Designing and Implementation of Solar Street Lighting Management System Using Wide Area Network Technique

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Abstract

In this work, an innovate system is designed and implemented to manage solar street lighting units which are distributed in urban. The designed system overcomes wireless sensor network's essential drawback used to automate these units. This drawback is represented by multi-hops networking technique. The system constructs from several clusters, each one is represented by single-hop topology of Wide Area Network (WAN). Each cluster has three type of nodes namely: ***lamppost stations, local station, and optionally master station***. All designed stations are attached to SX1272 modem from Semtech company in order to establish the WAN. This module provides ultra-long transmission range up to 1.4 Km with high interference immunity. The system tested practically in real urban environment. It gives an excellent results with respect to maximum communication range and monitoring of vital operation parameters related to solar panel and other unit equipment's. In addition, the system performed on/off command to controlling lamp. During the test period, the designed system was very efficient in a manner it enabled operator to identify the possible system malfunctions and increase solar lighting units lifespan, reduce maintenance costs consequently it ensures the continues the service from these units.

Keywords: Solar Street Lighting Units, ^{LoRaTM} modulation, SX1272 module, Lamppost station , Local Station, Sun Irradiant measurement.

الخلاصة

تم في هذا العمل تصميم وتنفيذ نظام مبتكر لأتمته وحدات انارة الشوارع التي تعمل بالطاقة الشمسية في المدن. النظام المصمم يعالج مشكلة جوهرية في الانظمة القديمة المصممة والتي تعتمد على تقنية شبكات الاستشعار اللاسلكية والمتمثلة بكون الاتصال اللاسلكي يكون من نوع متعدد القفزات. النظام المصمم يتكون بشكل اساسي من مجموعة من الشبكات (Clusters) من نوع (WAN). كل شبكة تحتوي على ثلاثة انواع من عقد الشبكة وهي محطة وحدة الانارة الشمسية والمحطة المحلية والمحطة الرئيسية. ان جميع هذه المحطات المصممة تحتوي على مرسلة من نوع SX1272 تم استخدامها لبناء شبكة (WAN). هذه المرسلات تتميز مدى ارسال كبير نسبيا يصل الى 1.4 كيلو متر و ممانعة عالية ضد التداخل . تم اختبار هذا النظام بشكل عملي في بيئة المدينة واعطى نتائج جيدة جدا فيما يتعلق بأقصى مدى للأرسال وكذلك مراقبة المتغيرات المهمة المتعلقة بالخلايا الشمسية والاجهزة الملحقة الاخرى اضافة الى ان النظام المصمم يعطي الامكانية للتحكم بمصابيح الانارة عن بعد. خلال فترة اختبار النظام تمكن الشخص المشغل للنظام من تشخيص الاعطال بسرعة حال وقوعها الامر الذي عمل على زيادة عمر هذه الوحدات وتقليل تكلفة التصليح وضمان استمرارية الخدمة.

الكلمات المفتاحية: وحدات الانارة الشمسية للشوارع ، تضمين نوع $LoRa^{TM}$ ، محطة وحدة الانارة الشمسية ، المحطة المحلية، قياس مستوى الاشعاع الشمسي.

1.Introduction

Traditional lighting units used with streets, roads, and highways have high efficiency to provide sufficient illumination level to prevent accidents and increase vehicles and human safety (Shilpashree *et. al.,*2014). But unfortunately, these units consume a huge amount of energy. According to studies,10 to 30% of the total electrical energy of any country is consumed by the public lighting used in transportation systems (Popa *et. al.,*2012) (Samir *et. al.,*2013). Moreover, these units still have high cost with respect to installation, maintenance, and environment pollution (Fabio *el. al.,*2014).

To solve this issue, solar based lighting units became the best solution to illuminate any part of that transportation system. In fact, the performance of each solar unit depends on several environmental factors such as dust particles, sun

