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IoT based smart and intelligent smart city energy optimization

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ABSTRACT

With the effective result of IoT architecture in all research areas, we propose IoT framework based energy efficient smart and intelligent street road lighting system that consist of IoT sensor bases smart electric pole with controller for tuning LED lamps. In our work we replace traditional metal halide lamps with mesophic design LED lamps based on human eye sensitivity and it provides significant saving of energy too. Based on the sensor unit information about traffic flow and presence and absence of occupant smart and intelligent decision making module compute intensity level that generate different width pulse using PWM dimming system which triggers LED power switch via DALI controller mounted inside LED Light Controller. For efficient use of sustainable energy resources we use sustainable power systems that consist of PV solar panel units, Battery storage systems and smart electric power grids. For the charging battery system we use MPPT based dynamic battery charging algorithm. From experiment and simulated result, we observe that proposed energy efficient Smart Street lighting saves considerable amount of energy during peak and off peak hours not only at highway roads but at residential and sub-urban pedestrian areas also. It will finally decrease the consumption of energy and carbon emission. We perform comparative result analysis of proposed systems with existing lighting systems based on energy consumption. Our experimentation result also represents the effectiveness of the proposed dynamic battery charging algorithm based on the battery storage PV solar panel system performance.

Introduction

Sustainable energy is the method of utilizing energy in an efficient way and at the same time satisfying the needs of the modern world. Sustainable energy can be used in economic, social and environmental issues. An efficient sustainable energy management system can be achieved by using renewable resources in all the possible ways, using sustainable energy resources, using alternative energy resources, making use of smart systems, implementing IoT systems, implementing green technologies. The smart system is the technique, which is used to embed the modern technology into functions already used by the world. In terms of smart system, the information about utility system and traffic flow of the large cities is extracted with the help of sensor also it analysis the pattern of information for prediction. Then, the ability to transfer data over a network without the help of human-to-computer or human-to-human interaction is called IoT or internet of things system and the green technology is used to explain the functions of science and technology to develop products as environmental friendly. Some of the examples of green technology is water purification, conserve natural resources, clan energy creation and waste recycle management. It is also used in digital and mechanical machines, objects and in correlated computing devices.

Smart grids, smart cities, smart transport systems, are the examples of sustainable energy systems. Sustainable energy system can not only be implemented in large scale methodologies, it can also be achieved by small activities like sending mails and messages without using papers which would reduce the usage of papers. This is also a part of contribution for sustainable energy [1].

Energy production and its distribution among the increasing population is a great challenge for the government. Due to wide increase in population the energy consumption is also high leading to a lot of environmental threats and health problems. Thus, an efficient way of producing and utilizing the energy resources is very essential. There are three main steps to implement a sustainable energy system as mentioned in Gonçalves and Santos [1]. These are: 1) To study the policies of energy management at industrial level, 2) To discuss the need and the

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methods of implementing sustainable energy, 3) To discuss the improvement of using sustainable energy after validating it with international experts [2].

Recently, there is a drastic increase of smart devices and it is soon expected to over reach around many billions. This is due to development of IoT systems in all the fields. The system of smart networks mainly comprises IoT systems of various interconnected devices like smart phones, sensors, vehicles, home appliances and many more. Smart grid system is one of the sustainable energy management systems. The evolution of modern smart, automatic and two directional power grid systems is another reason [3]. Implementation of these techniques is becoming more threat to the environment and acts against green technology and reduced carbon dioxide emission. While these techniques aim only for the profit of both industries and government. Previously, most of the energy meters used were analog systems. Therefore, inaccuracy, operational loss, theft were quite common. The fault cannot be identified efficiently and in most of the cases fault could not be rectified. Thus, introducing the smart meter was helpful for bidirectional communication between the meter, the grid and the user as well [4].

The smart meter was directly connected to the central power station wirelessly. The smart meter is one of the efficient technologies using the IoT system. The smart meter is an electronic device, which is used to gather the information about current, power factor, voltage level and electric energy consumption. It also enables the two-way communication between the central system and the meter. This is a smart and continuous electric supply system where the users can get information about the smart grid online. It is noted that any power grid can be transformed into a modern smart grid easily by enabling a few features into the system. The smart grid is considered to be the most intellectual and inter connected with other smart grids which ensure continuous, secured power supply to the consumers [5]. The huge demand for electricity throughout the world gave the rise to an absolute necessity for energy optimization techniques. Usage and non-usage of energy in environment to increase the benefits of people and climate is called energy optimization. Then, the comfort of living and the health benefits are increased by optimizing the use of energy. The techniques used for energy optimization is automation system, real time monitoring system and production planning system. Thus, resulting in the development of enormous smart grids and microgrids. Various researches were carried out to use renewable resources in all the possible ways. The hybrid systems used energy from conventional and as well non-conventional energy resources and thereby providing uninterrupted power supply. For an efficient and continuous power supply system, a well-planned grid system along with a proper load balancing mechanism is necessary. The system should include sensors, smart meters, and efficient forecasting devices to predict various parameters affecting the power supply [6,7]. The conventional source of energy is also termed as non-renewable energy resources because the conventional source of energy is only used for one time and it can't be restocked for future purpose. Some of the examples of conventional sources of nuclear energy, petroleum, natural gas and coal. An energy produced with the help of tides, biomass, small hydro, wind, geothermal heat and solar is called non-conventional energy. The conventional energy sources is similar to renewable energy generation process also, the energy produced by the conventional sources does not affects the environment.

In the highly competitive business world, competition with other organizations without smart systems is very difficult. The goods or the products need to be carried out from one location to another for business purposes. It is very much necessary to track the location of the products and can be achieved using a smart transportation system. RFID can be incorporated in vehicles carrying goods and it gives the information of the vehicles. Using few visualization techniques the location of the vehicles or the products can be viewed. Few other techniques like available products, product deficiency, and much more can also be noted using smart systems [8].

The climatic changes and decrease in fossil fuels, increases the need for conservation of energy and to decrease the pollutants in the urban cities. But providing good environmental conditions inside the building (IEQ) is much more important, as people spend most of the time inside the building itself. It is necessary to have a good spacious environment. The design and maintenance of the building should focus on energy efficiency. In Italy, the buildings should possess certain energy efficiency features for getting approval. The old buildings should also get refurbished with these features in the near future as soon as possible. The refurbishment features includes replacing windows, roofs, introducing energy efficient systems for conservation of energy, replacing with renewable energy resources [9]. The renewable energy is the natural energy resources, which is taken naturally from the earth sources such as biomatter and crops. Simply the sources which are restocked is called renewable energy. But, the sustainable energy are sources which doesn't need to be replenished for example wind and solar energy. Another sustainable energy growth can be achieved by a smart lightning system of street roads. For this a special PV solar light is used along with smart grids. The sensors are used to monitor the lights and its motions [10].

