Journal of Scientific Research & Reports
3(13): 1722-1737, 2014; Article no. JSRR.2014.13.002

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Photovoltaic Energy Source for Street Lighting in Hebron/ Palestine Using GSM Technology

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Original Research Article

Received 17th March 2014
Accepted 5th May 2014
Published 27th May 2014

ABSTRACT

This project presents a new approach of a street lighting system that uses a photovoltaic produced energy controlled by a GSM (Global System for Mobile Communication). The case study was conducted in an open area of Al-Hesbah Street in Hebron. This system is based on installinga light fixtures supplied with 24V DC loaded by photovoltaic energy. Long life rechargeable batteries are used to provide energy back-up by means of photovoltaic panels. The GSM system provides a light control for turning the light on or off according to the environmental illumination level via computers. Laboratory tests have shown that this system can produce a massive amount of energy savings for the Palestinian community in Hebron; hence it is very promising and compromising solution.

Keywords: Photovoltaic; street lighting; PIC microcontroller; GSM; LED lamps.

NOMENCLATURE

a : *spacing between two columns (m)*
AD : *daily autonomy*
C_{Ah} : *storage capacity of battery (Ah)*
C_{Wh} : *storage capacity of battery (Wh)*
DOD : *depth of discharge of the battery (%)*

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E : *illumination (lux)*
E_F : *lamp efficacy (lumen/W)*
E_L : *load energy (Wh)*
F_L : *luminous flux (lumen)*
H : *height of the post (m)*
GSM : *Global System for Mobile Communication*
LDD : *luminaire dirt depreciation*
LED : *Light Emitting Diode*
LLD : *lamp lumen depreciation*
LLF : *light loss factor*
n : *number of lamps*
P_L : *lamp power (W)*
P_{PV} : *peak power of PV panels (W)*
PSH : *peak number of sun hours*
W : *effective width of street (m)*
η_b : *battery efficiency (%)*
η_L : *utilization factor of lamps (%)*
η_W : *wiring efficiency (%)*

1. INTRODUCTION

Nowadays many applications in rural and urban areas use renewable energy systems. Solar energy represents one of the most important alternatives solutions to the use of CO2 producing combustibles traditionally used for energy production. The advantages of this energy are many including general reduction of CO2 emission, renewability, decentralized of source and availability [1,2,3,4].

In Palestine, solar radiation has high potentials with high values for annual sunshine hours. Average values of between 5.5 kWh/$m^2$and 6 kWh/m^2on a horizontal surface have been recorded for the annual average daily solar radiations [5,6]. These figures are relatively high and very encouraging to use Photovoltaic (PV) generators for electrification of certain loads as it has been worldwide successfully used.

This paper presents the design of a PV–battery installation for the generation of electric energy for a street lighting in Hebron as shown in Fig. 1 [7,8,9], which includes PV modules, charge controller, batteries, GSM system, Power switch, lighting units and control device such as PIC microcontroller. The charge controller acts as interface between PV panel and the batteries. It protects the batteries against both excessive overcharge and deep discharge. The suitable output voltage of the charge controller is fed to the GSM and control device. The system will communicate via the GSM network to a central computer for illumination of the lighting fixtures (DC loads) through sending a controlled signal to the power switch.

This system should be applied for a street lighting in Hebron called Al-Hesbah Street. Hebron is the most populated city in Palestinian territories and located in the southern part of West Bank, 36 kilometers to the south of Jerusalem (Fig. 2). The Google Earth Schematic of Al-Hesbah Street is shown in Fig. 3 with nearly one km length. This project results from fruitfully collaboration efforts between Palestine Polytechnic University (PPU) and department of electricity in Hebron municipality. With the significant progress in the ways of exploiting renewable energy, this study is expected to meet the requirements of solar energy and achieve the objectives of this collaboration.