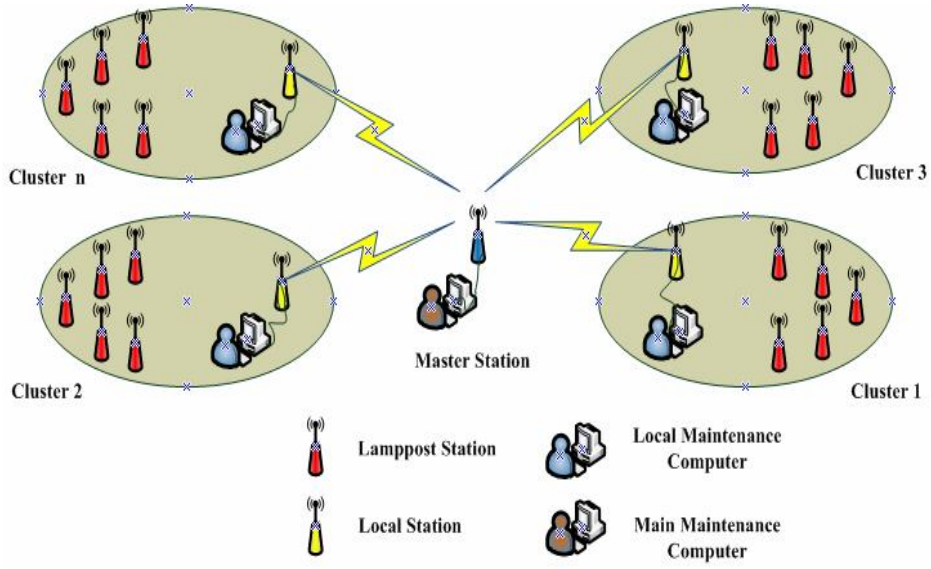
irradiance, temperature, and humidity (Emad,2013) (Mekhilef *et. al.,* 2012) (Ali *et. al.,* 2012).In addition, it depends upon all equipment included in that unit. Therefore,how to achieve full ability to manage [monitoring, controlling, fault diagnostic],these units have become urgent requirement in order to increase the efficiency and lifespan (Lian *et. al.,* 2011).

Researchers or designers understood that fact clearly. They chose Wireless Sensor Network technology and ZigBee protocol together to collect all vital information from these units. Theoretically, these technologies have good advantages supporting them design like low data rate, low power consumption, long battery life, large number of nodes and cheap with respect to instillation and maintains to implement these systems.(kavitha *et. al.,* 2014;Santhosh *et. al.,*2015; Katsioulis *et. al.,*2011; Resmi *et. al.,*2014*)*.

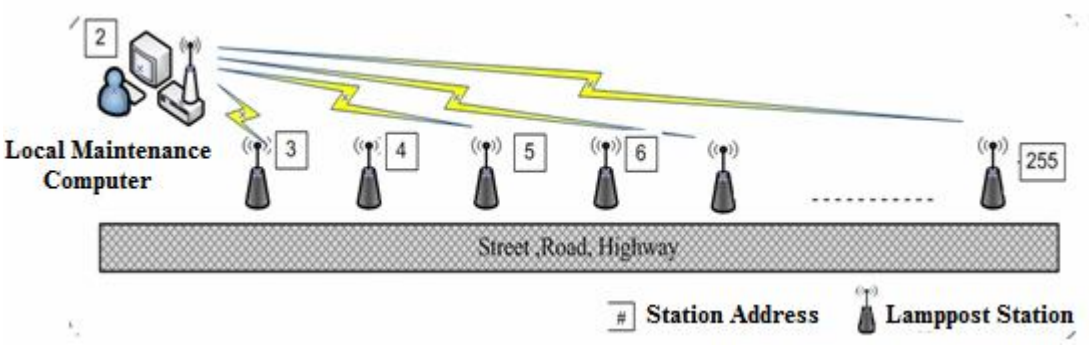
In the practical field, Wireless Sensor Network has not ideal solution for this type of applications. The most effecting point is represented by multi-hop wireless networking. In most public cases, lamp posts are deployed in chain fashion along the sides of streets, roads, or highways (Srikanth *et. al.,*2014;Pilar *et. al.,*2013). So that, when any fault occurs, we may not able to communicate with the other nodes after the faulty node. This problem imposes designers to increase network density to overcome the unexpected node's failure and hence to ensure the continuity of the network services. In its turn, this process leads to instilling extra nodes even if there is no lamppost, increase network complexity, and maintenance costs. Therefore, an innovate system is created in this work. The new design is depended upon single - hop Wide Area Network (WAN) using a new techniques from Semtech company. The design aimed to increase the efficiency and lifespan of solar lighting units. The system tested practically in real life conditions and the obtained results was satisfactory and excellent. The reset of this paper is organize as follows. The next section presents designed system overall. Section three and four describe lamppost and local stations construction respectively. In section five, researcher are going to describing an innovate networking technique which is used in this work. Section six illustrates our practical test and results. Finally, section seven indicates our conclusions from this work.

2. Overall System

The system is designed for a complete remote monitoring, controlling, and diagnostic of an isolated solar based lighting units which are distributed along streets, roads ,or highways. In general, The designed system is constructed from several cluster networks . Each cluster is composed of data logger devices as member nodes named lamppost stations. All nodes in cluster are managed by cluster head node named local station. Local station fixed on local maintenance center and serves up to 255 nodes per cluster. In addition, all local stations can be accessed from master station remotely for surveillance purposes. This station fixed optionally on the main monitoring center. Figure (1) illustrates the overall block diagram of the designed system and one cluster structure respectively.



