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Smart Street Lighting & Automated fault detection using power consumption data

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Abstract: Street lighting systems are one of the key infrastructures of a city and are important for safe driving and safety of the pedestrians. Also, owing to the large number of lamps, street lighting accounts to high energy consumption and thus a significant cost to the utilities. Smart street lighting solutions enable control, monitoring and automatic fault detection, transforming these systems into intelligent and energy efficient networks, resulting in huge savings in power bills. This paper presents an overall analysis of the smart grid solutions for street lighting and models a technique to detect the fault in a lamp, out of a plurality of lamps, using the aggregate power consumption data, maximizing detection probability and minimizing the false detection rate. The proposed method is tested and analyzed using Singapore data.

Keywords: Smart Grid, Street lighting, fault detection, automation.

I. INTRODUCTION

Perfect operating conditions of the public street lighting are essential to avoid unsafe driving conditions and public areas, which may lead to fatal accidents and crimes. This turns into a huge responsibility on the power system operator and in-turn on the utility. Present day fault reporting systems are completely manual and rely on a passing by pedestrian, driver or maintenance officer, to report back the fault to the operator. Inspection of the health of street light involves regular monitoring by maintenance officer, say once in a month, which is costly and even involves a possibility of a lamp failing shortly after the performed inspection or failing only during specific operating conditions. Lamps fail due to wear or other failures in the operation and control circuits and they fail prematurely due to incorrect power supply caused by faulty mains or ballast. Thus, power quality plays an essential role in determining the operable life of these components.

Smart street lighting systems, build on a general concept of smart electricity usage rationalization, are seen to be as one of the crucial elements of the future smart grids. They are a comprehensive system consisting of sensors, control unit, communication unit and management console to ensure energy saving and maximum visual safety of drivers and pedestrians. Availability of sophisticated technology enables varied functionalities from basic monitoring (power consumption, temperature etc.), controlling individual or sets of street lamps (on or off and automatically adjusting desired illumination level depending on road conditions such as increased traffic, special events etc.) to an intelligently optimized energy efficient solution in large installations. Other features include standardized lighting protocols [1], quick fault detection and locating abnormalities by alarming. Most of these lamp driving solutions are based on a digital approach where microcontroller and advanced semiconductor devices assures all the functions needed to drive the lamp and, at the same time, manages all the suitable data for implementing a smart street lighting network.

Lighting control is achieved either by increasing the self-efficiency of electrical equipment through utilization of the lighting technologies that produce more light per power unit or by making lighting systems smart and avoiding them unnecessarily. Incandescent lamp bulbs and fluorescent lamp tubes have been in use for ages but are fast getting replaced due to lower efficiencies. The latter is still more efficient than the former, as the power mostly gets wasted in the bulb heating. Light dimmers are used to decrease the power of the light bulb by essentially chopping parts out of the ac voltage. TRIACs (or bidirectional triode thyristor) are used in conjunction with microcontrollers to control the intensity of bulb by controlling the delay of the gate triggering. Similarly, remotely controlled electronics ballast can be used for achieving energy efficient solutions with fluorescent lamp tubes. Light Emitting Diode (LED) lighting systems have been in focus owing to their low energy consumption and longer operating life. The authors in [2] present a LED lighting system for a park illumination by using Pulse Width Modulation (PWM) signal as LED drivers for the buck converters. Reference [3] proposes a device for detecting a fault of at least one lamp connected to AC power supply, by measuring variations in the total active and reactive power supplied and will be discussed further in Section III.

The organization of the paper is as follows. Section II presents an analysis of the Smart Street lighting components and techniques. Section III discusses the system layout, present power quality scenario in Singapore and the methodology used for the fault detection. Finally results are presented and conclusions are drawn in Section IV.

II. SMART STREET LIGHTING

A. Smart street lighting system design

A typical smart street lighting system is designed following a three-level model. The first level includes devices that are integrated on the lamps in a section providing the data necessary for its control and regulation. The second level includes remote concentrators located in the electrical cabinets that power each light section. The third level includes the remote control unit, managing the data and controlling the lamps. Fig.1 shows the various layers in the smart street lighting system.