Smart city technologies use various communication and networking solutions for dealing with several problems. The IoT system is the major contribution for smart cities. IoT systems include sensors and actuators as its main components along with several other communication and networking devices. The sensors are used to detect many real time data and monitoring purposes [10,11]. It is expected that in a short time period, normal devices in industries, personal, home, city, office would be able to detect the data and process it into useful information for analysis. But it is quite difficult to frame an optimized structure of inter connected devices. Also, the solutions designed should be energy efficiently for rightly describing it as a sustainable energy system [12,13].

These conditions took the designers to consider many scenarios and conditions for implementing IoT systems. Choosing the right sensors and the optimal way of processing the IoT systems are very important for the efficient output. IoT enabled integrated smart cities should be efficient in energy management, cost, secured and protected. Iot systems should function in a self-dependent way without interrupting the operation of other networks and at the same achieving the quality (QoS) to enhance the operation of the system. So, the efficient operation of IoT systems and its life span is the key challenge for future enhanced smart city innovations [14].

Over the next upcoming years, the usage of energy is going to change and the prediction results say that in most of the scenarios the sustainable energy system is in demand. The universal GDP is expected to exceed 3% by 2040, specifically in Asia. This tends to increase the growth of economic conditions. The prediction of energy usage for the upcoming decades shows that there is a huge demand for energy consumption and therefore energy efficiency is very important to meet the necessity. Usage of energy efficient systems like smart meters, smart industrial equipment, optimal operational management and using sustainable and alternate energy resources in all the possible places can lead for conservation of energy [15].

Optimized energy usage and providing the best solution at all the situation is a key challenge for researchers. Multi-agent system has evolved for interacting with many agents and providing the best solution. A specially designed tool called Energy PLAN tool is introduced for providing the best solution for energy efficient usage and this could be applied in many cases at short term, long term, national level and international levels. Multi objective algorithms are introduced for producing optimal solutions by alternating various other existing algorithms and thus minimizing cost, using energy efficiently, replacing with renewable resources. Energy PLAN tool integrates many sectors of systems like electricity, heat energy, transportation system and industrial equipment. It supports stepwise modeling for migrating from the traditional energy system to sustainable energy growth [16].

The effectiveness of the proposed dynamic battery charging algorithm based on the battery storage PV solar panel system performance is analyzed in this paper. The organization of the paper is discussed as follows: An overview of the work is discussed in section 1 and the section 2 explains the literature survey of the work. Section 3 explain the proposed framework; simulation results of the proposed work is explained in section 4 and the conclusion of the work is explained in section 5.

Literature survey

The bigger problem in the world is Global Warming [17,18]. It is caused by the more emission of greenhouse gas. Sato et al. [19] proposed the overall smart city energy optimization by using the method Multi swarm differential evolutionary particle swarm energy optimization. The energy that should be used efficiently is essential in a contraction of emission of carbon dioxide as well as smart city demo work to be organized throughout the world for decreasing the quantity of emission of carbon dioxide. The issue can be formulated as a combination of nonlinear programming issues as well as several evolutionary calculation methods like differential evolution, particle swarm optimization still lacking for developing the solution quality. Multi swarm methods improve the solution quality by using the best model as well as the migration model. The best model technique with WB policy and hypercube topology is the maximum powerful compared to all existing multi swarm parameters.

Waleed Ejaz et al. [20] the usage of vehicles is increased more it needs intelligent solutions for quality of life, circumstances, and transportation. The Internet of Things provides various complexes as well as all over appliances for intelligent cities. Since the Internet of things devices persist to develop in both requirements as well as numbers, the energy requirement of the Internet of Things is also raised. Hence, intelligent city solutions should have the capability to accurately use energy as well as control their related challenges. To extend the period of low power devices the rising solution is the harvesting of energy in intelligent cities. It first aims at programming the energy-efficient in smart homes as well as then it encloses wireless power dislocation for the Internet of Things in intelligent cities. It has a drawback that the electricity cost is expensive.

In the past decade [21,22] real-time data set is applied on classical regression setup, then the forecasting is taped. Then the prediction is carried over by the neural network method is also noted [23]. The task comprises a simulation path that imitates multi-layered feedforward networks as well as extremely effective system performance has been declared. The authors Sofana Reka and Tomislav Dragicevic [24] noted a huge survey on the Internet of Things permitted intelligent grid methods for effective delivery of energy. There are various Internet of Things that familiarize energy management benefits depending on several aspects like energy efficiency, security, functionality, and sustainability [25].

Hamed Mortaji et al. [26] proposed a new setup that is Auto-Regressive Integrated Moving Average used for time series load data. The main aim is to reduce the peak to average ratio so that a forecasting setup based intelligent Internet of Things is Proposed in this task and it can be directly controlled. The authors Alberg and Last [27] proposed a sliding window method which is based on Auto-Regressive Integrated Moving Average finding to forecast the loads of non -seasonal as well as seasonal data. Tinghui Ouyang et al. [28] labeled a deep learning method for short-time load prediction. A data-driven design along with copula steps based on a belief network that has been labeled here. The deep neural networks, extreme learning machine, deep neural network approach as correlated as well. Kunjin Chen et al. [29] designed a short time prediction setup based on deep residual networks to boost the prediction outcome. Then labeled a two-stage ensemble strategy to boost the efficiency of the system.

Ashfaq Ahmad et al. [30] proposed an AFC STLF setup which is the mixing of a predictor, optimizer and a feature selector. The Accurate and Fast Converging Short-Term Load Forecasting (AFC-STLF) model is offered for daily industrial SG applications such as load changeover, maintaining infrastructure, contract evaluation, electricity generation planning and power purchases. Short-term load forecasting (STLF) modeling is critical for the electric sector in the energy trade. These models have a variety of applications in electrical utilities' day-to-day operations, including contract evaluation, infrastructure maintenance, energy procurement, power generation planning, and load switching [31,32]. The data based on time series is given to the feature selector. Previously the repetitions are eliminated from the sets of data then the final data is offered as input to the neural network that predicts the contraction of electricity for the subsequent days. Authors also permit a path on various challenges and problems in load predictions setup [33]. To label this issue various hybrid CI-based load prediction methods are noted. CI-based load prediction technique is a structured methodological solution intended for specific predictive situations, whereas the technology is a specialized model along with other associated models such as regression and neural network approaches, may be grouped into a single technological category. Liangzhi Li et al. [34] proposed an Internet of Things based load prediction method. Then a two-step based prediction method has been labeled which outcomes in more approximate predictions then compared to traditional methods. Senthil Murugan and Usha Devi [35,36] proposed hybrid model for analyzing large amount of data which can used for several analysis as the authors used machine learning and optimization techniques.