(a)



(b)

Figure (1) a- Overall system Architecture
b- Cluster Architecture

One lamppost station is coupled with each solar based lighting unit. It contained several sensors and powered by solar energy. Each station was responsible to collect, analysis, store vital parameters related to solar panel and unit's equipment status. Moreover, it used long range wireless transceiver modem manufactured by Semtech company to communicates with local station in same cluster.On the other hand, local station is fixed in the local maintenance center. Each station was responsible to manage all wireless communications inside one cluster as same as it connected all cluster nodes to a special GUI program. In fact,it established point to point communication with each lamppost stations in order to search for problems or to get real-time vital parameters. These parameters enabled person in charge to monitor and control all solar units and take the right decision in fault case. While, master station is a customize local station. It has high authorization to access any cluster network to manage that cluster remotely.

Star network topology is used to connect all stations. It is long rang point to point communication among local stations, any lamppost station, and optionally master station. The design depended upon SX1272 wireless modem. This modem contained a privet modulation technique named $\mathbf{LoRa^{TM}}$. Basically, $\mathbf{LoRa^{TM}}$ modulation is an emerging technology designed to provide long range spread spectrum communication, eliminating repeaters, low infrastructure cost, permits an increase in

link budget, increased immunity to in-band interference, and can even run on energy harvesting technologies.This technology is suitable for Internet of Things (IoT), Machine-to-Machine (M2M), smart city, and industrial applications.

Finally, this work included the designing and an implementation of a complete graphical user interface program (GUI) using LabView software. The designed program characterized by the simplicity in use,robust, and low cost. The program did well to monitoring incoming data, enabling remote control, and finally diagnostic faults occurred during system's operation .

2.1 Lamppost Station Structure.

Lamppost station is designed to record all important parameters related to solar panel and system's equipment status in solar lighting unit . As shown in figure (2). It depends on microcontroller chip and several sensors to perform these tasks. ATmega2560 microcontroller is used in this station. This controller characterized by good features in which they increased system functionality and reliability. Also, It has 54 digital input/output pins, 16 analog inputs, 4 hardware for serial ports (*ATmega2560*).In fact, the controller connected all station's parts and preformed a special designed algorithm shown in figure (3). In addition, XS1272 transceiver is coupled to our controller. This transceiver is responsible to connect all lamppost stations to the cluster network.

