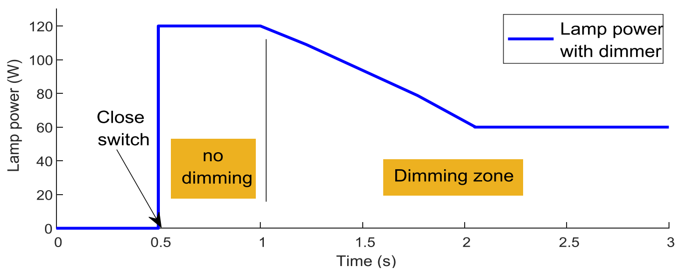


Fig. 15 Power consumed by DC lamp with dimmer

These simulation results showed the role of dimmer to reduce power consumption at each luminary that brings benefit for whole street lighting systems.

IV. CONCLUSION

This paper proposes a model that applies solutions overall in street lighting system that can adapt to requirements of the efficient program. This model combines solutions about replacing luminaries, using renewable energy and changing methods to operate whole lighting systems. It uses IoT technologies to reduce power consumption in street lighting system that ensures the best viewing comfort.

A structure using PVg and Wg is designed in this paper can help to absorb power from these generations and connected to the electric grid by controllable switches. Simulation results for an isolated grid at a street lighting column only using PVg showed the ability to harness maximum power from PVg to charge the battery through a charger in day time (having solar irradiance). Moreover, the battery can be used as an electric source to supply power to lamps (in range time have less solar irradiance).

Proposed solutions can be applied in any street lighting zone in any country. They bring a high benefit in long term for any street lighting system but cost for investment and operation is very high and complex. They also can help to reduce cost and frequency for maintenance of whole system, decrease air pollution caused by produced electricity and light pollution that affects much to animals and plant and increase the reliability for the power supply of street lighting systems. Because of having many advantages, these solutions will be applied widely in modern lighting systems.

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