Salim S. Maaji et al. [37] proposed a voltage stability setup based upon the machine learning approach. To achieve the best outcome Naive Bayes, as, well as K Nearest Neighbors classifiers, should be observed in this case. Mehdi Rafiei et al. [38] proposed a new hybrid technique of probabilistic load prediction along with generalized large learning machines. In the proposed system wavelet transformation approach is applied to separate electricity contraction into a series of well-behaved productive subseries. Nianyin Zeng et al. [39] proposed a swarm-based optimization method that is used for short time load prediction. This method is also called DPSO ELM. The term DPSO ELM stands for Darwinian particle swarm optimization extreme machine learning. In a collection of numerous swarms, Darwinian Particle Swarm Optimization (DPSO) replicates natural selection and each swarm acts like an ordinary PSO separately. The ELM is one of the most commonly used hidden layer feedforward networks (SLFN). It has faster computation speed and better generalization than conventional methods of artificial learning. This setup permits the right path to produce good results by avoiding the hidden node which is not necessary as well as training issues. Francesco Mancini et al. [8] analyzed the energy regeneration of the actual construction tradition as one of the supports of Italian energy policy. It mainly aims to save energy as well as use the energy efficiently based on Ventilation, Air Conditioning, and heating systems. The study aims at evaluating the energy consumption as well as Indoor Environmental Quality and varying the airflow rates. The analysis has been carried over by in situ measurement and dynamic simulations. It has an advantage of reduced energy consumption but it increases the carbon dioxide level up to forty-two percent [40].

Smart Street Lighting is a project that prioritizes not only for energy reduction but also for ease. Automatic intelligent lighting control during the night (from 11p.m. to 5 a.m.) is based on the movement of automobiles and people. It may also be turned on or off automatically based on the amount of sunlight. The adoption of an intelligent automation approach known as the Internet of Things can aid in energy conservation in street lighting. The street lighting system is extremely expensive in terms of energy expenditures. On Smart Street, the average cost of smart lighting systems may be cut in half to seventy percent.

Proposed framework

The information and energy flow of proposed sustainable energy efficient smart street road lighting system (EESSRLS) is shown in Fig. 1 that consist of smart electric pole that transmit the light and motion information via sensors and actuators to Master control unit (MCU) that perform intensity computation based on this information and tuned the

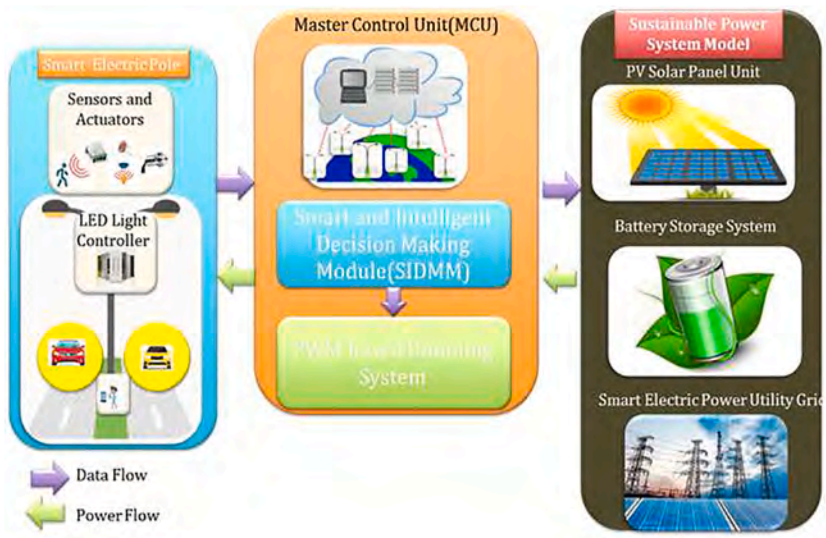

Fig. 1. Proposed flow of energy efficient smart and intelligent street road lighting system.

LED lamps using PWM based dimming system via LED light controller (LLC) equipped on smart electric pole. For sustainable energy, we use a separate sustainable power system that consists of a PV solar panel, battery storage system and smart electric power utility grid.

Smart electric pole

In order to design a smart and energy efficient street lighting system we use smart electric poles that consist of various sensors and actuators and LED light controllers that monitor and control illumination of proposed smart LED lighting systems through Zigbee wireless network. Zigbee is the wirelss technology, which is mainly used to states the needs of low power and low cost wireless IoT newtorks. It can transmit the data over long distance by passing through the intermediate devices of mesh network in order to reach larger distance. Also, it is used to low data rate applications to provide secure networking and long battery life. The major advantages of Zigbee network is its flexible network structure with low power consumption, but the transmission rate of the Zigbee network is less.

Sensors and actuators

We use different sensors for different purposes like Motion sensor is used to sense the presence or absence of occupants or vehicles at residential street pedestrian or city highways; light sensors used to sense the brightness status of particular location based on the sunlight that ensures minimum illumination level of street; Control sensor is used to sense system fault maintenance and management.

LED light controller (LLC)

LLC receives intensity levels transmitted by Smart and intelligent decision making modules (SIDMM) based on the sensing data computation. The LED controllers is considered as an essential component for all dynamic lighting control system. The controller is used to control the colors of RGB LED lights and RGBW lights and it is used to select and change the color temperatures with the help of CCT LED color changing temperature strips and single color dimming. Meanwhile, the white LED strips is different to light levels of the system. This intensity information is then further sent to ballast of LED luminaire via DALI controller that controls street road lighting system. The expanded form of DALI is Digital Addressable Lighting Interface, it a lighting interface system which allows to use digital signal with flexible and more precise control. The DALI lighting control system permits the lighting features of digital controller for given lighting system. Also, it uses low voltage two-way communication protocol to transfer messages between the features.

