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# IoT based Energy Efficient Smart Street Lighting Technique with Air Quality Monitoring

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***Abstract*— This paper presents an Internet of Things (IoT) based solar and piezoelectric powered street lighting system focusing on energy conservation, automation, air quality monitoring and detection of faulty streetlights. It presents a hybrid and dynamic IoT based approach for smart street lighting system (SSLS) along with real time online monitoring of air quality. The free energy generation from solar panels and piezoelectric transducers makes the proposed SSLS a standalone infrastructure. It smartly maneuvers the streetlights based on the presence or absence of vehicles and sunlight via light dependent resistor (LDR) and infrared (IR) sensors. Moreover, an online detection system is used for detecting faulty streetlights with the help of voltage and current sensors. Depending upon number of vehicles passed during night, streetlights are operated at four different intensities i.e., from 20% to 50% with the step size of 10% in the absence of vehicles while operating at 100% intensity upon vehicle's arrival. This dimming operation not only enhances the life span of streetlights but also enables significant conservation of energy up to 84%. Besides, real time online air quality monitoring helps authorities to take suitable action whenever air quality index reaches an undesired level.**

***Keywords— Smart Streetlights, Air Quality Monitoring, Piezoelectricity, Solar Energy, IoT, Energy Conservation.***

## I. Introduction

Today with the advancement of technology, concept of smart cities is rife. The rapid industrialization, fast urbanization , rapid growth in population, drastic increase in traffic on roads and other anthropogenic activities have affected air quality, causing health hazards and other problems. Similarly, street lighting systems are modernizing due to fast-growing urbanization and development of cities. Normally, conventional streetlights like high-pressure sodium(HPS) lamps, once turned ON, tend to remain ON without any intensity change until any power switch turns them OFF. This results in increased power consumption, more manpower and maintenance requirement of system. In addition, people often complain about either the non-functionality of some streetlights or the unnecessary glowing of the streetlights in daytime. So to rectify these problems SSLS with light emitting diodes(LEDs) as streetlights is presented which improves overall system's reliability, reduces maintenance problems and provides real time monitoring of air quality thus enabling authorities to take suitable actions when air quality index exceeds safe limits. Besides the lifetime of the streetlights also gets enhanced because the lights do not have to stay at 100% intensity the whole night. This suggests promising results for future development in this area to help make the cities smart.

Among different works consulted, energy efficient intelligent street lighting system using traffic adaptive control is presented in [1] where LED lights are used. A smart web based LED street light system was presented, in which weather related visibility issues for vehicles were addressed to avoid traffic accidents [2]. A smart street lamp's intensity control system was proposed based on how crowded its surrounding area was, while also informing the serviceman if the lamp was stolen [3]. The smart monitoring and control of streetlights through IoT and energy generation via solar cells is presented in [4,5]. Electrical energy was generated through piezoelectric transducers from the vibrations of train wheels [6]. LDR sensors and ultrasonic sensors were used to automatically turn ON/OFF streetlights based on sunlight while intensity was varied from 100% to 60% based on the presence of vehicles or people [7]. Another smart street lighting system was proposed in [8], just to switch the streetlights ON/OFF with the help of LDR sensor while also using closed-circuit television (CCTV) camera for surveilling any suspicious activity on roads. An intelligent streetlight system was proposed where streetlights were switched ON/OFF based on the presence of vehicles but their intensities did not vary according to traffic flow [9]. To save energy, a system utilizing LED lights was proposed instead of traditional high-intensity discharge (HID) lamps for streetlights, in which automatic monitoring and control of LED lights was performed through IoT [10]. An IoT based weather adaptive approach was proposed to monitor and control the ON/OFF status of streetlights based on vehicles' frequency at different times of the night but it did not develop a dedicated energy generation system for streetlights [11]. To control light intensity based on different time intervals and presence or absence of vehicles, pulse width modulation (PWM) technique was presented [12]. A solar panels based approach focusing on idea of cloud and IoT through ZigBee network for real time streetlights monitoring and control was presented [13]. One of the IoT technologies i.e., Raspberry pi was used for real time air quality monitoring using different sensors like MQ9 etc., [14]. Using IoT technology a real time indoor monitoring of air pollutants like CO2 and PM10 was presented where an exhaust fan was also used to control air condition [15]. IoT based air pollution monitoring and forecasting was presented which involved prediction of the future trend of air quality using current trend of air quality [16]. An IoT based air quality monitoring system was discussed for smart cities where data from different air pollutants sensed through sensors like MQ2, DHT11 etc., was uploaded to ThingSpeak via Raspberry pi [17]. Similarly, using different meteorological factors which affect air pollution like daily mean temperature, air pressure, etc., an artificial neural network model was trained for air pollution forecasting [18]. A cost effective air quality monitoring system was presented using crowd sensing approach where air quality index values obtained from different sensors were uploaded to cloud using an android app [19]. IoT and Long Short Term Memory technique were integrated for air pollution monitoring and prediction [20].

