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EFFECTIVE ROAD AND STREET LIGHT LOAD DEMAND CONTROL IN A SMART CITY

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Abstract:

Road and street lighting consumes maximum energy. The demand on the grid varies from time to time and becomes difficult to handle the load during peak hours. Demand side management system, intelligent load shifting, scheduling techniques can be used to handle the load smoothly. Energy curtailment and shedding techniques are used to handle the loads during high demand. Effective Street lighting control and maintenance is a major issue during high demand. In this paper, an adaptive smart street lighting based on the energy availability at the distribution substation is proposed. The major objective of this paper is to handle the road and street lighting effectively by switching lights based on the hierarchal priority of the load when the available energy is less than the required level. The proposed scheme controls the lighting based on the available energy on the grid, provides effective lighting and improves the comfort, safety and security of the smart city.

Key Words: Curtailment, Demand Side Management, Shedding, Smart City, Smart Grid & Street Lighting

1. Introduction:

The road and street lighting in the world consumes 19% of total energy consumption and contributed 75% demand of the total load [1-2]. For example, the electricity cost paid by a city with one lakh population in European Country is around 1-3M$ [3]. India has 35 million street lights with 3,400MW (18%) demand and contributes 1.6 billion tons of CO_2 per year [4]. It is essential to look after energy efficient techniques in street lighting to reduce the energy demand, energy cost and CO_2 emission. The energy efficient streetlight or Smart street lighting (SSL) [5-6] improves the lifetime, energy efficiency, color rendering, quality of life, comfort and security. SSL reduces cost, CO_2 emission, and glare which improves visibility. It provides proper light distribution, cut off and automatic shut off. Most of the city street lights are replaced mercury lamps with energy efficient lamps which support advanced technology and has provision of advanced intensity control. Smart Street Lighting (SSL) in smart cities should have

- ✓ City wide wireless network with streetlight control using sensors
- ✓ Dedicated street lighting during the day time to power video surveillance cameras, WiFi spots, 4G or 5G base stations, environmental sensors and other electrical devices [3].

The energy demand on the smart grid is growing day by day due to automation, home, office, industry, road and street lights and other appliances. The energy demand during peak hours is more compare with the energy available in the grid. The demand side management uses various techniques like scheduling, shifting, valley filling, energy conservation, load curtailment, shedding to handle the peak demand based on the available energy at the grid [7-12]. The main objective of this work is to provide efficient lighting when demand is high by integrating street lighting control and substation control of the grid. The rest of the paper is organized as follows. Section 2 describes the street light luminaries and their advanced features; Section 3 defines proposed technique, and simulation results are discussed in Section 4. Conclusions are drawn in Section 5.

2. Street Light Luminaries and Advanced Features:

Various luminaries, latest advances in street light, effective energy efficient, intelligent street lighting systems for smart cities are highlighted in this section. The various luminaries are available in the market and are compared in Table 1. Solid State Lighting *i.e.*, LED, organic light-emitting diodes (OLED), or polymer light-emitting diodes (PLED) etc., are energy efficient, contributes less CO_2 and has longer life over fluorescent, incandescent or HID (High Intensity Discharge) lamps. The LED has less total annual cost among all. The advantages of LED are [13-16]: high efficiency, long life, low maintenance cost, shorter switching time, intensity control or dimmable from 100-0%, solar panel compatibility, supports luminance control using motion detection, better color rendering index >70, high power factor>0.9, operating temperature -5°C to 50°C, operates with DC, no warm-up required, average rated life span of 50000 hrs, no ultraviolet light (not attract insects), free from toxic chemicals, humidity 10 – 100%, operated at a forward current less than 90% of its rated current, flexibility in controlling light levels and has no glare effect which reduce visual fatigue for both drivers and pedestrians. Few drawbacks are: (i) LED use luminary with a minimum angle of 120 degree limits directional light hanging or facing downward and mostly useful for street lights, (ii). Requires heat sink, and (iii) high initial establishment cost lead to long (several years) paybacks.