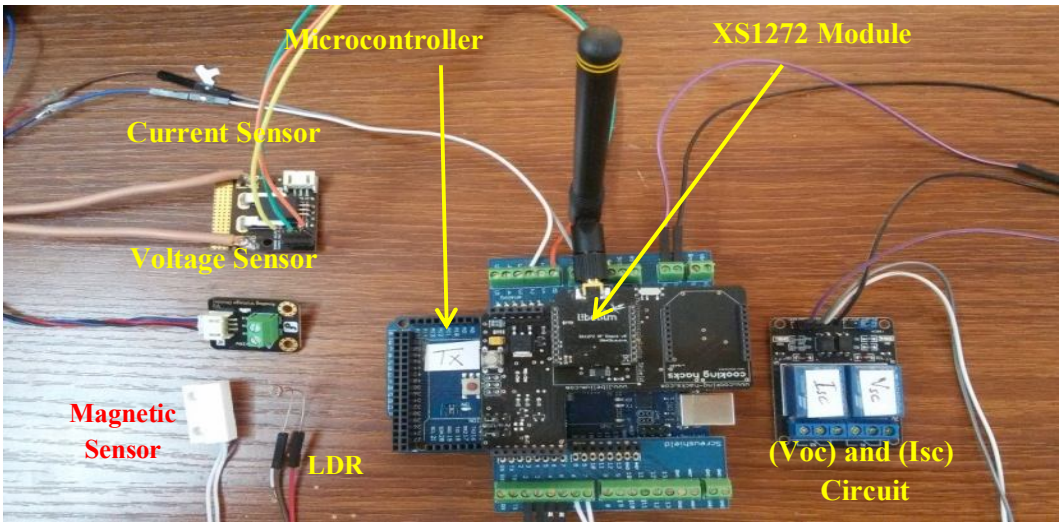


Figure (2) Lamppost Station

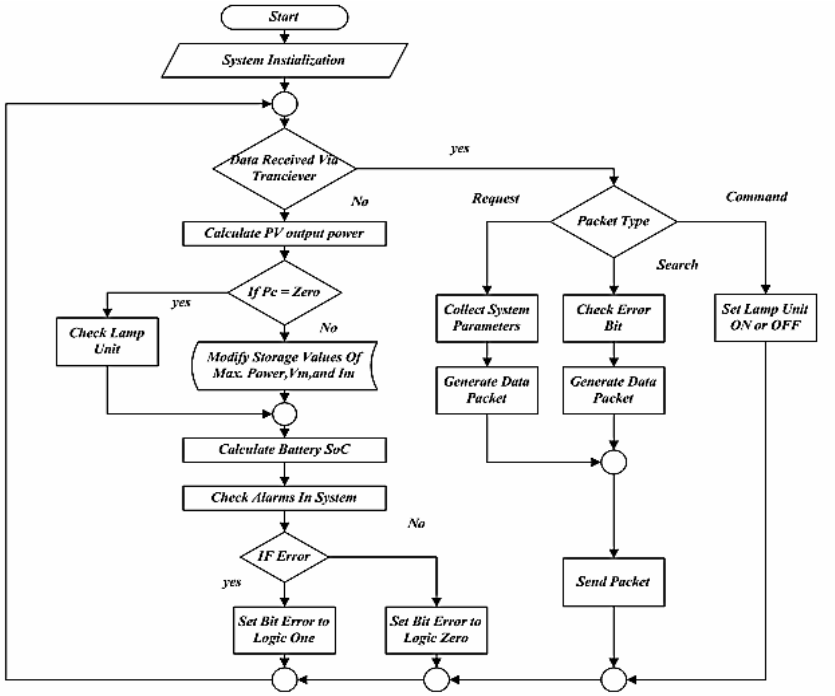


Figure (3) Lamppost Station

2.1.1 Solar Panel Monitoring

The designed lamppost station monitored in real-time nearly all solar panel vital parameters. It calculates the electrical power generated from this panel continuously using high efficiency current and voltage sensors. Our design depends on ACS758 sensor to measure the delivered current. The main features of this sensor included thermally enhanced, fully integrated, and hall effect-based linear current sensor IC with 100 μΩ current conductor (*ACS758 data sheet*). On the other hand, a special voltage divider with reduction factor ($^{1}/_{5}$) is used to measure panel output voltage. Microcontroller turned both of these sensors "ON" periodically in order to estimate instantaneous power generated by solar panels. At same time, it tracked the value of maximum delivered power form the panel in order to modify its storage value. This value is compared continuously with a predefined value configured during unit installation. Station controller toggled Boolean variable named "error bit" to logic one when the value of maximum power drop less than the set value.

This work also has included an innovate design to calculate real-time short circuit current and open circuit voltage of the solar panel remotely. The circuit consisted of four high power relay and interface circuit as shown in figure (4). After receiving request from the local station , lamppost station executed a special algorithm to measure short circuit current and open circuit voltage values. By this method, microcontroller estimated the intensity of incident sunlight value ($\frac{w}{m^2}$) at panel's surface. In fact, our irradiant measurement depends upon [irradiance vs. short circuit current] curve presented in the solar panel's data sheet (*NE-80E2E data sheet*). Real–time solar irradiance measurement may give operator an indication about the cleanliness of the panel surface because dust particles accumulation on the surface of solar panel have the great effect on its performance (Majid Shahatha *et.al.,*2013). In addition to that, other important parameters are calculated depending on the values of (I_{SC}) and (V_{OC}) such as fill factor and panel efficiency.

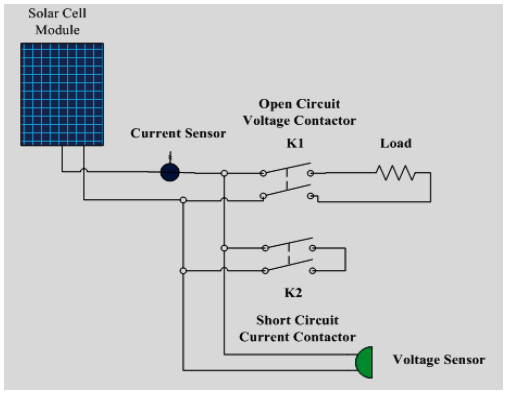


Figure (4) Circuit to find (I_{sc}) and (V_{oc}) remotely

2.1.2 Solar Unit Equipment Monitoring

The design employed "LDR" sensor to detect light source status. This sensor fixed in front of lamp inside lamp container and connected to the microcontroller .Station microcontroller activated "LDR"sensor during night only. In fact, it depended upon the generated power value from the solar panel to distinguish night or morning time. Consequently, the controller modify "error bit" Boolean value according to sensor output to enable person in charge to solve the problem as fast as possible. In addition to lamp monitoring function, our design included the ability to control lamp with two modes named "**Automatic and Manual**". The default mode was automatic. In this mode, lamp unit depends on the panel output power to get "ON" or "OFF ".As it illustrated above on the other hand, manual mode enables person in charge to directly control light unit over the wireless channel .

Battery healthy is another an important factor to increase solar based light lifespan. Therefore, lamppost station calculated battery state of charge (SoC) value by assuming constant discharge current [constant load current].Microcontroller monitored battery's socket voltage continuously using a special voltage divider circuit with reduction factor equal to (1/3).The following table represents our complete calibration process to estimate the relation between (SoC) and instant battery voltage. In same manner, controller modify "error bit" value if the voltage of battery dropped less than 12 volt .

Table 1. Calibrated table of battery voltage and (SoC) percentage for 12V Deep

Battery State of Charge (SoC) in Percent (%)	Battery voltage In Volte
100%	13
75%	12.5
50%	12
25%	11.5
0%	10.9

To product lamppost station against threat of thefts,the designed station equipped with magnetic switch indicator . It may fix at the door of the cabinet which containing lamppost station equipment in a way that it gives signal if the door is opened.This switch was important to alert local maintenance center of any tampering or removal of solar unit equipment.