The literature review reveals that, it is hard to find any study that simultaneously deals with energy generation through integration of solar panels & piezoelectric transducers for both online monitoring & controlling of streetlights and city's air quality along with detection of faulty streetlights. The main contributions of the proposed work are as follows:-

- Free energy generation via integration of solar panels & piezoelectric discs for powering up the streetlights.
- To help implement the idea of smart cities, LDR and IR sensors are deployed for smart maneuvering of streetlights at four different intensities (i.e.,50%,40%,30%,20%) in the absence of a vehicle or person while maintaining their intensity at 100% level in the vehicle's presence at night.
- Up to 84% energy conservation through efficient monitoring and controlling of LED streetlights with the help of sensors, node micro-controller unit (MCU) & ThingSpeak server.
- Deploying air quality sensors at every 6th streetlight to help authorities keep a tab on city's air quality.
- Its off-grid nature makes it incur minimal operation and maintenance costs & having no moving parts, it requires less maintenance.
- It performs online detection of faulty streetlights.

The rest of the paper is structured as follows. Section II describes the proposed SSLS. Electricity generation through piezoelectric transducers is explained in section III. Section IV discusses the system architecture and design. Results and discussions are presented in section V. Finally, the conclusive remarks are given in section VI.

## II. SMART STREET LIGHTING SYSTEM

The proposed SSLS not only addresses the energy wastage problems associated with traditional lamps i.e., HPS etc., but it also overcomes the problems associated with modern lighting system operating at just two or three intensity levels. It does so by not only generating free energy from solar panels, speed breakers and footpaths via piezoelectric transducers but also by maneuvering the streetlights smartly at five different intensities (100%,50%,40%,30%,20%) using PWM technique based on the presence and absence of sunlight, vehicles and pedestrians. For online monitoring ThingSpeak server is used, which provides API for the IoT in order to visualize, aggregate and analyze live data streams in the cloud [21]. Firstly, solar panels are installed on each streetlight pole and piezoelectric plates are installed beneath the speed breakers and on footpaths to generate energy using kinetic energy of vehicles and pedestrians. Then, the energy is stored in a set of rechargeable batteries. To prevent batteries from overcharging an additional circuitry of Maximum Power Point Tracker (MPPT) is designed that automatically cuts the supply, once the batteries are fully charged. The stored energy from the rechargeable batteries is used to turn the lights ON and OFF. Streetlights are controlled through LDR, IR sensors and Node MCU in such a way that after sunset, streetlights start glowing at 50% intensity which is set through Pulse Width Modulation in Node MCU ESP8266. Here for better range and accuracy PIR sensor instead of IR sensor can also be used. As the vehicle is detected by IR sensor, streetlights in the vicinity of IR sensor, start glowing at 100% intensity. The intensity level depends upon the number of vehicles passed during that night. Subsequently, in the absence of vehicles, when the set limit of vehicles' traffic at night is crossed, intensity of streetlights is reduced from 50% to 20% in steps of 10% as evident from the flowchart shown in Fig. 1.