Table 1: Comparison of Luminaries

Luminary Category	luminous efficacy lm/W	Rendering Properties	Lifetime (hours)	Comments	Total Annual Cost* (in Rs.) (Energy bill & Operating Charges)
High Pressure Mercury Vapor (MV)	36-65	Normal	10000-15000	Less life	849,545/-
Metal Halide (MH)	70-130	Excellent	8000-12000	High luminous efficiency, less life	542,657
High Pressure	50-150	Normal	15000-24000	Energy efficiency,	355,906

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Sodium Vapor (HPSV)				low yield of color	
Low Pressure Sodium Vapor	100-190	Very poor	18000-24000		514,037
Low pressure Mercury Fluorescent Tubular Lamp (T12&T8)	30-90	good	5000-10000	Bad lifetime, available in low powers	586,670
Energy efficient Fluorescent Tabular lamp (T5)	100-120	Very good	15000-20000	Energy efficient, long lifetime, available in low powers	579,620
LED (Light Emitting Diode)	70-160	Good	40000-90000	Intensity control, Very high Energy efficiency, low maintenance, long lifetime.	372,300

*Source: Industry data provided by ELCOMA of India. Assuming 7.5 m. wide, dual carriageway type, 1 km. long road

Various street light control techniques using Zigbee, sunlight detection based, sensors, using traffic density, adaptive control was discussed in [17-37]. LED arrays integrated with solar panels [38] are cost effective for airports, parking lots, residual streets, *etc*. LED array intensity can be controlled with PWM by controlling duty cycle, which saves energy and sensor less street lighting control is given in [39]. In the world, at first, Estonia street of 1.3 km long was replaced with LED smart lighting control which saves 65-85% energy and reduces maintenance cost to half [40]. In Budapest (Capital of Hungary), all lights are replaced with LED's of low installation cost and the reduced energy cost payback investment in a year [39]. Recently, Indian Prime Minister announced the replacement of street lights with LEDs of 1,400 MW demand and save 9000 million kWh of electricity annually, worth over $850 million which in the process. Four central government power utilities joined hands to set up a company Energy Efficiency Services Limited (EESL) to save energy and modernize street lighting facilities of the Indian Municipality [42]. If all domestic and commercial sectors use LED bulbs, we can save 100 billion kWh per annum ($7 billion cost per year) [42]. In India, EESL started replacing street lights with LEDs, Example: Nashik Municipal Corporation [14]. Model specification network outdoor lighting control systems, LED Roadway Luminaries, BBA and BBA LED Site (Parking Lot) Lighting are given in [43]. Open standards (example: ISO 14908) put lighting owners in control of their own destinies [42].
Based on the controlling and advanced features, the available luminaries in the market can be classified into 5 types. They are:

- ✓ Non controllable or non-dimmable LEDs: saves 35% energy compared to HPSV lamps.
- ✓ Autonomous Dimmable: An electronic ballast/driver HPSV or LED lamp, not costly over type-1, saves 25% energy and has 20% improved lifetime.
- ✓ Streetlight networks with cabinet control: remote control dedicated network master control helps the lamp to identify faulty one, save 30% energy, on/off scheduling, unit cost $40 to $80.
- ✓ Proprietary individual light point control: Above 50 companies developed their own protocol for individual light point control and monitoring in real time via segment controller with secured network software for maintenance. On-off scheduling; fault detection via mobile or net, unit cost $70 to $180, saves 30-40% energy, 20% lifetime more and requires huge investment cost.
- ✓ Open individual light point with cabinet control: Compatible with open central management. It uses a standard communication protocol for real time remote monitoring with interoperability facility over complete network and system related operators. It has $70 to $120 unit cost, on-off scheduling, automatic failure detection, step less dimming, saves 45% energy, and 20% lifetime improvement. ISO14908 standards are used at present.

From the above, type 5 is preferable for smart street lighting, which supports various integrated technologies and has future expansion scope. Based on the light distribution, luminaries are classified [38] into:

- ✓ Cutoff type: light intensity reduced between 80^{o} and horizontal plane.
- ✓ Semi-cutoff type: intensity reduction between 80^{0}-90^{o}.
- ✓ Non-cutoff: without limitation.

Table 2: Performance of different types of Luminaries with advanced control features

	LED	**Adaptive LED**	**LED + Network Control**	**Adaptive LED + Network Control**	**Post-Top: Adaptive Led + Network Controls**
Street lighting	Good	Better(100-20% intensity control)	Better	Best	Best
Energy saving	72%	88%	80%	91%	93%
Area& post-top lighting	Non-compliant	Good	Better	Best	Best

Project Cost	$370	$420	$595	$645	$525

Some of the works related to advance street lighting are discussed below.