Master control unit (MCU)

Master control unit consist of smart and intelligent decision making module (SIDMM) that computes intensity level based on the traffic flow at residential pedestrian and highways; and PWM based dimming system that generate intensity based pulse width to trigger power electric switch of output voltage of DC-DC converter for dimming LED lights.

Smart and intelligent decision making module (SIDMM)

In this section we propose a smart and energy efficient system based on the traffic at highways and residential street pedestrians and an optimized energy efficient model can be designed only by determining realistic mobility behavior and pattern of vehicles or humans. Intelligent decision making is the cognitive based system, which makes the decision with in-depth analysis. Also, it uses big data to make decision with more accurate decision rapidly. Intelligent decision making uses pervious decision making outputs to predict the output for a specific problem in a driven systems. To determine the mobility pattern, analysis of large scale parameters like average traffic speed; and microscopic parameters such as vehicle headway time and vehicle inter-spacing need to be performed. The time difference between any two successive vehicles while traversing a spot is known as time headway. As a result, the time progress is determined by the horizontal distance between the automobiles is represented by lines. The reciprocal flow is currently ahead of the average time between the automobiles. The IVS (Inter vehicle spacing) is a user-friendly interactive interface that enables the users to calculate the minimum initial spacing between two vehicles with definite deceleration profiles, tire-to-road friction, initial speeds and reaction times so that there are no collisions or collisions with relative speeds below the given speed in IVS. The mean average of speed for area space where installation of smart light done is calculated using following equation:

$$\overline{v} = \frac{\square}{\square} \tag{1}$$

Where, $\square$ represent road length to determine travelling time and $\square$ represent average vehicle time travel at a speed of 40 km/hr. The realistic mobility and distribution of traffic is measured by using microscopic parameters that can be modeled by probabilistic Poisson distribution space in which probability of occurrence of vehicle on road is by mapped by following probability function. The poisson distribution is the probability distribution, which is used to deliver how many time that the event occur in a system over a particular period of time. It is also used to know the constant rate value of the independent variables in an interval of time.

$$\text{Æ¤}_n(x) = \begin{cases} \frac{(\gamma t)^x e^{-\gamma t}}{x!}, \begin{cases} Swi_{on}(N_p = 12), Highwaysroad \\ Swi_{on}(N_p = 4), Residentialpedestrians \end{cases} \\ 0, Swi_{off}(N_p) \end{cases} \quad (2)$$

Where, $\text{Æ¤}_n(x)$ is the probability of occurrence of vehicles incoming in a preset time, and γ is the average rate of arrival of vehicles in time t., $\gamma \geq 0$ is preferred here to model the arrival of number of vehicles at speed of 40 km/hr passes over area of 300 m roadways, N_p is the number LED lamp poles. Based on the traffic flow pattern, power supplied to LED lamp poles. For efficient energy management we propose integrated PV battery power and utility grid power resources are used with smart and dynamic power resource scheduling (SPDRS) algorithm. If the traffic pattern is recognized, electric poles demand power from PV battery storage systems. If the demand is not satisfied by the battery storage system then utility grid power is supplied to satisfy the power requirement.

For low frequency pedestrian areas we develop Smartphone application based control systems where each Smartphone periodically transmits user locality and configuration parameters to SSL server using GSP system. As the application server retrieves user location, it broadcasts this information to the Street lighting controller system. Based on t received information and spatial database, the controller performs switched-on or -off operation of LED street lamps. This will help in conserving a considerable amount of energy.

PWM based dimming system

Dimming system that controls brightness of LED based on these motion detection sensors at highways and residential pedestrian street lightening is proposed because occupant's activity during the time slot from 12 PM to 5 AM is very less so for minimum energy consumption. Fig. 2 shows the block diagram of the proposed PWM based dimming system in which according to sensor input adaptive control circuit generate different voltage level power which is then fed into PWM pulse generator that generate width duty cycle pulse. The pulse width modulation (PWM) is the modulation technique, which is mainly used to produce variable width pulses to deliver the amplitude of an analog input signal. The signal generated by the PWM is high-amplitude signal means the time of the switching transistor output is high or else the system having low-amplitude signal means the time of the switching transistor output is low. These PWM pulse widths trigger the electrical power switch of the DC-DC converter to produce output DC voltage with two different voltage levels for dimming function. The dimmer is an electronic device which is connected in the light fixture to control the brightness of the light. The lower of the intensity of the light output is achieved by applying voltage waveform to the lamp. Commonly, the output of the lamp is measured in terms of lumens (lm) also called as "luminous flux".

We design adaptive control function f(C) based on the batteries state of charge condition for dimming LEDs:

$$f(c) = \begin{Bmatrix} D_{led} B_{soc} \leq B_{soc_{min}} \\ 1 + (1 - D_{led}) \left[\frac{B_{soc} - B_{soc_{min}}}{1 - B_{soc_{min}}} \right]^a B_{soc} > B_{soc_{min}} \end{Bmatrix} \quad (3)$$

Where, D_{led} represent the minimum dimming threshold value set corresponding to minimum acceptable brightness value of LED; $B_{soc_{min}}$ is the minimum threshold value of batteries SOC.

Mesophic design based Street Road Smart Lighting System

In order to save more energy we propose energy efficient street lightening system in which

Traditional more energy consuming street lamps are replaced by LED lights.

Use of Mesophic LED design: As per European human eye and road lightening standard [1] during hours of darkness the illustration conditions are generally mesopic. Therefore, illumination sources that are more effective under mesopic circumstances can be used to lessen the luminance on the surface of road with same visibility. Thus, mesopic photometric design has potential to conserve energy. The Mesopic vision is the combination of both scotopic and photopic vision, which is used in low lighting situations but it is not used in dark lighting situation. The