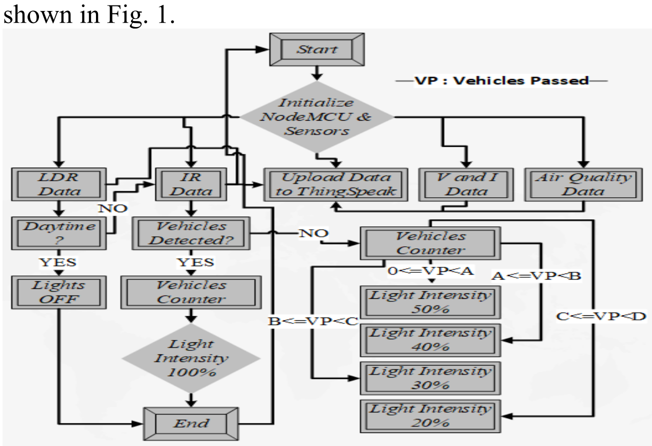


Fig. 1. Flowchart of smart street-lighting system with air quality monitoring

## III. ELECTRICITY GENERATION

Under sunny conditions, this SSLS relies on energy generated through solar panels and piezoelectric discs. As will be shown in the cost analysis section that the solar panels selected will result in surplus energy generation. So, to avoid wastage of this energy net metering can be used to export the excess kWh to the utility grid which could in turn provide electricity to streetlights during rainy conditions for reliable operation of streetlights. Following renewable energy sources are considered in this paper for powering streetlights.

### A. Piezoelectric Transducers

The generation of electricity from piezoelectric discs involves application of force along certain orientation. To avoid too much decrease in voltage & current from piezoelectric materials, a Buck-Boost converter is required.

#### 1) Mathematical Model

Assuming piezo material as an ideal capacitor, all governing equations of capacitors can be applied to it for calculation of equivalent capacitance & voltage across these transducers:

$$Q = C \times V \quad (1)$$

$$V_{eq} / Q = V_1 / Q_1 + V_2 / Q_2 + V_3 / Q_3 \quad (2)$$

$$V_{eq} = V_1 + V_2 + V_3 \quad (3)$$

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Energy consumed by streetlights at different intensities as given in Table 1, is calculated by equation (4) as follows,

$$P_C = n_s \times P_s \times t \times Intensity \quad (4)$$

where, Pc gives energy consumed by streetlights, ns represents no. of streetlights, Ps is power rating of a streetlight and t is the time period a streetlight has to remain ON at a specific intensity. Traffic flow is measured in vehicles per hour using the following Equation (5):

$$q = n_t \,/\, t \quad (5)$$

where, q and $n_t$ represent traffic flow and total vehicles passing a streetlight respectively while t indicates time period in hours.

*2) Circuit Model*

To enhance both voltage & current without affecting either one too much, a series-parallel combination of piezoelectric transducers is considered in this paper as shown in Fig. 2. For a 12V battery bank (3 batteries in series) charging, synchronous buck converter steps down the voltage to 4V.

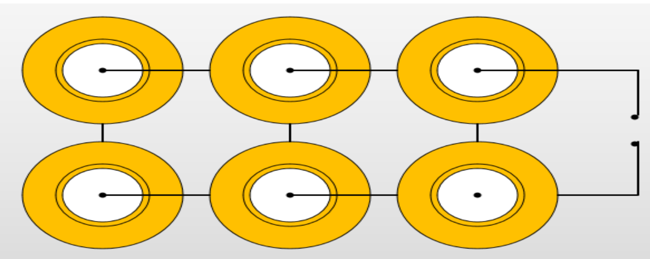

Fig. 2. Series-parallel connection diagram of piezoelectric transducers

### B. Solar Panels

In this paper a 50W solar panel per streetlight is used for generating electricity when there is sunlight present.

*1) Mathematical Model*

The mathematical equation used for computing energy generated through solar panels is given by Equation (6):

$$Epv = P_{rated} \times h_{fs} \times DF \quad (6)$$

where, $Epv$ is solar output energy, $P_{rated}$ is solar panel's rated power, DF is derating factor that incorporates all system losses & has value of 75% while $h_{fs}$ represents full-sun hours.

*2) Circuit Model*

Circuit of a 50W solar panel used to feed LED streetlight via charge controller and battery is shown in Fig. 3.