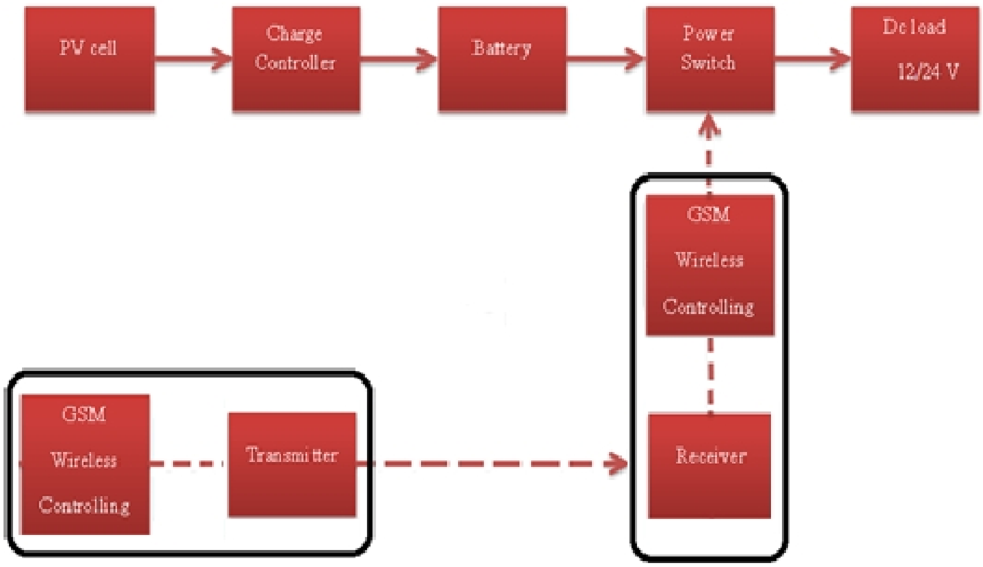

Fig. 1. PV-Battery system for street lighting with GSM technology

Fig. 2. Map of Palestine

Lighting is an essential element in most lifestyles, and electricity or natural day lighting generally provide it. The uses of lamps can be an appropriate option because they effectively reduce the electrical load requirements of a photovoltaic system. Today, many different light sources are available, which make choosing the correct energy efficient light source, much more difficult. A wide variety of attractive, economical lighting options are available in 12Vand 24V direct current and 220V alternating current types making photovoltaic powered lighting a feasible choice for many homeowners. New types of lamps with enhanced electrical and light output characteristics are far superior to the familiar incandescent and fluorescent lamps further confuse a potential purchaser [8,10,11].

The principle aim of lighting control is to reduce energy consumption and therefore the cost of annual energy budget is significantly reduced. Different mechanisms of control meet to the desire of human and the operating conditions which are required. Utilizing photocell control enables automatic turning the street light fixtures on at sunset and off at sunrise. It is an efficient, simple, economic and common method of lighting control.

Fig. 3. Google earth schematic of Al-Hesbah Street

Applying a GSM wireless controller in addition to photocell control will increase the capability of the system by monitoring the state of the light fixtures and controlling the switching. GSM is an open, digital cellular technology used for transmitting mobile voice and data services. It is a modern method in street lights controlling, especially because of its ability to cover long distances and increase the charging time for the batteries remotely for the Light Fixtures. This approach, particularly can be used by the municipalities and remote control centres [12,13,14].

This system uses GSM network, and will be controlled by computers. The determination of when light should be turned on or off will depend on the level of environmental light brightness such as the reduction of light intensity during low light brightness.

Applying this technology for public lighting, energy savings would be incredible, as well as resulting in far less light pollution. If the Public lights were fitted with solar panels, making the system self-powering, the system will be more efficient. The utilization of light sensors provides a simple yet effective way for the automatic regulation of lighting power according to ambient light conditions thus enabling the system be turned on out of strict time schedules (e.g. during cloudy daytime) [15,16,17]. The implementation of the proposed system could be in future more improved by using modern simulation environments [18]. The whole system is controlled by using a PIC microcontroller [19].

The design has passed through several stages such as: selecting the practical components of the overall block diagram, purchasing these components, designing an external frame, mounting the photovoltaic solar panel, connecting it to the charge controller [20], interfacing GSM with PIC microcontroller and installing the LED lighting fixtures. Using LEDs lamps with GSM control system is a modern way in saving energy.

Finally, a prototype model is built and tested for a street lighting by using solar energy, which is controlled with the wireless technology (GSM).

2. DESIGN OF LIGHTING AL-HESBAH STREET

Off-grid systems, such as street lighting system as shown in Fig. 1, should be designed with great care to assure satisfactory performance with respect to lighting level, GSM communication and energy saving.The design and selection of the system components illustrated in Fig. 1 are restricted to the following conditions: Off-grid PV energy system, using LED lamps, 24 V DC system voltage and two fixtures erected at the middle of the street for each lighting unit (Twin Central). The distribution of lighting units of Al-Hesbah Street is shown in Fig. 4 with total number of 19 units.

2.1 DC Loads (Lamps)

For design and selection of a lamp type, important criteria called lamp efficacy should be considered. In most cases, a more efficient light source can be substituted for a less efficient source with little or no loss in visibility or colour rendition. The total annual cost savings help to decrease the size of the photovoltaic system.

Lamp efficacy $\boldsymbol{E_F}$ is measured in lumens per watt (lm/W) and defined as follows:

$$\boldsymbol{E_F = \frac{F_L}{P_L}} \quad (1)$$

where $\boldsymbol{F_L}$ is a luminous flux in lumen (lm) and $\boldsymbol{P_L}$ lamp power. Table 1 shows luminous efficacy of different types of lamps. If a lamp produces more lumens from each watt of electrical energy input, it is more efficient.