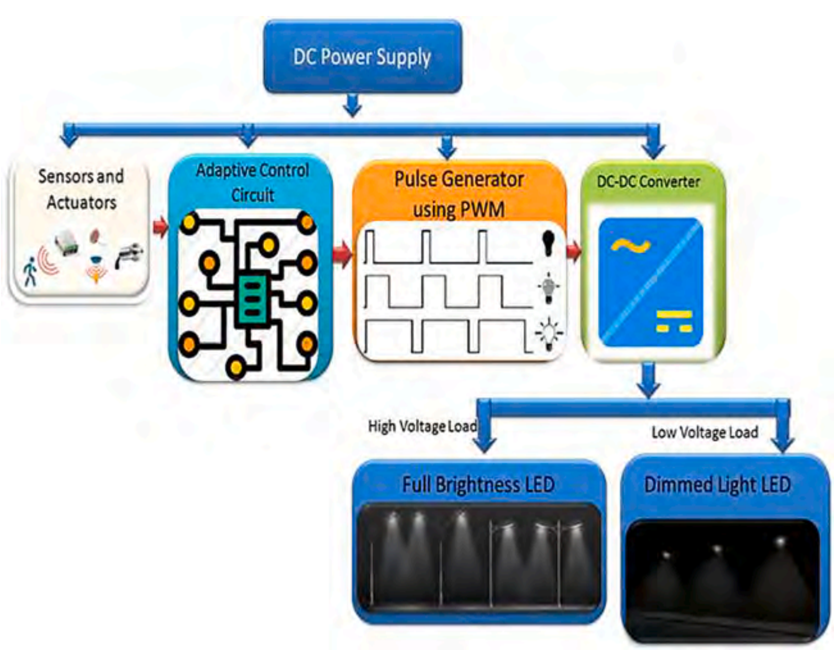

Fig. 2. PWM based dimming system.

light levels of mesophic ranges from the luminance of approximately 0.01 cd/m2 to 3 cd/m2. The street light and night time outdoor scenarios are in the range of mesopic vision. The mesopic visual system can be design by following equation:

$$N(\varphi)\vartheta_{mes}(\omega) = \varphi\vartheta(\omega) + (1-\varphi)\vartheta^{'}(\omega) for 0 \leq \varphi \leq 1 \quad (4)$$

Where, $\vartheta_{mes}(\omega)$ represent mesophic visual efficiency function, $N(\varphi)$ is the normalization function with maximum attainable value of $\vartheta_{mes}(\omega)$i.e. 1 and φ is the coefficient depends on spectrum and luminance adaptation.

Design of LED driver depends on various factors such as input value of voltage supplied by batteries i.e. V_{min}^{bat}, number of LEDs and their voltage $\tilde{N}_{led}$. For sake of simplicity and cost-effectiveness serial connection arrangement is chosen. Based on the initial parameter minimal duty cycle D_{led} of converter to derive LED can be defined as follows:

$$D_{led} = 1 - \frac{V_{min}^{bat}}{\tilde{N}_{led}} \quad (5)$$

The inductance value of converter used for LED driver L_{led} is defined as follows:

$$L_{led} = \frac{V_{min}^{bat} D_{led} T_l}{\Delta I} \quad (6)$$

Where, T_l is the switching time period of convert to drive LED and ΔI is the ripple input current.

Sustainable power unit

Sustainable power systems consist of photovoltaic solar panel (PVSP) units, Battery storage units and power electric grid.

PV solar panel unit

Battery storage units get charged and store energy produced by PVSP during day time through DC to DC converters. Solar energy generated capacity by PYSP unit is computed using following equation:

$$C_{PVSP} = V_P^{max}.I_P^{max}.S_{peak}.C_{fac} \quad (7)$$

Where, V_P^{max}, voltage at maximum power (36 V), I_P^{max} current at maximum power (5A), C_{fac} is correction factor of PV panel and S_{peak} is sunlight at peak which is calculated by following equation:

$$S_{peak} = \frac{S_r}{\frac{1kWh}{m^2}} \quad (8)$$

Here S_r is the radiation of the Sun. Using battery storage power supply LED drivers illuminate LEDs with full brightening voltage or dimming voltage. Capacity of battery storage system is defined by following equation:

$$C_{bat} = \frac{C_{PVSP}}{V_{min}^{bat}} \quad (9)$$

Battery storage system

In PV solar panel system batteries are exposed to various unfavorable operating conditions because non– non-linear behavior of Sun, and therefore batteries are considered as the most sensitive part of PV solar panel system. Fig. 3 represents a PV solar panel system based battery storage system in which all devices are directly or indirectly connected to a DC bus. During day time the battery is charged completely using a dynamic charging algorithm and during night time this storage power is used to drive LED lamps.

The major advantages of photovoltaic (PV) cells is explained as follows:

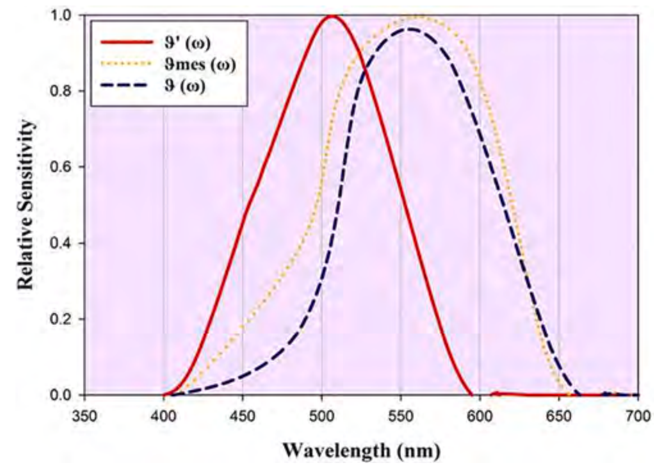

Fig. 3. Relative sensitivity function of scotopic vision ($\vartheta^{'}(\omega)$), Photopic Vision ($\vartheta(\omega)$) and Mesophic Vision ($.\vartheta_{mes}(\omega)$)

- Deliver clean and green energy
- Easy installation
- Low maintenance cost
- Impact on smart energy networks

The PV cells also having some disadvantages such as:

- High area requirement
- Intermittency issues
- Reliable power option is low

With this fact, we use dynamic battery charging algorithm with non-linear behavior of Sun which is described as follows:

Based on the initial conFigd voltage and current value of batteries i.e. V_{min}^{bat} and I_{min}^{bat}, proposed charging algorithm work in three different modes:

If the minimal current available to battery by PVSP unit is less than 0.1CAh $(I_{min}^{bat} < 0.1CAh)$ the converter searches out for maximum power point so as to maximum possible current to charge the battery.

If the minimal current available to battery by PVSP unit is greater than 0.1CAh $(I_{ini}^{bat} > 0.1CAh)$ then converter set 0.1CAh as current $(I_{set}^{bat} = 0.1CAh)$ from the current grid and disable maximum power point search.

If battery is charged already, then constant level of voltage is applied and set i.e. $V_{set}^{bat} = 2.2\frac{V}{C}$.