Finally, the designed station detected charger or controller status. These parts informed lamppost station if there are any problems related to operation. Microcontroller is depended upon logic output from these parts to detect error .It togged "error bit" according to out coming information.

2.2 Local and Master Stations

It responsible to control all communication traffics inside the cluster and connects the designed Wide Area Network (**WAN**) to our graphical user interface program running in the computer of the local maintenance center. As in the lamppost stations, local station based on ATmega2560 microcontroller to manage data flow as it illustrated in figure (5).XS1272 transceiver is also attached to this station. This transceiveruses SPI protocol for communication with the microcontroller. Therefore, it added more flexibility to our design by exhibit a high speed communication as same as it frees UART port for connecting station to GUI program. Also, the designed station is coupled to 20*4 Liquid Crystal Display (LCD). LCD provides a brief information about errors in the cluster , number of active station inside the cluster , and master station connectivity . So that , authorized person has the ability to continues monitor cluster's status if the computer is removed. Figure(6) illustrates the implementation of the local and master stations.

One master station is designed and implemented in this work . In fact, master station is similar to local station in all parts except channel selection ability. In local station, one operation channel (cluster) is selected by the designer while, master station is designed to has the ability to select any channel (cluster) from all available channels (clusters). Therefore, master station has high-authorization to access any cluster and requests information about any station in that network.

On the other hand, this work included the implementation of a Graphical User Interface (GUI)program using LabView software. The designed program was friendly to use, uncomplicated, and provides a complete set of information about solar panels and other parts. The program contained two designed tabs namely: cluster monitoring and PV Module interface. Cluster monitoring is used to indicate faults in any station, the address of faulty station, and number of current stations connected to that cluster.While, the second tab is designed for direct interfacing to solar lighting unit by using unique 8 bits network address.