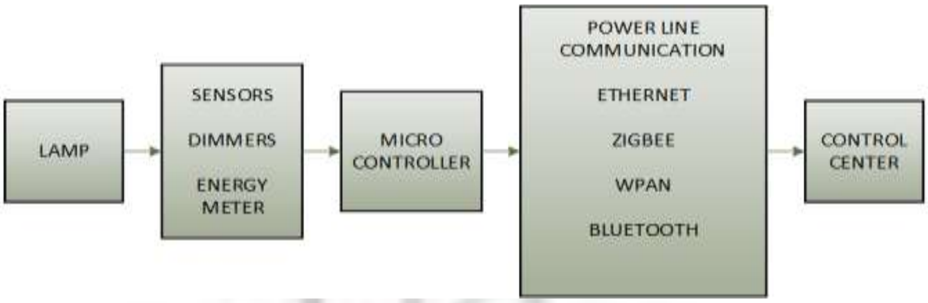

Figure 1. Block diagram of smart street lighting

a) First Level

The lowest level of the hierarchical model enables continuous transmission of data from each pole or lamp section. It includes lighting control and sensor technologies for determining the health of the lamps and controlling the intensity of brightness, medium range communication interface to transmit the lamp data and receive the controlling instructions from the control unit. To offer flexible and proper illumination of the lamps, a sensing capability must be established by using sensors like passive infrared, light dependent resistor, ultrasonic, hybrid etc., which detects ambient light intensity, motion, traffic and occupancy etc. as controlling factors for lamp light intensity.

b) Second Level

The second level of the smart street light design includes the micro controller and remote concentrator unit that control each light section. Being the intermediate level connecting the terminal units and the control center it plays a crucial role in managing data from the sensors such as traffic, temperature, light availability etc. and power consumption data from the energy meter. This acquired data is transferred to the remote control center through a two way communication network. The smart street lighting solutions include both wired and wireless communication. The wired communication includes Power line communication while the wireless including Zigbee, Bluetooth, WiFi etc.

c) Third Level

All the smart lighting systems build a centralized control system that manages the data obtained from the remote concentrators and generates the necessary instructions remotely. Though the microprocessor units control the street light without the instructions from the control unit, the crucial decisions which are not programmed in the processor are taken at the control center. Also to offer interoperability, scalability and ease in control, many smart cities adopt a generalized feature of integrating the street light management console with the existing SCADA systems.

III. FAULT DETECTION

In Singapore, Land Transport Authority (LTA) [4] maintains more than 98,000 streetlights along public roads, back lanes and service roads. It also manages the lighting for other road facilities within public roads such as: bus shelters, footpaths, bridges and pedestrian passes etc. LTA checks the street lighting conditions across the island every 2 months during the night [5] and faulty streetlights are spotted and fixed promptly during these scheduled inspections.

A. Power Quality

It should be noted that Singapore has one of the best electricity networks, maintained by SP Power Grid [6], with very few and short supply interruptions. SP Power Grid proactively focuses on power quality (PQ) to serve the needs of the high-technology manufacturing and process industries. A Power Quality section studies state-of-the-art power quality technologies, that can provide performance improvements and monitors power quality performance across the system. It can be illustrated using the system voltage dip performance index called the System Average RMS (Variation) Frequency Index (SARFI). Voltage dip is one of the prominent PQ problems in the present day distribution systems. SARFI X is the number of dips per year, a customer on the average would have experienced, with remaining voltage is less than X percent of the declared voltage. Fig.2 presents a PQ comparison of the 22kV systems, benchmarking Singapore's system with other major utilities.

22kV System Compares Well Against Systems in USA and Europe

	SARFI-70	SARFI-80	SARFI-90
Singapore	4.1	5.0	8.5
EPRI DPQ Project (USA)	17.7	27.3	49.7
UNIPEDE DISDIP Mixed Systems (Europe)	44.0	NA	103.1
UNIPEDE DISDIP Cable Systems (Europe)	11.0	NA	34.6

Notes:
EPRI DPQ: Distribution Power Quality Project carried out by Electric Power Research Institute on 24 utilities in the USA.
UNIPEDE DISDIP: Distribution Survey carried out in nine European countries by the Union of International Producers and Distributors of Electrical Energy, Europe

Figure 2. 22 kV System - Power Quality Comparision

It can be observed that the system faces minimal occurrences of voltage dips and other power quality related issues, applicable to the distribution network which includes public street lighting. The most common fault occurrence in street lighting is the open circuit fault. Though other incidents of PQ problems like flickering etc. are noticed, they are assumed to be negligible.