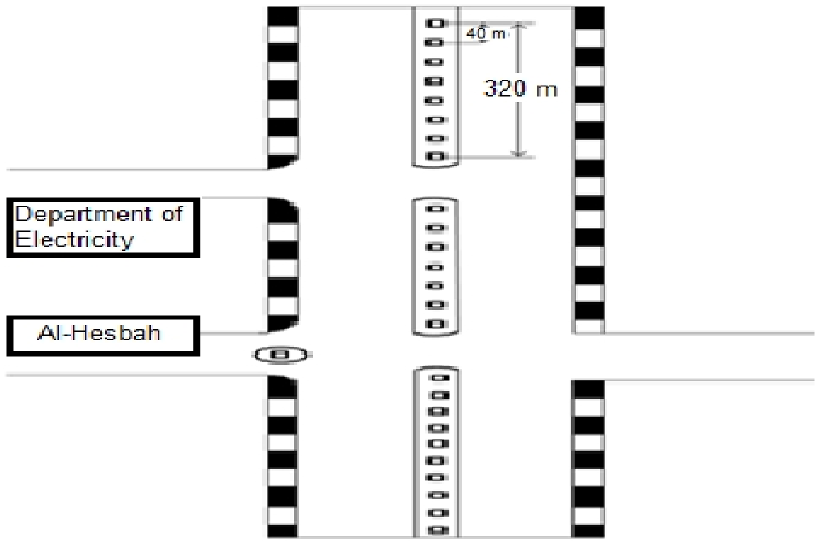

Fig. 4. The schematic sketch of Al-Hesbah Street

In the past, Light Emitting Diodes (LEDs) were only used as indicators of operability on electrical equipment. In recent years, advanced types, in different colours and better specifications than early ones, have been available on the market and used for outdoor lighting. When they were compared with other lamp types, they showed a longer duration life (see Table 1) and a greater efficiency since they do not heat filaments or produce arc. In addition, they can emit in the Red, Green, Blue and Orange colours, and can be arranged in arrays to increase their output, furthermore they resist vibration, and can be easily organized under a programmable control system since their lightening can be regulated (from 100% to 15%) by the current intensity provided.

Table 1. Typical efficacy ranges for the main lamp categories

Lamp Type	Conversion Efficacy (Lumens per Watt)	Life(Hours)
Incandescent	14	800
Low Voltage Halogen	20	2000 to 5000
Mercury Vapor	40 to 60	22000
Fluorescent	64 t0 90	7000
Metal Halide	70 to 90	12000
High Pressure Sodium	90 to 125	25000
Low Pressure Sodium	120 to 200	20000
LED Lamps	100 to 150	50000

According to Fig. 3, Al-Hesbah Street has two side with (*W*=10 to 11 m) as an effective width (*W*) of each side. The height (H) of the post (hanging column) is given by

$$\boldsymbol{H} = \left({}^{2}/_{3}\; to\; 1\right) \times \boldsymbol{W} \quad (2)$$

To be selected ***H*** = 11m with an arm of 1.5 m and the inclination of the fixture is 10 degrees.

Al-Hesbah Street has medium vehicular and pedestrian movement at night, so selecting Illumination value (***E***= 6 lux) is enough based on the second classification in the Tables 2 and 3. Standard unit for illumination (***E***) is lux which is equal to lm/m^2.

Table 2. Illumination (*E*) for different environments

Illumination *E* in (lux)	Environments
1	full moon
4-10	street lighting
100-1,000	workspace lighting
10,000	surgery lighting
100,000	plain sunshine

Table 3. Illumination design of roads

Road and area classification	E_{ave} in (Lux)
Local Residential Roads (Local-Low)	4
Residential Collector Road (Collector-Low)	6
Employment Collector Road (Collector-Low)	6
Arterial Roads (Major-Low)	9
Rural Local Residential (Local-Low)	4
Rural Collector Road (Collector-Low)	6
Low Density Residential	3

The existing space between two columns (***a***) of Al-Hesbah Street is 40 meters. Therefore, ***a*** should be selected 40 m in this study in order to use the same posts (columns) if Hebron Municipality decided to exchange its current lighting system with off- grid photovoltaic solar energy system.

The luminous flux F_L of n lamps in a street is given by [10]

$$F_L = \frac{E*a*W}{n*LLF*\eta_L} \tag{3}$$

where *n* is the number of lamps in the lighting fixtures, η_L is the utilization factor of lamps (0.8 for LED's lamp with reflector) and *LLF* is the light loss factor. The last factor (*LLF*) can be calculated as

$$LLF = LDD*LLD \tag{4}$$

where *LDD* is luminaire dirt depreciation (0.95) and *LLD* is lamp lumen depreciation (0.85).