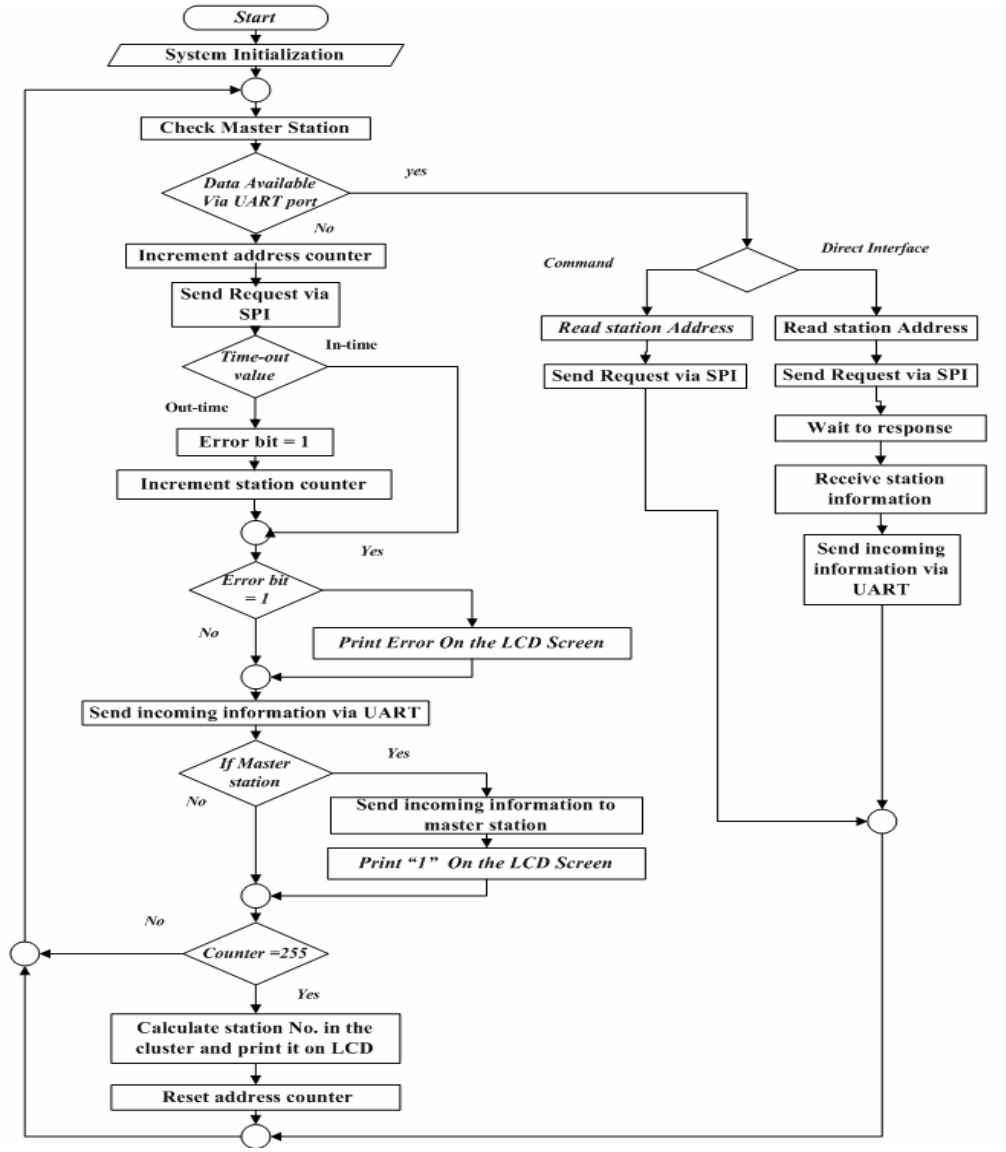


Figure (5) Local or Master Station flowchart

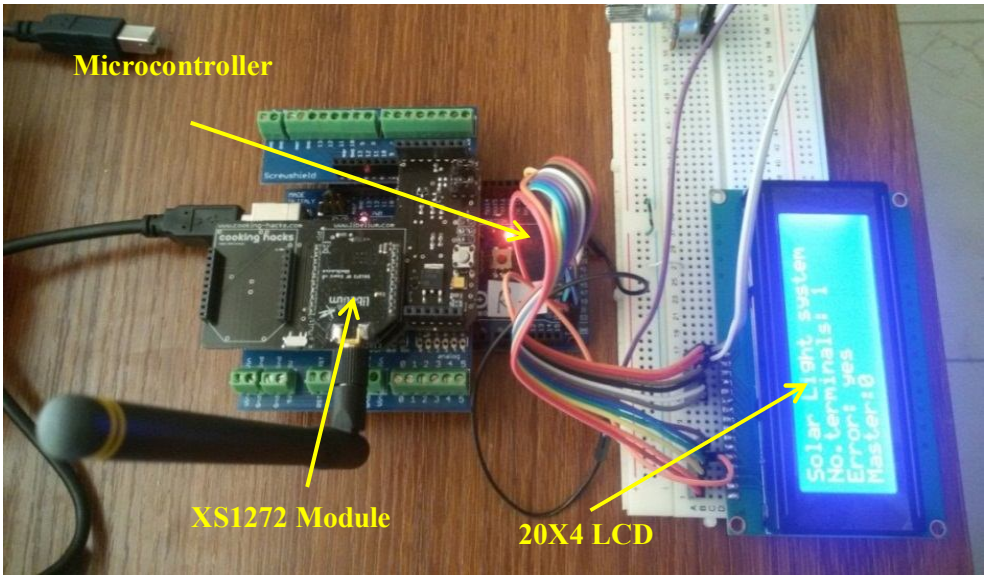


Figure (6) Designed Local or Master Station

3. Networking and Operation

Based on LoRa™ modulation technique which is implemented in SX1272 chip (*SX1272 data sheet*), Wide Area Network is built in this work as a novel networking approach to monitor and control of an isolated solar lighting units for any urban's transportation system.

Star networking topologies are designed in each cluster. At the same frequency channel (cluster), local station depended upon single-hop LoRa™ communication to contact each lamppost station. According to the factory test, SX1272 range start from 2 km to 21 km for NLOS and LOS transmission respectively. In addition, this module works over 22 different channels with a maximum number up to 256 stations per channel. These channels included two different frequency bands 800 MHz and 900 MHz with bandwidth equal to 0.3 MHz and 1.2 MHz respectively (*LoRa Modem Networking guide*).In each frequency channel (cluster),lamppost stations hold addresses starting from 3 to 255. While, local station hold address 'one' because it was the central node and master station reserved address'two' in all of the 22nd channels in order to access all these channel and request data.

Local station preformed unicast communication in order to search about faults, interface to solar lighting unit, or master station information request. As it illustrated in figure (7-step one) system search for faults by sending a small polling frame in round-robin fashion. y this mechanism, it requested fault status from each lamppost station inside the cluster. Lamppost station responded to this frame by sending Boolean value named "error bit".After it received that Boolean, local station polled the next station and the cycle is repeated until all cluster stations are scanned. In addition to that, the design used time-out function to track each polling frame in order to prevent perpetual waiting for response. After search process ended, person in charge could request all real-time information related to unique solar unit using solar lighting unit interfacing as it shown in figure (7-step two).This task is done by using lamppost station's network address directly. In fact, it sent request or control frame asking information or to modify some storage values. Finally, local station started to send identical copy of all collected information to the master station when the last is discovered.