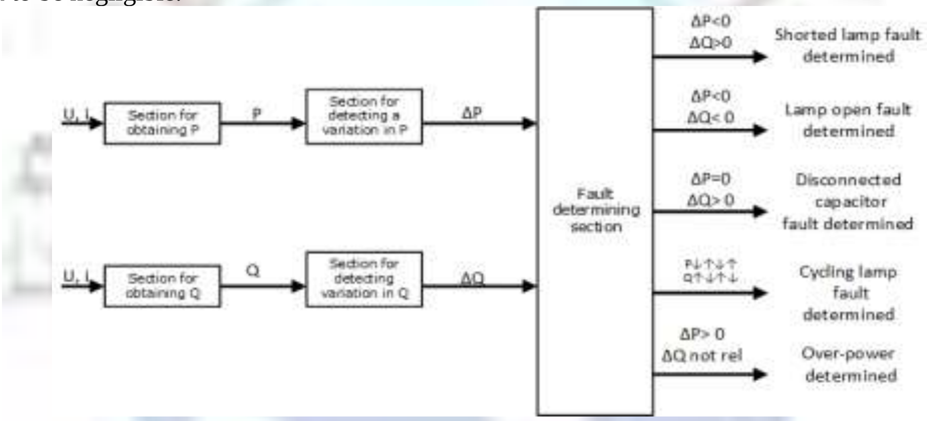

Figure 3. Fault determination from Real (P) & Reactive(Q) power measurement

B. System Layout

Reference [3] proposed a device for detecting faults of shorted lamp, lamp open, disconnected capacitor, cyclic lamp and over power types, based on the variation of real and reactive power as shown in Fig.3. The present study is a special case for open circuit faults. Since, it is uneconomical to install sensors/ meters on every single light, a series of street lights are connected to an energy meter and the aggregate power consumption data is analyzed for determining faults. Fig.4 shows the system layout. When an open circuit fault occurs, there is a reduction in the total power consumption. The street lamps in Singapore are switched on between 7 PM to 7 AM every day. The energy meter logs the aggregate power consumption at an interval of 1 minute. Fig.5 shows the aggregate power consumption data over a week. It can be observed that the values vary in specific range even during the normal operating conditions and the aggregate power consumption falls to zero when the lamps are turned off in the morning. The values between 7.30 PM to 6.30 AM are used for the analysis which gives 660 data points for each day.

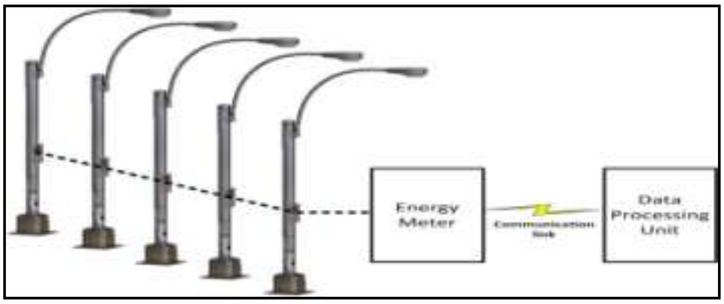

Figure 4. System layout

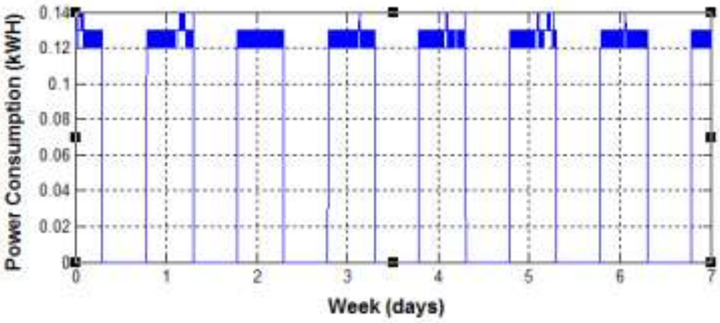

Figure 5. Aggregate power consumption data over a week

C. Methodology

A number of techniques were attempted to design a tradeoff between the time of fault detection and false alarm rate. Only the successful technique will be described in detail. Setting of proper threshold values remains a key in reducing false alarms, but owing to high variation in aggregate power consumption values even under no fault conditions, poses a huge challenge in determining fault, solely on the basis of power consumption data. The mean of 660 data points over a week under no fault conditions is used to determine the threshold. The Power consumption in any subsequent interval is compared to these threshold values. Whenever it falls below the threshold a temporary flag is raised. To further confirm the fault, the power consumption data is compared to the set thresholds for the next 5 hours and if the value crosses the threshold, coming back to normal operating conditions, the flag is cleared else a fault alarm is raised. This approach is justified owing to the high power quality in Singapore and the transient faults observed due to the variations in power supply would be cleared in the longer time frame analysis. Figure 6 presents the flowchart of the approach.