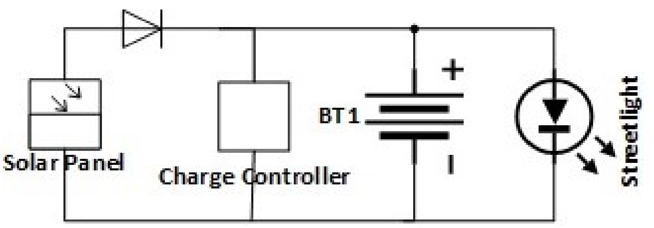


Fig. 3. Circuit Diagram of Solar Panel feeding Street lighting load

## IV. System Architecture & Design

The proposed SSLS that uses solar panels and piezoelectric transducers for generation of electricity for powering the streetlights and online air quality monitoring can be deployed in a city. A Wi-Fi Module (Node MCU ESP8266) which collects data from LDR and IR sensors and sends it to ThingSpeak server which is an open source IoT platform with MATLAB (MATrix LABoratory) analytics, is shown in Fig. 4 along with its supply. As vehicles or pedestrians pass over piezoelectric transducers, energy is produced and stored in batteries for glowing streetlights at night. A 12V battery bank is used to store the electricity generated from solar panels and series-parallel combination of piezoelectric transducers. Battery bank consists of three cells connected in series with each cell having 4V potential. With piezoelectric transducers a buck converter is used to charge the battery faster which steps up the current while stepping down the voltage as shown in Fig. 5. To further shield the batteries from overcharging MPPT is used. MPPT circuitry, which is shown in Fig. 6, prevents the rechargeable batteries from overcharging by automatically cutting off the supply once the batteries are fully charged. This system architecture consists of the following features: -

### A. Smart Streetlights Maneuvering

LED streetlights are smartly maneuvered using LDR and IR sensors. LDR senses the presence or absence of sunlight and based on this data, streetlights are automatically turned ON and OFF. Similarly, during night hours, IR sensors come into play. Initially at night, intensity of streetlights is set at 50%, when an IR sensor detects the presence of a vehicle or a person, the corresponding streetlight starts glowing at 100% intensity and when the same vehicle or person leaves the vicinity of that IR sensor, it goes back to previously set intensity. As 3 limits are set, so streetlights continue to glow at 100% intensity in object's presence but in its absence, intensities of streetlights change from 50% to 20% with 10% decrement through PWM technique when the set limits are crossed.

### B. Air Quality Monitoring

For monitoring air quality, MQ135 sensor is used at every 6th street lamp. MQ135 sensor is chosen for its wide range for detection of gases like NH3, NOx, CO2, etc., and fast response. Real time city's air quality is monitored online via ThingSpeak server that helps authorities to take suitable measures like rerouting traffic etc., especially in highly polluted area whenever the air quality deteriorates. ThingSpeak based IoT graph of real time air quality index is shown in Fig. 7.

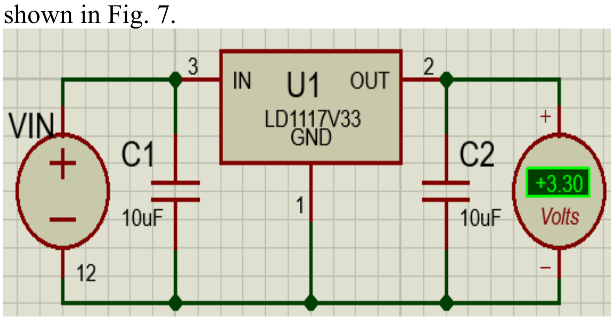


Fig. 4. Node MCU and its 3.3V supply

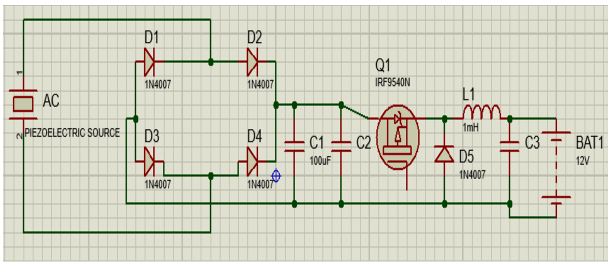


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Fig. 5. Battery Power supply with Buck Converter

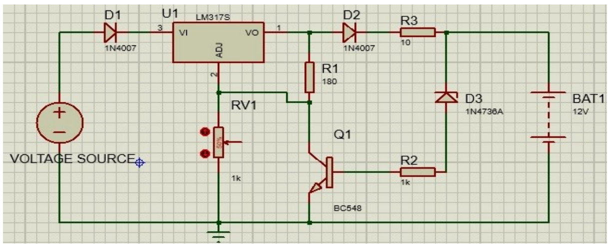


Fig. 6. MPPT for solar panel acting as charge controller


Fig. 7. Air Quality Monitoring

## C. Streetlights Fault Monitoring

Faulty streetlights are detected using voltage and current sensors data as shown in Fig. 8, 9. Normal values from current and voltage sensors means streetlights are working properly. However, abnormal states of streetlights as interpreted from different readings of voltage and current sensors are given as follows:-

1. Broken: Streetlight is considered broken if its associated current is zero but voltage is not zero.
2. Offline Mode/Power Failure: Streetlight experiences power failure or it is offline, if both its voltage and current are zero.