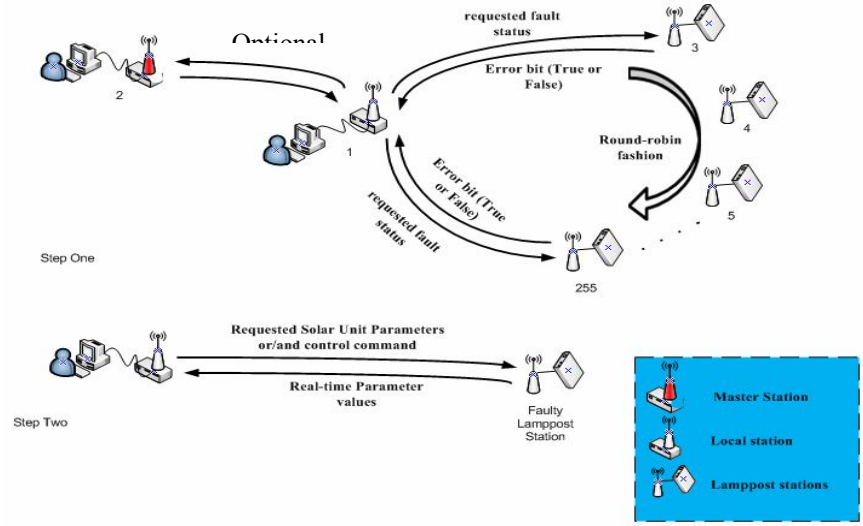


Figure (7) Design System Operation Steps

4. Results and Discussion

Implemented system has been tested practically using prototype solar lighting unit constructed from one solar panel (sharp NE-80E2E model) with 80 watt as output power in standard conditions (25ºc and 1000W/m^2), lead-acid battery (12 volt,80 Ah), inverter, and light source. As show in figure(8) lamppost station coupled to the prototype in order to remotely monitoring several parameter related to solar panel such as real-time output current, output voltage, power delivered, open circuit voltage, short circuit current, sun irradiance (W/m^2), fill factor, and panel efficiency. As well as the Max. power delivered during the operation. At the same time, this station monitored light source and inverter status, board's door position, battery state of charge percentage and performs on/off command to controlling lamp.

Figure (8) Prototype Solar Light Unit With Lamppost station

local station is connected to a GUI program and communicated with the lamppost stations via Wide Area Network inside the cluster. The practical transmission test of SX1272 module in urban environment demonstrates that the star topology of Wide Area Network (WAN) coverage's an acceptable area with average radius reach to 1.4 Km as shown in figure (9). The obtained distance is represented NLOS scenario with a maximum transmission power from the modem. In addition, it

can be observed that hundreds of streets can be served by attaching the designed lamppost station to each lamppost in the all area under cover. The system pass range test successfully and the output results are verified.

With respect to unit monitoring and controlling . Lamppost station is instilled far away from our GUI by 1.4 Km with NLOS scenario on Monday (7/9/2015) at 11.00 AM. One station is instilled in one cluster which is occupied 903.08 MHz channel. In that lamppost station, network address is set to "five" and maximum level of the generated power from solar panel and minimum battery voltage are set to 49 Watt and 10.9 Volt respectively.