With the previous mentioned values of the parameters of Eq. (3), the value of luminous flux for one lamp F_L= 4074 lumen is obtained. Therefore, the lamp rating has the value (P_L=4074/100=40Watt) according to Eq. (1) and Table 1 for LED's lamp.

For good design and better illumination, a lamp with rating (P_L = 48 W) is selected. The load power for each lighting unit is (P_L = 2 * 48 = 96 W).

Power needed by a load, as well as energy required over time by that load, are important for system sizing. In the simplest case, energy (Wh or kWh) is just the product of the nominal power rating of the lamp multiplied by the hours that it is in use. With an average night hours in Hebron among the year (11.72 h), the load energy per night is obtained as $\boldsymbol{E_L}$ = 96 * 11.72 = 1125 Wh. This is the dc load that the batteries must provide.

The dc output voltage of the battery bank, which is the same as the voltage of the PV array, is called the *system voltage*. The system voltage is usually 12 V, 24 V, or 48 V, which depends in this case on the rating of the used dc lamp (LED). Higher voltages need less current, making it easier to minimize wire losses. On the other hand, higher voltage means more batteries wired in series, which impacts the number of batteries that may be needed to supply the load. For this study, a 24 V as the system voltage is selected.

2.2 Batteries

Stand-alone systems obviously need special method to store energy gathered during light exposure to be able to use it during the night. In addition to energy storage, batteries provide several other important energy services for PV systems, including the ability to provide surges of current that are much higher than the instantaneous current available from the array, as well as the inherent and automatic property of controlling the output voltage of the array so that loads receive voltages that are within their own range of acceptability.

The storage capacity ($\boldsymbol{C_{Wh}}$) can be calculated according to the following relation [4]:

$$\boldsymbol{C_{Wh}} = \frac{\boldsymbol{E_L \times AD}}{\boldsymbol{\eta_b \times \eta_W \times DOD}} \tag{5}$$

where *AD*: Is the daily autonomy, *DOD* is depth of discharge, η_b is battery efficiency, η_W is the wiring efficiency. It is obvious from (5) that total capacity of the battery depends on daily autonomy which represents number of days that battery will be capable to supply the load in case of shortage of the renewable sources.

With E_L = 1125 Wh, *AD* = 1.7 days, *DOD* = 0.6, η_b = 0.85 and η_W = 0.98, the required storage capacity C_{Wh} = 3825 Wh. With the selected system voltage of 24 V, the required ampere hours of batteries C_{Ah} = 3825 / 24 ≈160 Ah.

If 12 V blocks with 80 Ah each are chosen, 4 batteries (12 V, 80 Ah) are needed. They are divided in two parallel connected groups. Each group has two batteries connected in series. This battery bank can drive the loads for more than 3 nights without any sunshine.

2.3 PV Panels and Charge Controller

Respecting the standard conditions, the PV peak power ($\boldsymbol{P_{PV}}$) is computed as [9]

$$\boldsymbol{P_{PV}} = \frac{\boldsymbol{E_L}}{\boldsymbol{PSH}} \tag{6}$$

where ***PSH*** is the peak number of sun hours on the site of the system.

To account for the effect of temperature, dust, variation of solar radiation and resistive losses on the output power produced by the PV generator, it is necessary to multiply the value obtained for $\boldsymbol{P_{PV}}$ Eq. (6) with a safety factor amounting to 1.3.

If ***PSH*** = 6 hours and E_L = 1125 Wh, the total PV power $P_{PV} \approx$ 240 W.

The chosen modules are mono-crystalline silicon, 120 W peak power and 12 V. Thus, 2 modules are used to supply each lighting unit of Al-Hesbah Street with the required energy. The modules are in series connected to give the desired voltage according to the design of the other parts of the PV system and the load specifications.

The battery charge controller is chosen to maintain a longer lifetime for the batteries. It has to be capable of carrying the short circuit current of the PV array. Thus, the rating of the charge controller should be 240 W / 24 V = 10 A. Thus, in this case, it can be chosen to handle 15 A for safe operation and to maintain the system voltage in the range of 24 V.

The PV system just designed for each lighting unit of Al-Hesbah Street is shown in Fig. 5.