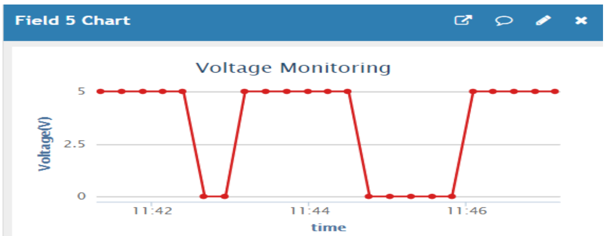


Fig. 8. Voltage Monitoring

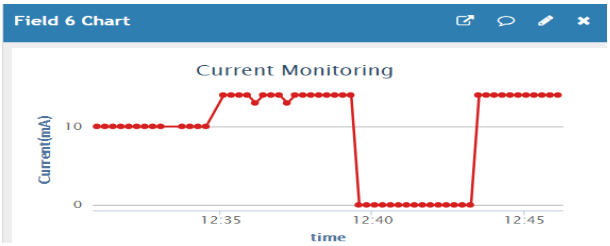


Fig. 9. Current Monitoring

## V. Results & Discussions

Three IoT graphs obtained from ThingSpeak with the help of sensors deployed at each streetlight are shown below, where Fig. 10 illustrates detection of the presence of sunlight while Fig. 11 & Fig. 12 demonstrate the arrival or departure of vehicles and their count, respectively. Under sunny weather solar panels will mainly contribute to energy generation with piezoelectric discs also contributing their portion. To rectify the problem of low current from piezoelectric transducers, a series-parallel connection is presented in this work for reasonable voltage and current. The complete setup of proposed system is shown Fig. 13, 14 and 15.

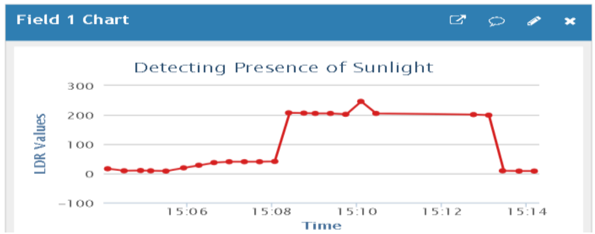


Fig. 10. LDR Sensor detecting presence of sunlight

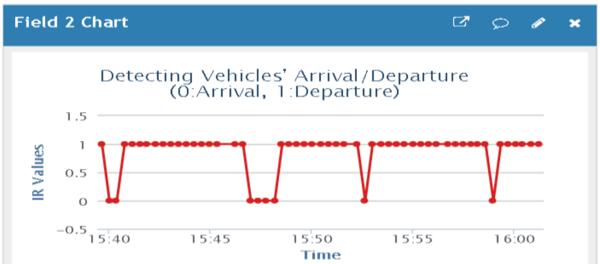


Fig. 11. IR Sensor detecting arrival/departure of vehicles

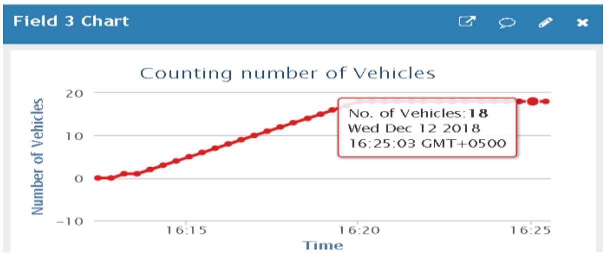


Fig. 12. Serial Counter: counting number of vehicles passed at night

Both LDR and IR sensors are special pieces of this framework, as they help LED streetlights operate at different intensities resulting in reduced power consumption. Based on behavioral uncertainty and different contingencies, the flow of traffic does not remain same especially at late nighttime and early morning hours and thus leads to wastage of energy due to unnecessary glowing of streetlights. In addition, with energy sources depleting at a rapid rate it is need of the hour to use renewable energy sources for free electricity generation. Therefore, to address aforementioned problems, SSLS is proposed which generates electricity from solar panels and piezoelectric sensors to automatically control the intensity of streetlights depending upon the no. of vehicles passed at night as evident from Fig. 13, 14 and 15. Similarly, keeping in mind how devastating the deteriorated air quality is for human beings, an air quality sensor i.e., MQ135 is deployed at every $6^{th}$ streetlight which provides real time monitoring of air quality via an IoT platform like ThingSpeak as shown previously, with which authorities can take suitable measures whenever the air quality deteriorates or exceeds the safe limits.