After dynamic battery charging algorithm with non-linear behavior of Sun calculation of duty cycle and Pulse Wavelength Modulation is performed based on the design of the converter. The duty cycle corresponds to the time, when the charge or the circuit is OFF. As a proportion of the time, the duty cycle is also known as "service factor." For converter design following equation are used:

$$D_{bat} = \frac{V_{min}^{bat}}{V_{min}^{bat} + V_P^{max}} \quad (10)$$

$$L_{\varsigma 1} = L_{\varsigma 2} \geq \frac{V_P^{max} D_{bat} T_{\varsigma}}{2 I_{ini}^{bat}} \quad (11)$$

$$\zeta_{\varsigma 1} = \zeta_{\varsigma 2} \geqslant \frac{I_{min}^{bat} D_{bat}(1 - D_{bat})}{V_P^{max} f_{\varsigma}} \quad (12)$$

$$\zeta_{\varsigma 3} = \frac{V_P^{max} D_{bat} T_{\varsigma}^2}{8\ l_{\varsigma 2}\ \zeta\ V_{min}^{bat}} \quad (13)$$

Where, D_{bat} represent minimal converter duty cycle to charge battery,

$L_{\varsigma 1}, L_{\varsigma 2}$ are the inductance values, T_{ς} and f_{ς} are the switching time period and frequency of converter, ΔV_{min}^{bat} is the output ripple voltage, $\varsigma_{\varsigma 1}$, $\varsigma_{\varsigma 2}$ and $\varsigma_{\varsigma 3}$ represent capacitance values.

Smart electric power utility grid

Brightness level of LED street lamps of residential pedestrian areas can be tuned and power load can be transferred from electric utility grid to battery storage power devices mounted with the smart electric pole. During off peak hours with least frequency hours, load at minimum energy consumption smart electric poles can be transferred to solar panel PV energy systems. The status of the energy saving and consumption at smart electric poles is transmitted to smart electric utility grids periodically. Based on this information smart electric grid perform dynamic load configuration and management.

Simulation results

Performance evaluation of proposed energy efficient Smart and Intelligent road Lighting System is performed by replacing 24 units of metal halide light lamp (140 W) with mesophic design LED illumination lamp (70 W). Metal halide light systems replacement with LED lamps itself results in approximately 50% of energy saving but the main concern of this research is to maximize energy saving and minimize emission with real crux. The metal-halide lamp is a kind of electric lamp, which generated light in form of electric arc with the help of gaseous mixtures of metal halides and vaporized mercury. It is also called as high–intensity gas discharge lamp.

Power consumption based on proposed dimming algorithm

Traffic flow based on time and ambient status are the key features of our proposed PWM based dimming system that contributes in energy saving by controlling current through PWM on the basis of luminance and power. Power and luminance measurement is carried out using standard power meter ICs of Yokogawa (WT210) and light meter ICs of Tenmars (TM-203). The power and lux data parameters are noted simultaneously from both instruments. Light meter sensors take reading from and fight successive light sensor board meters for effective result analysis.

Experimentation results for the proposed dimming system based on power and illumination value is demonstrated graphically in Fig. 4. Fig. 5a demonstrate comparative analysis of calculated power between the standard power meter ICs and power meter instrument equipped to the smart and intelligent LED luminary, while Fig. 5b represents the intensity response of the proposed smart LED luminaries with varying power and illumination values using PWM based dimming system. From the graphical representation shown in Figs. 5(a) and (b), it is observed that both the power and intensity show analogous responses to different values using a PWM based dimming system.

Energy saving rate proposed by the PWM based dimming system is shown in Fig. 3. To calculate an approximate amount of energy saving, we suppose that the total illuminating hours of the street road lighting system is 12 h i.e. from evening 6:00 PM to morning 6:00 AM. Based on traffic flow during these illuminating hours is shown in Fig. 6.

Comparison analysis based on energy and power saving

In this section we present comparative analysis based on energy and power saving of proposed energy efficient smart and intelligent street road lighting system with traditional lighting system. The proposed lighting system saves energy by switching LED lights based on traffic flow with minimum energy consumption power mode using the proposed PWM based dimming system. For ensuring safety and security at pedestrians with different types of road we set the minimum dimming

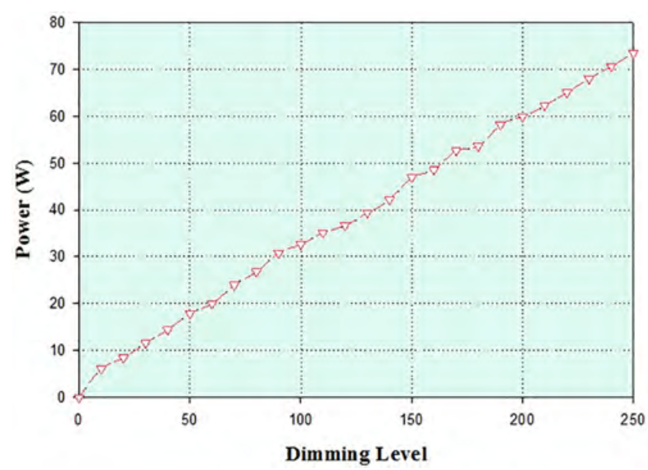

Fig. 5a. Power consumption at various dimming level using PWM based dimming system.

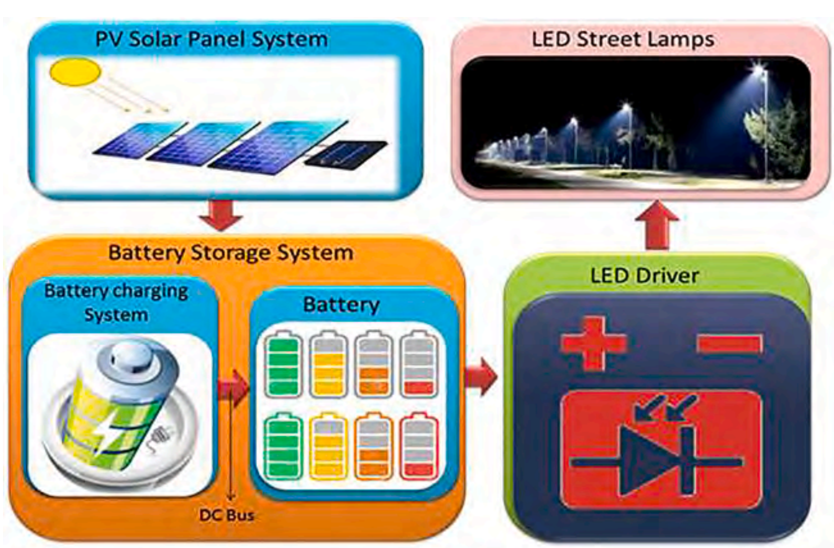

Fig. 4. PV solar panel based battery storage system.