Energy efficient, intelligent LED lighting control using Ethernet for a household was proposed in [44]. Street lighting using intensity controllable (dimmable) LED arrays with drives can save energy up to 70% and provide high performance. Programmable three tier architecture based wired or wireless street lights controlling system with segment control using scheduling capability was proposed in [42]. In this model energy saving up to 20% can be achieved by dimming with additional 5% by dynamic dimming called follow-me [42]. Street light dimming to 20% using motion sensor reduces the energy consumption and CO_2 emission by 80% [45].

Intelligent light dimming [33] saves energy and helps power reduction. Intelligent drivers with scheduling controls the light dimming gradually in steps based on time, the density of traffic and nonpeak traffic hours. It saves 50% energy at off-peak times. Dimming the light intensity up to 30% of sodium vapor lamp and HID, 50% for metal halide are permitted for good lifetime. Alternate lights switch off leads to safety issues, and dimming is best over it. In crowded areas, dimming leads to public safety issues, so careful dimming control and scheduling is required.

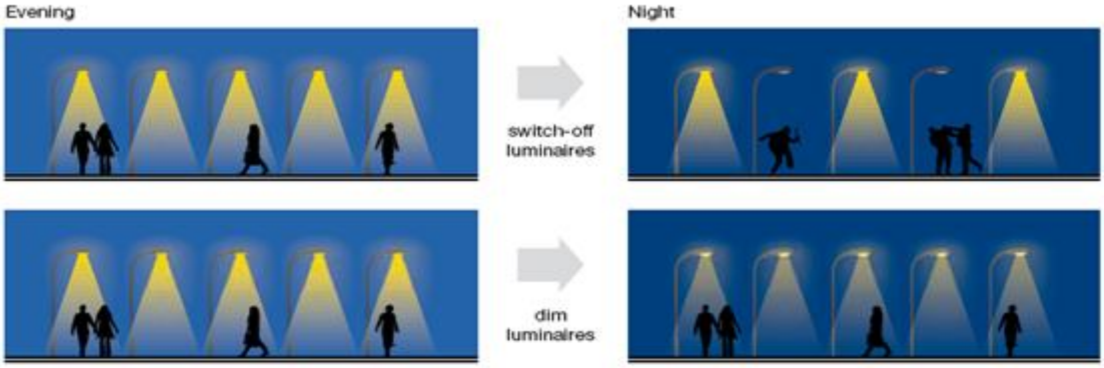

Figure 1: Street light dimming

An adaptive street light intensity control using motion sensors by motion detection of vehicles and pedestrians was investigated in [46]. Hierarchical SSL lighting control with motion detection sensors using Ethernet was proposed in [16]. Illumination sensors based data acquisition with lighting control using real time pricing were proposed in [47]. An Intelligent Streetlight Control and Management System (LCMS**)** with IP based networking control for the entire street lights which helps in achieving higher efficiency [4], [13]. Advance techniques like Stationary and Mobile Energy Storage Systems, photovoltaic PV modules and Spatial Load Forecasting will provide flexibility and lead to the betterment of street light service [48]. Light Grid solutions provide accurate, energy efficient real time street light's control using wireless communication with web based central management system [49]. It runs rescheduled program in case of network failure. It offers customized scheduling, grouping, user level access management and reporting. Evolve LED Street Light with controllable dimming provides greater energy efficiency [49]. T-Light LCU Light Control Unit with DCU which provides control over the internet via central management software [24] which reduces energy to 70%, cost by 30%.

Latest technologies offering a light pointer controller in each luminary with a motion sensor on the pole and a wireless segment control, communication network with open central management software for maintaining city wide street lights most efficiently [3]. The latest development for SSL and Smart Grid Development was highlighted in [50]. The BIS- 1981 standards defined road and street lighting standards [38]. 24 hour fault and anti-theft identification system with remote on/off and dimming and status report was explained in [29]. Adaptive LED streetlights of turning fixture to 30-50% power in low mode with motion sensors and a wireless network using central network control was given in [51]. Individual, group of fixtures or entire network control was possible with this technique. Intelligent lighting provides light on demand using the lighting point control with daylight sensors; motion, speed and direction sensors enhance the safety [52-53]. Intelligent street lighting in [53] takes the traffic intensity, weather conditions (e.g. fog, rain) and current road construction. An individual lighting program can be installed on the controllers for any kind of traffic situation and for each lighting group. If communication between the controller and the light is interrupted, an emergency program automatically activates the lighting level for heavy traffic [53]. They offer reduced energy consumption, light pollution by zero emission street lights providing electricity from renewable sources.