Fig. 13. Status of LED streetlights when OFF during daytime

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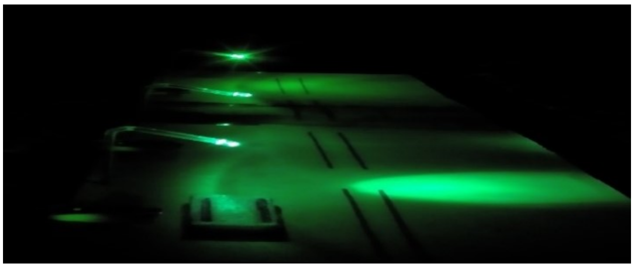

Fig. 14. Status of LED streetlights at 100% intensity

Fig. 15. Status of LED streetlights at 20% intensity

Two case studies were conducted in Wah Cantt area where approximately 520 LED streetlights rated at 20W are deployed. Here it is assumed that a vehicle goes past a streetlight in approximately 3 seconds so using this assumption, time for which streetlights operate at 100% intensity and other intensities in accordance with set limits can be calculated. Similarly, power consumption by streetlights is calculated during a specific time period keeping in mind the traffic flow rate and streetlights' intensity during that period as shown previously in Equation (4). Average traffic flow for both case studies is shown in Fig. 16.

*1) Case Study 1*

Here average traffic flow is considered for summer months from April to September. As in summer, nighttime is shorter which means streetlights will have to operate for few hours. Table 1 shows the intensity level and the power consumed (Ec) by 520 LED streetlights at various time intervals in summer months when the streetlights are ON during night. Here 1st limit for number of vehicles passing a streetlight is set at 1200, 2nd at 1420 and 3rd at 1620.

*2) Case Study 2*

Here average traffic flow is considered for winter months from October to March. Longer nights in winter months mean streetlights will have to operate for more hours. Table 1 shows the intensity level and the power consumed (Ec) by 520 LED streetlights at various time intervals during winter when the streetlights are ON during night. Here 1st limit for number of vehicles passing a streetlight is set at 700, 2nd at 1000 and 3rd at 1200.

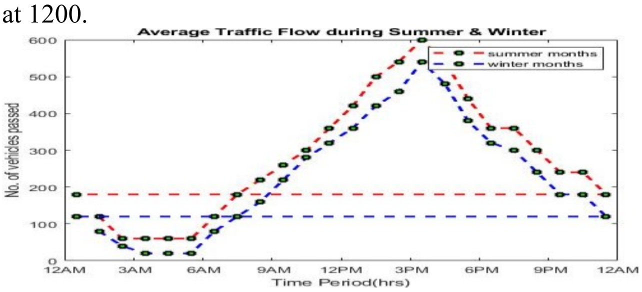


Fig. 16. Average Traffic flow in Summer & Winter months

Besides, power generated by 50W solar panels is shown in Table 2.

TABLE 1. Power Consumed at different intensity levels

| Winter /Summer | Ec at 100% | Ec at 50% | Ec at 40% | Ec at 30% | Ec at 20% |
|---|---|---|---|---|---|
| 5:30-6:50 | 6.67Wh | 13.33 Wh | 0.933 Wh | | |
| 6:50-8:30 | 7.33 Wh | 2.5 Wh | | | |
| | 9.0 Wh | 12.167 Wh | 4.67 Wh | | |
| 8:30-10:30 | 6.0 Wh | | 4.27 Wh | 7.0 Wh | |
| | 8 Wh | 15.167Wh | 0.67 Wh | | |
| 10:30-1:30 | 5.33 Wh | | | | 15.67 Wh |
| | 8 Wh | | 16 Wh | 3.6 Wh | |
| 1:30-5:30 | 1.67 Wh | | | | 15.67 Wh |
| | 4 Wh | | | 11.4 Wh | 7.6 Wh |
| 5:30-6:30 | 1.33Wh | | | | 3.73Wh |
| Total Ec in summer months is 100.274Wh/Streetlight | | | | | |
| Total Ec in winter months is 91.403Wh/Streetlight | | | | | |