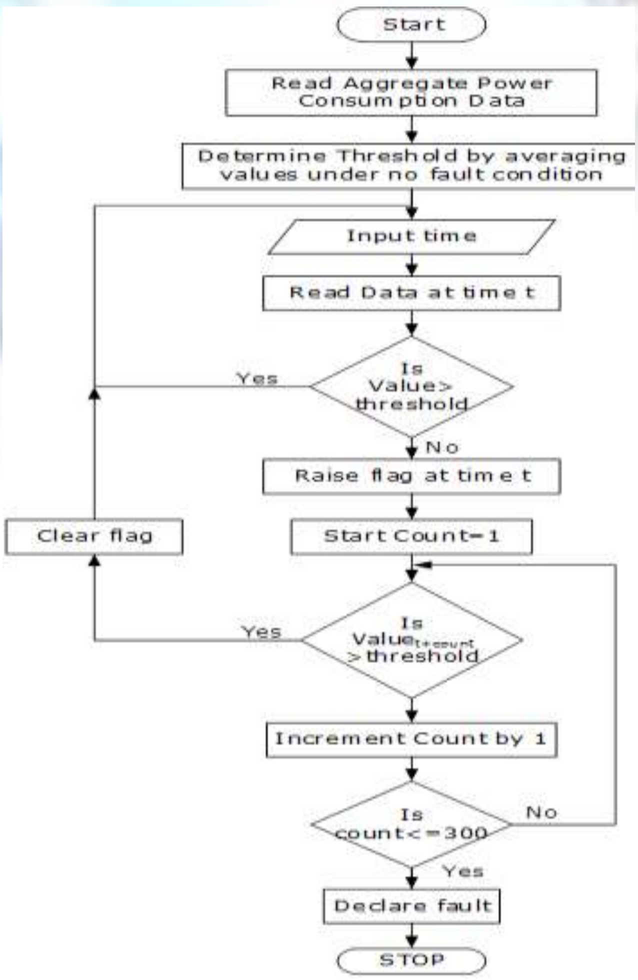

Figure 6. Flowchart of the used methodology

D. Result

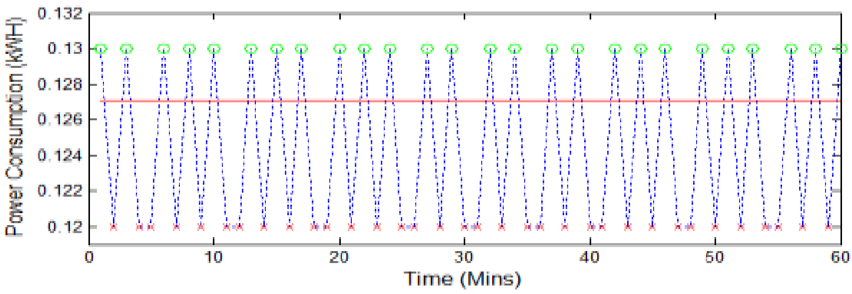

Figure 7. Fault Analysis

The simulation was run for an analysis of data logged over a month. The lamps were physically observed too to confirm if there was any fault occurrence. Also artificial faults were created in the dataset to validate the used technique. Fig.7 shows the fault analysis over a period of an hour. It can be observed that a flag is raised (represented by red-cross) for all the data points below the set threshold value. Fig.8 shows a sample output of the analysis. The technique worked fine and all the fault points were promptly detected.

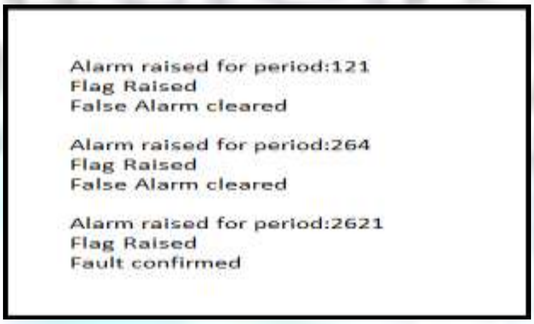

Figure 8. Alarming and fault confirmation

IV. CONCLUSION

A method to detect fault in a lamp, out of a plurality of lamps, using the aggregate power consumption data was described and implemented. The results can be summarized as follows:

1. The used technique detects all faults correctly but has a large computation time, owing to the high number of alarms and longer fault confirmation process. But other techniques attempted detected high number of faults even under no fault condition. So a longer computation is justified, as false detections will lead to unwanted visits by the maintenance officer to the detected fault site.
2. Fault detection accuracy also depends on number of lamps connected to the energy meter. Higher number of lamps reduces the resolution, making the fault detection tougher. However, further research is required to determine optimal number of lamps and more robust and quicker fault detection techniques.

Smart Street lighting creates better living environments, which are more reliable and safer, leading to sustainable future.

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