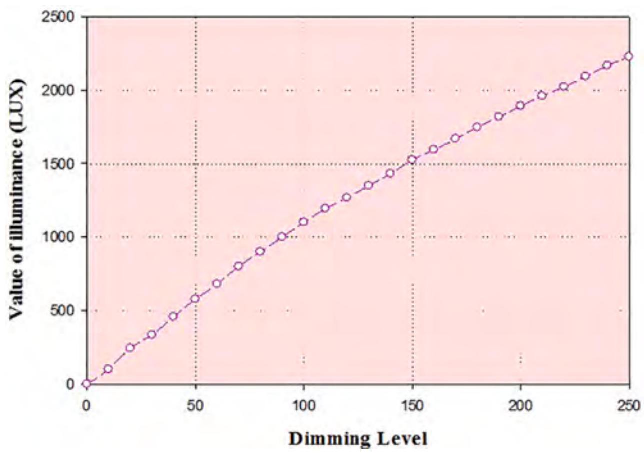

Fig. 5b. Illumination value (Lux) for various dimming level.

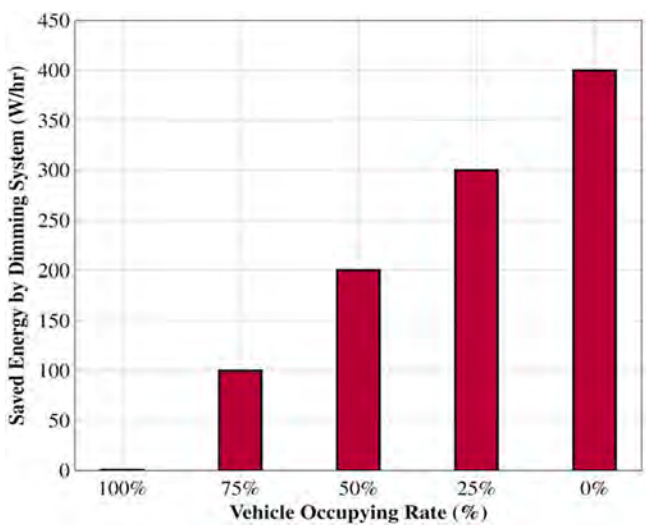

Fig. 6. Energy saving by PWM based dimming system with varying traffic flow.

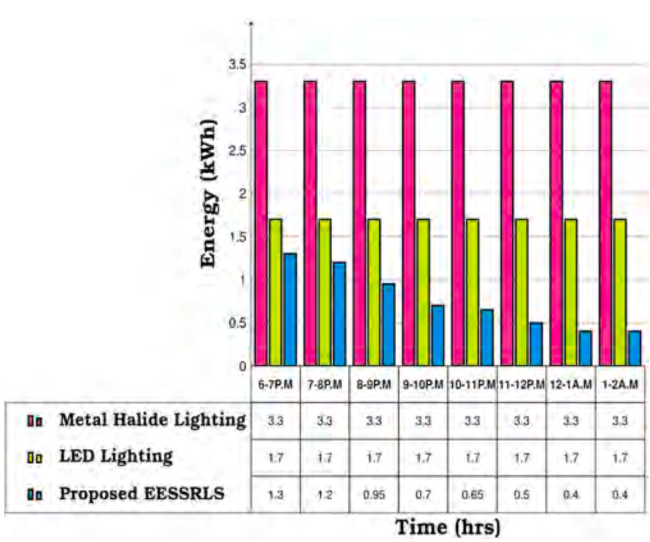

Fig. 7a. Comparative analysis of energy consumption between traditional lighting system and proposed EESSRLS for single day.

value that maintained the standard level of luminance (lux) according to the illuminating engineering society of North America (IESNA) recommendation. Figs. 7(a) and (b) demonstrate comparative analysis of the energy consumption between traditional lighting systems and proposed LED lighting systems for a single day. Fig. 7(a) represents a significant amount of energy saving by proposed smart and efficient brightness controlling dimming system based on low and high traffic time as compared to traditional systems. From Fig. 7(b), in addition to the traditional lighting system we also represent the energy consumption for residential pedestrians as well as highway road brightness controlling systems. Fig. 8 represents an energy saving graph for the proposed dimming system as well as a conventional lighting system during very less traffic flow (off peak hours). The result simulation for different frequency traffic of highway roads and residential pedestrians is shown in Figs. 9 and 10 respectively.

Battery storage and PV system performance

Performance of proposed dynamic battery charger algorithm is shown in Fig. 11(a) and Fig. 10(b) Form the Fig. 11(a) it is observed that the proposed PV system provides a maximum power of 180 W with a solar radiation of 1000Wh/m^2 and this power is used to charge the battery with a current of 7.5 Amp. However, as the solar radiation falls to 700 Wh/m^2, power obtained from this radiation is also decreased by 125 W which consequently affects and reduces the charging current of the battery bank by 5A as shown in Fig. 10(b).

Conclusion

Lighting systems are an immense source of high cost and energy consumption and with the constant decrease in non-renewable energy resources, this lighting system drives the requirement to address issues concerning budget and environmental effect. In this paper, we propose an energy efficient sustainable smart and intelligent street road lighting system that saves energy consumption with the IoT sensors, sustainable energy resources and efficient decision making module and dimming system. For detecting traffic flow and ambient status we use various sensors and actuators that detect motion and light information which is then transmitted to the master control unit via ZigBee network. At MCC the information computation is performed at an intensity level using an adaptive control circuit which is then fed in a PWM pulse generator that produces pulse width based on this intensity which triggers the power switch of LED lamp via LED light controller. LED lamps are lighted by solar energy which is stored in the battery storage system during day time and utilized at night time. For the charging battery system we use a

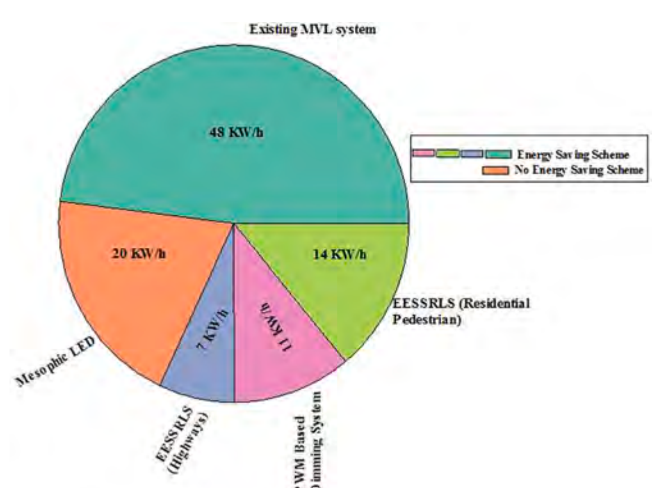

Fig. 7b. Comparative analysis for energy consumption between existing and proposed system.