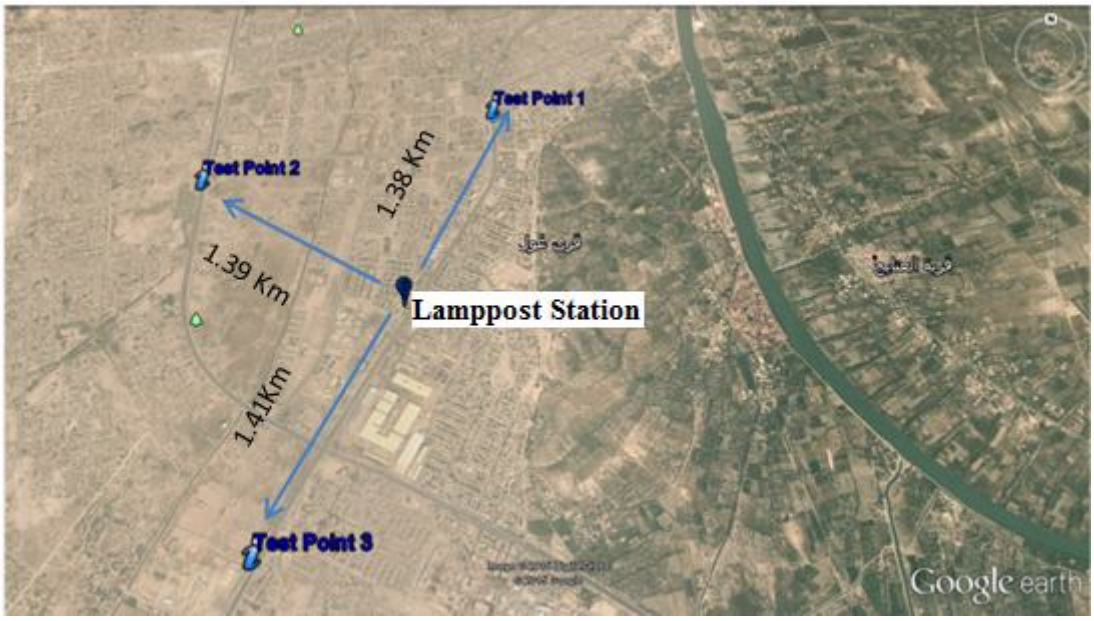


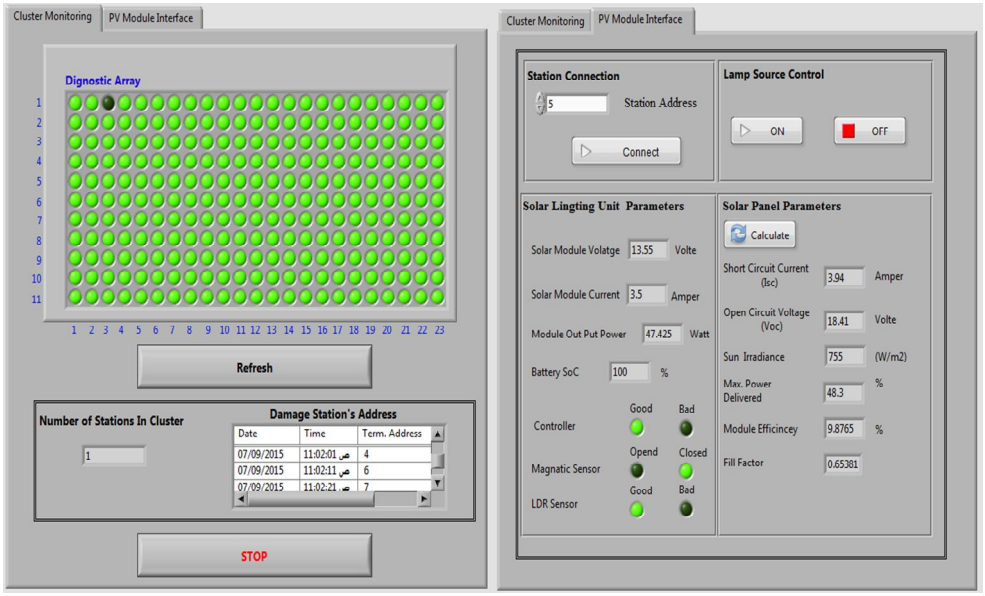
Figure (9) Practical SX1272 modem range test

Table (2) Experimental Measured Value from One Solar Street Lighting Unit during sunny day at 11 am.

Unit	Value	Parameter
Volt	13.55	Solar Module Voltage
Ampere	3.5	Solar Module Current
Watt	47.425	Module Output Power
Percentage	100	Battery SoC
Ampere	3.94	Short Circuit Current
Volt	18.41	Open Circuit Voltage
$Watt/_{m^2}$	755	Sun Irradiance
Percentage	48.3	Max Power Delivered
Percentage	9.8	Module Efficiency
	0.65	Fill Factor

According to the results illustrating in figure (10),the system distinguished all inactive lamppost stations and then displayed the summery on the diagnostic array. All green LED are representing stations holding address from (3 to 255) except our active lamppost station with network address equal to (5). Also, the designed system shows us total number of an active station in our cluster as while as the address of each damaged station with table format. With respect to station interfacing , the

design is successfully collected all required information remotely with acceptable transmission delay as shown in table (2) and figure (10) respectively.



All obtained values on GUI are verified by comparing same parameters measured by instrument directly. In frankly speaks, the system presented in this work gives excellent results as well as it was very efficient, the user can easily identify system malfunctions .

5. Conclusion

This work included the designing and implementation of a new method to automate an isolated solar lighting units using WAN. In this system , operator can estimate the clearness of solar panel surface depending on the real-time irradiance level incident at that surface in (W/m^2). From practical result, The value of short circuit current of NE-80E2E model has the lowest effect to the panel temperature variation among the other parameters so that, the measurement of the sun irradiance can be correct in deferent temperature range. Also, the system calculated solar panel real-time efficiency, maximum power delivered, and module fill factor remotely and enabled operator in charge to make right decision. SX1272 networking module offered large number of API functions to configure or monitor its operation. But unfortunately, the practical test illustrates that the model should be instilled in a higher position in order to increase transmission range and obtains LOS connection. With respect to transmission security, the SX1272 does not implement any security method. Data encryption should be done previously before transmission. However, solar lighting units automation system need simple encryption algorithm to prevent network from attacks or intruder nodes.

The designed system ,compare to other systems in this field, is produced a complete information set about solar based lighting units . Also, it produces a good impact on the determination of fault early , reduce maintenance time , cost , and then ensure continuity of service. The system tested in laboratory and practically in different conditions. The obtained results were excellent and expected if they compare with the same parameters measured by instrument tools.

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