TABLE 2. Power produced by 50W solar panels

| Months | Average full sun hours | Daily Power produced by Single 50W Solar Panel |
|---|---|---|
| Jan | 4.03 | 50*6.85*0.75=256.875 Wh |
| Feb | 4.63 | 50*7.11*0.75=266.625 Wh |
| Mar | 5.85 | 50*8.79*0.75=329.629 Wh |
| Apr | 6.40 | 50*9.36*0.75=351 Wh |
| May | 7.14 | 50*9.48*0.75=355.5 Wh |
| Jun | 6.86 | 50*9.09*0.75=340.875 Wh |
| Jul | 6.34 | 50*8.62*0.75=323.25 Wh |
| Aug | 6.08 | 50*8.29*.75=310.875 Wh |
| Sep | 6.30 | 50*9.28*0.75=348 Wh |
| Oct | 5.77 | 50*9.08*0.75=340.5 Wh |
| Nov | 4.83 | 50*7.82*0.75=293.25 Wh |
| Dec | 4.18 | 50*7.32*0.75=274.5 Wh |
| Pavg in Summer=244.5Wh & Pavg in Winter 183.0625Wh/solar panel | | |

*3) Cost Analysis*

Increase in traffic flow at night means more often streetlights will have to operate at 100% intensity, which increases power consumption, so limits are set on traffic flow to vary intensity from 50% to 20% in a bid to reduce energy consumption. For summer months, when the first limit set at 1200 vehicles, 2nd limit at 1420 vehicles and 3rd limit at 1620 vehicles is crossed, intensity of streetlights changes from 50% to 40%, 30% and 20% respectively in the absence of vehicles. For Winter months, when the first limit set at 700 vehicles, 2nd limit at 1000 vehicles and 3rd limit at 1200 vehicles is crossed, intensity of streetlights changes from 50% to 40%, 30% and 20% respectively in the absence of vehicles. Now considering a 50W traditional lamp, its energy consumption during 12 hours at night=50*12=600 Wh. Now, consulting Table 1, total energy savings per streetlight during summer months=600-100.27=499.73Wh/night and % energy saving in summer months=(499.73/600)*100%=83.28%. Similarly, total energy savings per streetlight during winter months=600-91.403=508.59Wh/night, which is 84.76% energy saving. After obtaining full sun hours data for 50W pv panel from National Renewable Energy Laboratory [22], we see from Table 2, that each pv panel produces an average of 244.5 Wh in summer, which after supplying 100.27Wh to its streetlight, has a surplus power of 144.23Wh. Similarly, in winter, same pv panel produces an average of 183.0625Wh which after supplying 91.403Wh to its streetlight, has a

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surplus energy of 91.66Wh. This surplus energy from each solar panel can be collectively sent back to utility grid via net metering during sunny days. In this way, even under rainy conditions when streetlights have to draw power from the grid, the proposed SSLS could be either free of cost or could cost less as a result of net kWh credited against kWh exported to the grid. The SSLS used here is eco-friendly & reduces carbon footprints making it a green lighting solution [23]. This SSLS is promising both in terms of energy conservation and the effects it has on personal well-being of people, as the dimming of streetlights is not associated with increase in road traffic collisions, crime or public discomfort [24].

## VI. CONCLUSION

In this paper, smart street lighting framework is presented to first generate free electricity from solar panels and piezoelectric transducers, and then IoT is used for efficient and smart maneuvering and monitoring of streetlights and city's air quality respectively. This SSLS prevents unnecessary glowing of streetlights via LDR and IR sensors by smartly operating the streetlights at five different intensities (100%, 50%, 40%, 30%, 20%) based on traffic flow rate and the presence or absence of sunlight and vehicles. As air quality is an important factor for a green environment, so to help authorities keep a tab on city's air quality, sensors are deployed at every $6^{th}$ streetlight for its online monitoring. This SSLS not only conserves energy significantly up to 84% but also enhances streetlight's lifetime. Similarly, online detection of faulty lights also enables authorities to replace them timely. As solar panels do not operate in rainy conditions so the integration of piezoelectric transducers with solar panels and the use of net metering comes in handy in such a scenario.

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