3. Proposed System Model:

In this paper, an adaptive smart street lighting based on the energy availability at the distribution substation is proposed. The load connected to the smart grid is classified into four types [54].(I) Class A : Critical and emergency service loads like hospitals, defense and communication; (ii) Class B: education, industry, commercial loads; (iii)Class C: Domestic loads, garden lighting; and (iv) Class D: Street lights, entertainment loads, Hoardings. The loads connected to the substation to the grid are given in Fig. 2. The smart grid has communication and control center [11] at each substation and grid which controls the energy distribution. Based on the demand and energy availability at the grid, the energy is distributed to Class A (mandatory), Class B, Class C and Class D from category 1, 2 to 3 by micro step wise. The demand on the grid is given by

$$Demand = \begin{cases} High, if\ E_R > E_G \\ Low,\ if\ E_R < E_G \end{cases} \quad (1)$$

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Where E_R= Energy request from total load,

E_G= Energy available at Grid.

During each time slot t_i of a day, the demand is calculated. When the demand is low, the requested energy is supplied to the load. If the demand is high, the energy is allocated and distributed micro step vice [54] based on the priority of the load from Class A to Class D, category wise. Remaining loads will be shed down.

As per the discussion in section 1 and 2, street lighting contributes high load request at grid from 17.30 pm to 6.30 am (evening and night). Shedding street lights in important places due to high demand (non availability of energy) lead to unsafe and unsecure life. So a sub prioritization control of the streetlight (Class D, Category 1) is required.

The roads are classified into different types as per International Commission on Illumination (CIE) [5] and are given in Table 3. CIE 115-1995 Street lighting Standard highlights light visibility for vehicle and pedestrian's safety, and security among residential communities. Depending on this classification, based on the city traffic density, city road structures, and city map the roads are grouped into different subgroups.

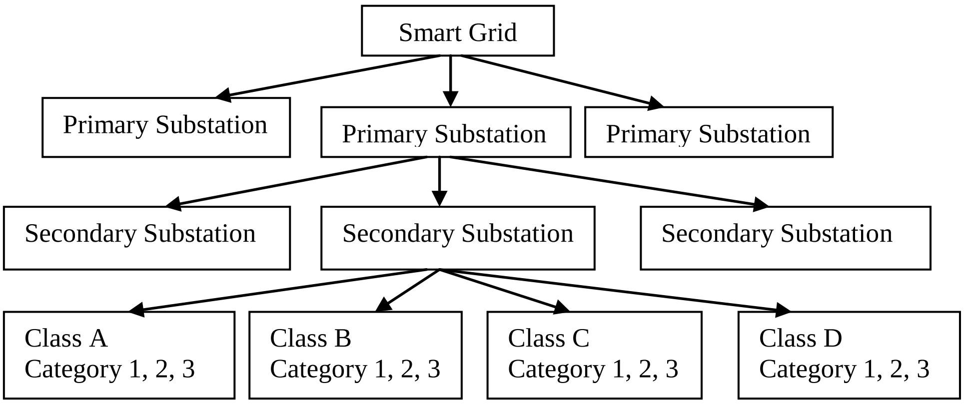

Figure 2: Energy distribution from smart grid

Table 3: Classification of Roads for Street Lighting

Type	Road Description	Average level of Illumination on Road Surface in Lux	Ratio of Min./ Average Illumination	Type of Luminaries Preferred
A1	High density traffic roads with public safety	30	0.4	cutoff
A2	Important roads with city and arterial roads	15	0.4	cutoff
B1(secondary)	Local busy roads (secondary)	8	0.3	Cutoff or semi cutoff
B2	Low density traffic secondary roads	4	0.3	Cutoff or semi cutoff
C- residual, D-bridges & flyovers, E- towns a& city centers, F- roads near air port, railway, sea shores etc.				

Viewing the needs of the smart cities and its integration with smart grid for energy distribution, adaptive smart street lighting concept is highlighted to increase the safety and comfort life of the people. The street lighting in smart city uses Type-5, open individual light point with the cabinet control system, where lights connected to sensors for day and night time identification, motion detection and dimming control. A wireless network is deployed around the city. The central control system of street lighting control system is integrated with energy distribution substation of the grid. The class D loads of Category 1, 2, 3 are subdivided into different subgroups as primary group-1 & 2, secondary group-1 & 2 and other groups. Here each group is selected according to the population density, road junction priority like main junctions, railway, bus stand, commercial places; primary essential streets with high population are grouped as 1& 2. Next other important roads and streets are grouped as secondary and so on. Here under each group, critical loads in crucial places are further identified and given higher hierarchy. For example, at the railway station, few streetlights in key points up to auto/bus stand, vehicle parking, at junction is given higher hierarchy than the remaining. Each subgroup is classified into different hierarchy levels.