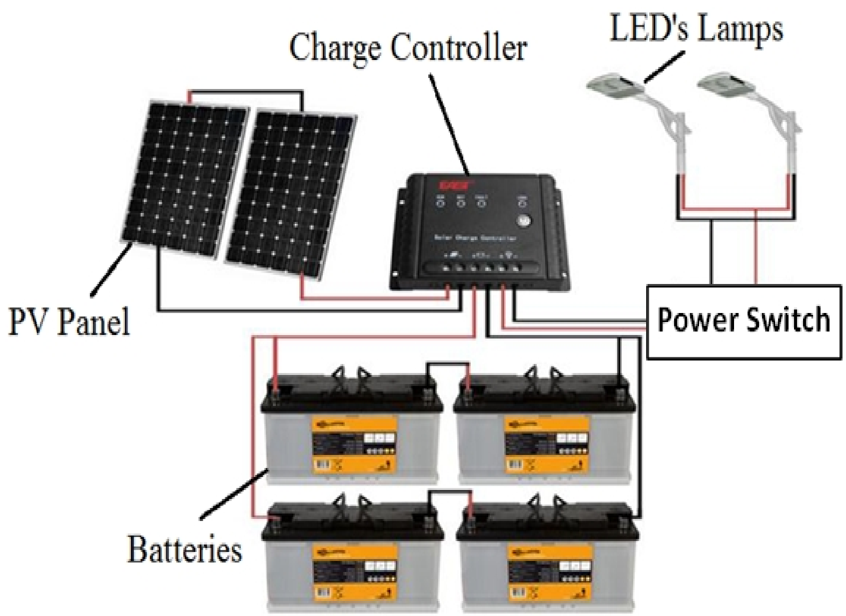

Fig. 5. PV system for each lighting unit of Al-Hesbah Street

3. CONTROL OF SYSTEM LIGHTING

The main reason of lighting control is to reduce energy consumption and the cost of annual energy budget. Different control mechanisms will match human desire and operate required conditions. Utilizing photocell control will enable automatic turning the street light fixtures on at sunset and off at sunrise. It is efficient, simple, economic and a common method of lighting control.

Applying the GSM wireless controller in addition to photocell control will increase the capability of the system by monitoring the state of the light fixtures and controlling the switches. It allows to operate certain lamps and turn off others, or to dim the lights when the pedestrian and vehicular movement decreases.

The power switch in Figs. 1 and 5 consists of the GSM wireless controller circuit and photocell sensor that are controlled using a PIC microcontroller.

GSM is an open, digital cellular technology used for transmitting mobile voice and data services. It is a modern method in street lights controlling especially because of its ability to cover long distances. Particularly it can be used by the municipalities and remote control centres. The system will communicate via the GSM network to a central computer to determine when the lights should be illuminated, how bright they should be lit based on ambient light levels, and to also dim the lights after dark when the areas have less traffic. Applying this technology to public lighting, energy savings would be incredible, as well as resulting in far less light pollution. If the Public lights were fitted with solar panels, making the system self- powering, the system will be more efficient as shown in Fig. 6. Depends on the day light timings the street lights can be controlled by ON, OFF, dimming and staggered with the help of Real Time Clock (RTC). If any over load occurs the load will be cut and the information is transferred through GSM to server. Any disconnect in power the information is sent to server through GSM. If any complaint raised the user needs enter the number in the keypad which will be fixed in the street lamp and the message will be sent to Server through GSM.

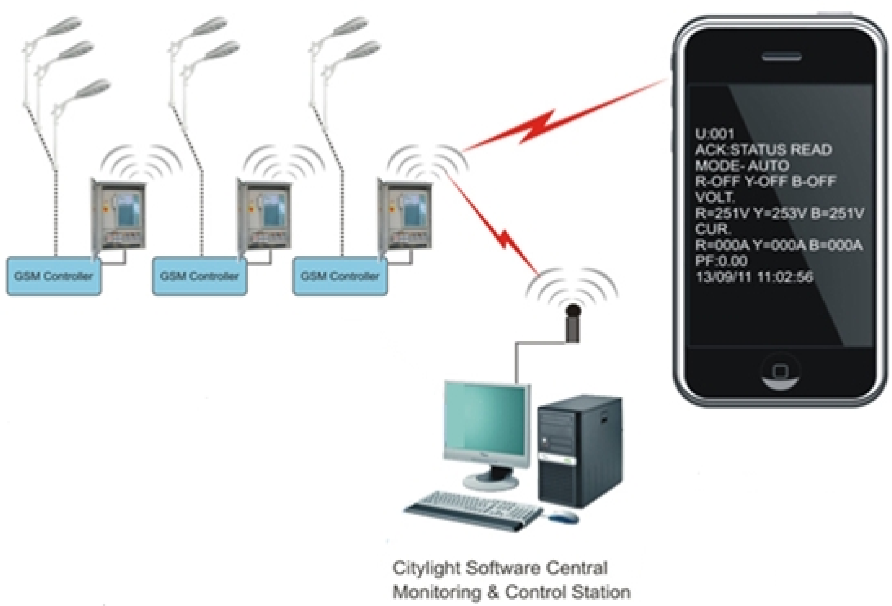

Fig. 6. Controlling and monitoring by GSM

Microcontrollers contain data and program memory, serial and parallel I/O, timers, external and internal interrupts, and peripherals. These make them a strong choice when implementing control systems. The major component is the PIC microcontroller.