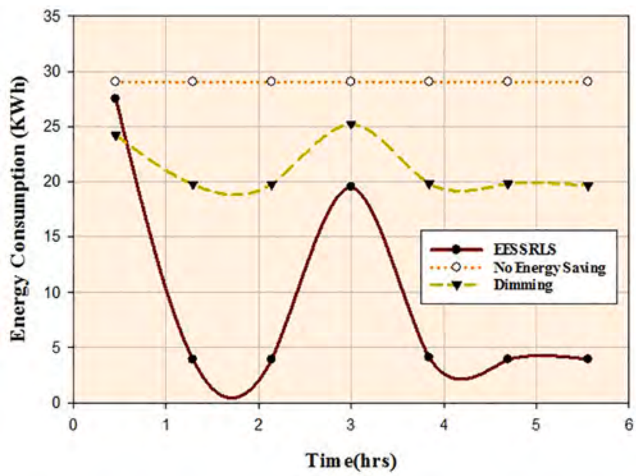

Fig. 8. Energy consumption for low traffic off peak hour.

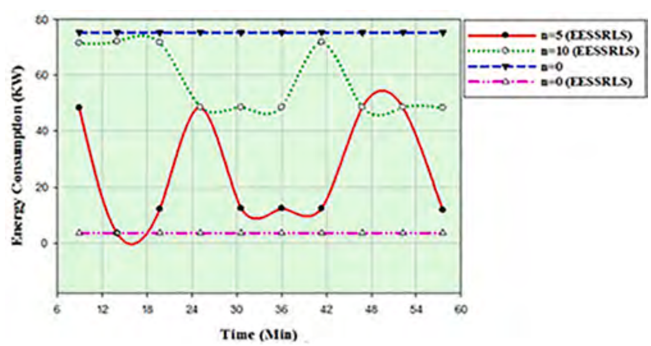

Fig. 9. Energy consumption at highway road with different traffic flow pattern.

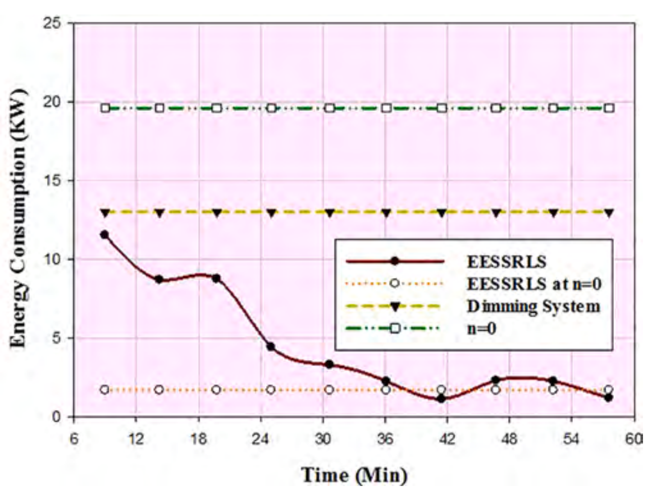

Fig. 10. Energy consumption analysis at residential pedestrian area in single hour.

dynamic battery charging algorithm based on MPPT. Experimental performance of the proposed system is carried out based on power consumption during peak and off peak hours. Based on the simulation result it was observed that proposed smart LED lighting system saves more energy using effective decision making module and PWM based dimming system then traditional metal halide lighting system. Through experimentation we also present the performance of the battery storage charging system and PV solar panel. In future this work can further

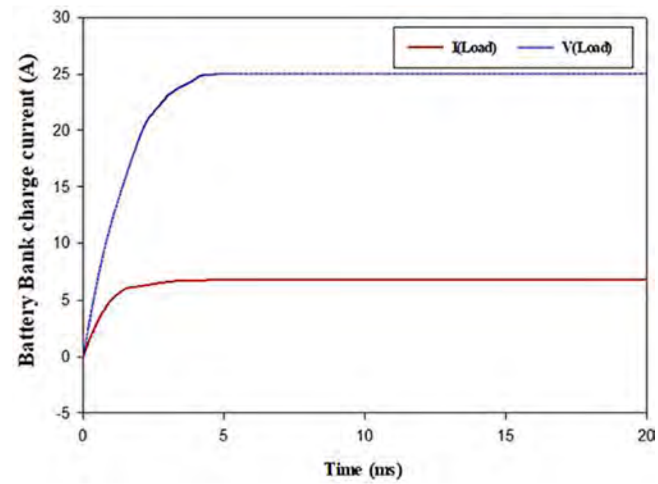

Fig. 11a. Battery bank charging current at 25 °C with 1000 Wh/m^2 PV solar radiation.

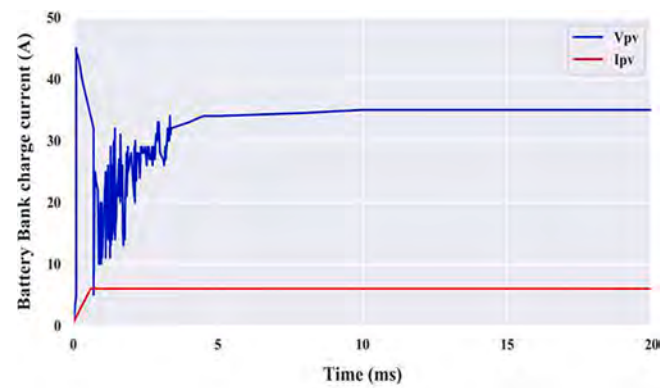

Fig. 11b. Battery bank charging current at 25 °C with 750 Wh/m^2 PV solar radiation.

extend to reliability and security performance of ZigBee network so as to ensure safe and secure function of the critical street lighting infrastructure.

Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

CRediT authorship contribution statement

Zhong Chen: Conceptualization, Methodology, Writing – review & editing. **C.B. Sivaparthipan:** Methodology, Data curation, Writing – original draft, Software. **BalaAnand Muthu:** Investigation, Methodology, Visualization, Supervision, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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