Based on the demand and load at the grid, the energy supplied varies. Based on the supply and time (evening, night, midnight, early morning hours), the street lights are ON/OFF and dimming levels are controlled based on the traffic density, time, peak or non peak hours when the required energy is available. In addition to that, if the supply falls below certain levels, based on the energy availability, the proposed method turns on essential streetlight points of higher hierarchy, such that partial street light is provided across the city first at crucial points, then to next hierarchy and so ON. The architecture of street lighting with local, zonal, central level integrated with grid is shown in Fig. 3. The communication and control centers of street lighting and energy distribution system are integrated and the available energy for distribution, load request is updated each time for effective controlling of the street lights.

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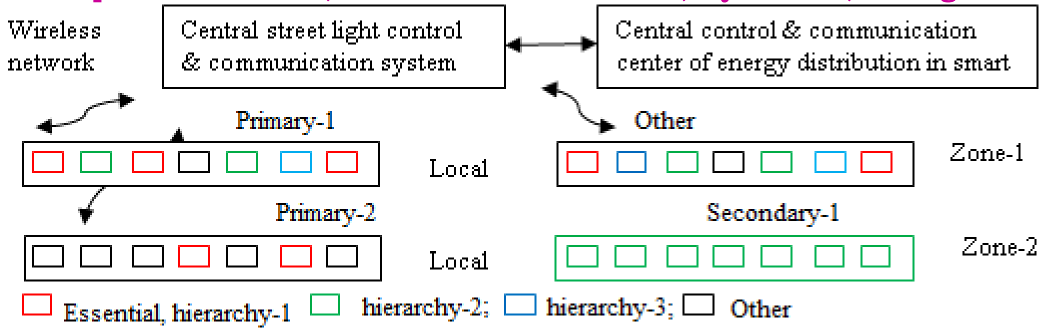

Figure 3: Integration of Smart Street Lighting with substation of the Grid

4. Simulation Results:

The adaptive smart street lighting control based on the energy availability at the distribution substation is described in Table 4. The central street light control & the communication system coordinates with central control & communication center of energy distribution, and based on the availability of the energy the street lighting is adaptively step down in micro step vice. This technique maintains very fair, effective street lighting and provides light in essential and prime areas. It is very much effective compared to shedding and this intelligent controlling improves the comfort and safety of the citizens in the smart cities.

Table 4: Adaptive smart street lighting control based on the energy availability at the distribution substation

Street light Load	Overall Demand at grid	Availability of energy at energy distribution center	Over all control description
Normal/ high	low	≥ 100%	Normal operation with dimming
High	High	≥ 90%	Primary, secondary loads, other essential hierarchy 1, 2, 3 loads with dimming
High	High	≥ 80%	Primary, secondary-1 loads with dimming; secondary-2 & other essential hierarchy 1, 2, 3 loads with dimming
High	High	≥ 70%	Primary loads with dimming; Secondary & other essential hierarchy 1, 2 loads with dimming
High	High	≥ 60%	Primary-1 loads with dimming; Primary-2, secondary & other essential hierarchy 1, 2 loads with dimming
High	High	≥ 50%	Primary-1 loads with dimming; Primary-2, secondary & other essential hierarchy-1 loads with dimming
High	High	≥ 40%	Primary, secondary & other essential hierarchy-1,2 loads with dimming
High	High	≥ 30%	Primary, secondary & other essential hierarchy-1 loads with dimming
High	High	≥ 25%	Primary, secondary hierarchy-1 loads with dimming
High	High	≥ 20%	Primary hierarchy-1 loads with dimming

5. Conclusions:

In this work, adaptive smart street lighting control based on the energy availability at the distribution substation is proposed. In the proposed method, the central street light control & the communication system coordinate with central control & the communication center of energy distribution. The advanced street lighting system contains open individual light points with cabinet control. Dimming is controlled by motion detection and daylight detection sensors. Individual light and its dimming are controlled by a central street light control & the communication system via wireless communication. Based on the availability of the energy, the street lighting is adaptively step down micro step vice and maintains lighting. The proposed technique proves better security, comfort and improves the safety of the citizens.

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