To perform this scenario of control, the PIC microcontroller circuit will be programmed that achieves a link between lighting fixtures in the street and PIC microcontroller (18F4550) and Construct a code for the PIC microcontroller to do sampling, digitizing and transmitting and receiving the desired messages depending on dimming modes and fixture states to GSM modem.

The whole control system for lighting of Al-Hesbah Street with power switch is shown in Fig. 7.

In Fig. 7, the 12 V DC output of the charge controller is fed to the voltage regulator (LM317). The output voltage of the voltage regulator is 4V which feeds the GSM 94VOE99006 TYPE2B and the PIC 18LF2550 via pin20 (V_{DD}, V_{CC} positive supply for logic and I/O pins), while pin 19 (V_{SS} Ground reference for logic and I/O pins) is connected to the negative line of the supply.

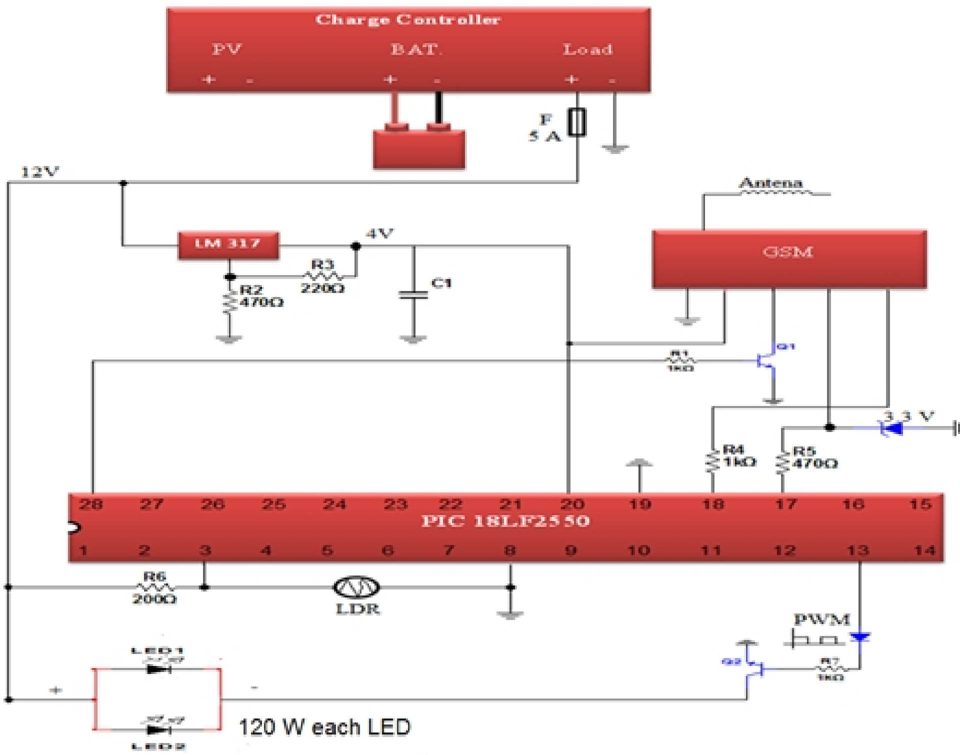

Fig. 7. Control lighting system with power circuit

The command of the system is accomplished remotely by the text messages which are sent from a mobile phone with known serial number of used JAWWALSIM. GSM receives the messages through the Antenna and the SIM card. These messages are transferred to the PIC. GSM and the PIC are interfaced through pins 17 (transmit output TX), 18 (Receive input RX) and 28 (compatible input RB 7). The impact of the night darkness on the system is included via the Light Dependent Resistor (LDR), which is connected to the analogue input of the PIC via pin 3 (AN1) and pin 8 (ground). The PIC controls the brightness level of the street lighting fixtures (100%, 80%, 50% and off operation modes) by pulse width modulation PWM control as shown in the Fig. 8. Pin 13 (PWM output) is connected to the base of the NPN power transistor Q2 (TIP41C) through the resistor R7. The negative terminals of the LED lighting fixtures are connected to the collector of the transistor; meanwhile the positive terminals of the fixtures are connected to the positive line of the 12 V supply voltage. According to the train of the positive pulses between the base and the emitter, the current will flow to the lighting fixtures through the collector of the power transistor. When the voltage of the pulses is zero, the voltage on the collector will be high and the voltage on the fixtures will be zero (off mode). If there is a pulse from PWM between the base and emitter the voltage on the collector will be low (0.2V), the transistor is saturated and the rest of the voltage (12-0.2=11.8V) will be on the lighting fixtures. Controlling the duration of the pulses will affect the average voltage which is applied to the load (LED lighting fixtures). Table 4 shows all of the commands which are programmed in the proposed control system. Table 5 shows a proposed control program for timing schedule of lighting diming for Automatic Sequence Modes (A1) to achieve energy saving in a clear and reasonable way.

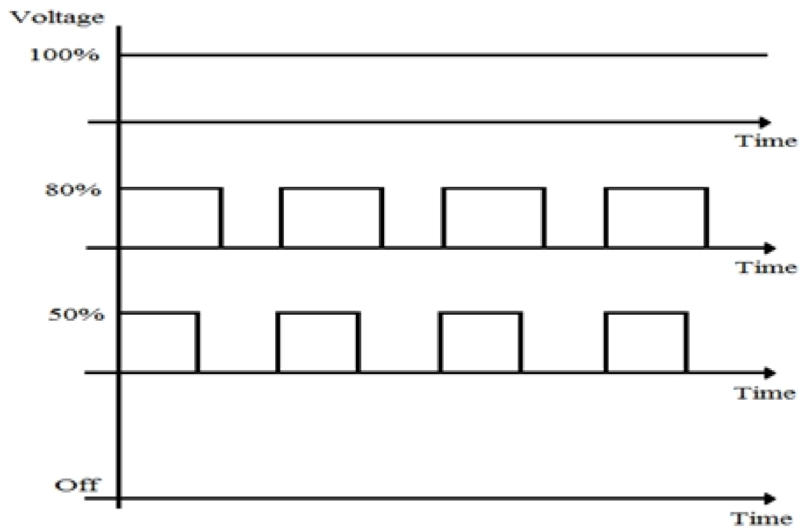

Fig. 8. Pulse width modulation signals

Table 4. Program commands

Activated photocell	
A1	Automatic Sequence Modes
A0	Photocell is Deactivated
B0	Lamps are Off
B1	50% Dimming
B2	80% Dimming
B3	100% Dimming

Table 5. Timing schedule of diming for automatic sequence modes (A1)

From	Till	Lighting mode	Actual time (hours)
Sunset	22:00	100%	4
22:00	24:00	80%	2
24:00	Sunrise	50%	6
Sunrise	Sunset	Off	12

4. ENERGY SAVING AND FEASIBILITY STUDY

The costs of the proposed system include the components initial costs, and components replacement costs, while the system maintenance costs should be done by the department of electricity in Hebron municipality. The existing hanging columns will be used for the proposed system. Initial costs include PV modules, batteries, charge controllers, lighting units and other accessories used in the installation. The life cycle period of the system is taken to be the life cycle period of the component that has a maximum life time. In this analysis, it is for the PV system 24 years. The life time of the battery is dependent mainly on number of charge-discharge cycles which in turn depends on value of depth of discharge of the battery (DOD) assumed. In this analysis a typical value of 12 years is considered as a life time of battery where a DOD is assumed to be 80%. According to Table 1, the life times of the used LED lamps are 12 years with effective night hours of 11.72 hours.

The life times of the other components of the system such as charge controllers and management system generally take values greater than 20 years. Because the cost of each is small in comparison with the other components, in this analysis a 24 years life time is considered for each. Therefore, batteries and lamps should be replaced one time during this period.

Al-Hesbah Street has today 58 fixtures: 8 metal halide fixtures at entrance of the street and 50 high pressure sodium fixtures along the street. The total power of these fixtures are (58 * 250 W = 14.5 kW). With effective night hours of 11.72 h, the total annual consumed energy is (365 night/year * 11.72 h/night * 14.5 kW = 62031 kWh). Then, the annual total cost of the consumed energy is (62031kWh * 0.15 $/kWh ≈ 9300$). Installing photovoltaic system for Al-Hesbah Street instead of the current existing one according to Table 6, the total cost of the proposed system is ($83868). Therefore, the proposed lighting system of Al-Hesbah Street is an economical one comparing to the annual total cost of the consumed energy of the current existed lighting system; the payback time of it is about nine years.

Table 6. Total cost of components required for Al-Hesbah street lighting

Components	Cost ($)
Mono Crystalline Silicon Solar Panels	29 * 2 *120 *$1.8 = $12528
Charge Controller 15A, 12-24V	29 * 1 * $100 = $ 2900
Sealed Deep Discharge Maintenance Free Batteries 12V 80Ah	2 * 29 * 4 * $ 195=$ 45240
GSM Controller	29 * 1 * $100 = $2900
48 W 24 V_{DC} LED Street Fixtures	2 * 29 * 2 * $150 = $ 17400
Accessories (Control Panel, Photocell, Wiring)	29 * 1 * $100 = $2900
Total Cost	**$ 83868**

5. PROTOTYPE DESIGN AND SCALING

In order to verify the theoretical study of the proposed project to the installation of PV system for lighting of Al-Hesbah Street, a prototype of the PV system has been built and tested. It is scaled to one sixth of the proposed system. Fig. 9 shows the final schematic of the lighting system with the calculated dimensions according to the international specifications, while Table 7 shows the components of prototype with their costs. It is clear from Table 7 that the PV system with a total power of 55 W has a total cost of (1383 $).

The control system for prototype PV lighting system is shown again in Fig. 7 with 5*3W LED lamps instead of 2*120W lamps and the same programmed commands shown in Table 4. While the timing schedule of diming for automatic sequence modes (A1) can be selected according to the desired test such as in Table 8.

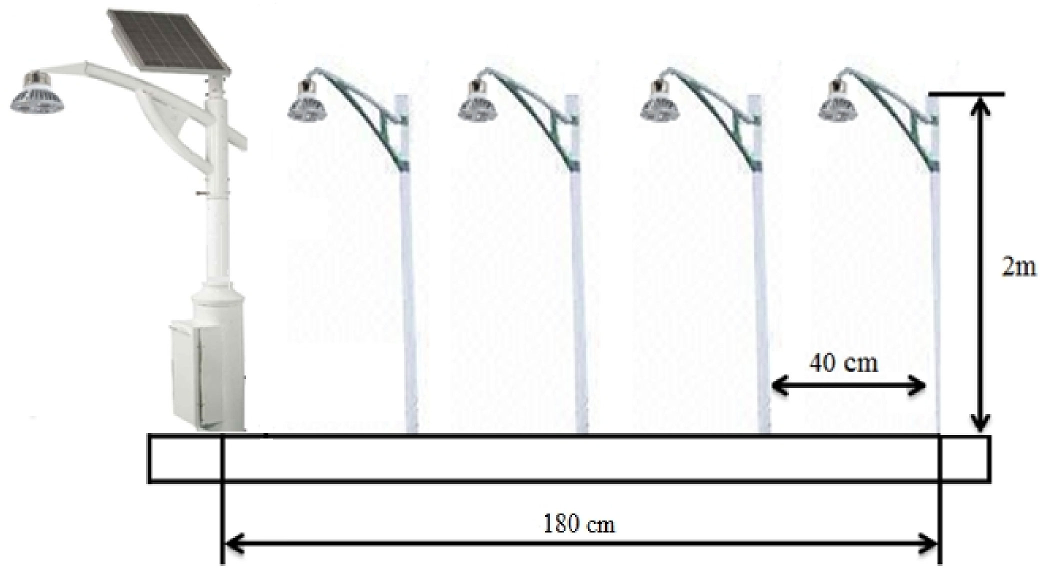

Fig. 9. The sketch of the prototype and its dimensions

Table 7. Total cost of components for prototype PV lighting system

Components	**Cost ($)**
Mono Crystalline SIEMENS SM55,12V, 55W PV	$ 85
Charge Controller 15A, 12V	$ 100
Rechargeable Valve Regulated Sealed Battery (REMCO) 12V, 40Ah	$ 195
GSM Controller94VOE99006 TYPE2B	$ 560
LED Lamps 15W, $12V_{DC}$	$ 50
Electrical Switch Panel	$ 38
External Frame (Metal Base, Galvanized Metal Posts Battery Box)	$ 270
LDR Photocell, Wires, Accessories	$ 85
Total Cost	**$ 1383**

Table 8. Timing schedule of diming for automatic sequence modes (A1) for prototype PV lighting system

Lighting mode	**Time (second)**
100%	40
80%	20
50%	60
Off	Depend on test

The practical prototype PV lighting system is shown in Fig. 10.

Fig. 10. Practical prototype PV lighting system

6. CONCLUSION

Utilizing generated electricity from solar energy is a promising alternative solution, as it is renewable, eco-friendly. The project study of Al-Hesbah Street which is about one kilometer long showed that the annual cost due to electrical lighting energy consumption is about $9300 which is a large amount. Installing photovoltaic system for Al-Hesbah Street instead of the existing current one is economically efficient; the payback time of the project is about nine years. Adopting GSM Wireless controller of the street lighting by utilizing the Internet and the local cellular communication networks which enables the municipalities to operate and monitor the lighting fixtures in an efficient and economical way.

A prototype of the PV system has been built and tested that verifies the analytical results of the proposed project to the installation of PV system for Al-Hesbah Street.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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