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Full Length Research

An Empirical Investigation of Automatic Streets Lighting Systems Design and Implementation for Crime Prevention in Residential Areas

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Abstract: Engineering professionals and the essential roles they play in creating solutions to challenges cannot be underestimated. These essential roles are central to basic solution, most especially in developing nations. One of such challenges is the security of lives and properties. However, in other to combat security issues in our neighborhood, adequate and efficient outdoor lighting to illuminate our homes, offices, streets, and communities is a pre-requisite and a must in order to ward off intruders and buglers from hiding in the dark around our premises. The purpose of this study was to carry out an empirical investigation of automatic streets lighting systems design and implementation for crime prevention in residential areas. The methodology used in this study was to design the lighting system and the automatic control unit, to assemble and construct the automatic control panel, to install the control panel and its earth protection, to install the streetlights and terminate to the low voltage (220V AC) distribution conductor, and to test and commission a working Automatic Controlled Street Lighting System. This study concluded that for engineers to reduce and eliminate human effort in every areas of life is evident in virtually all disciplines and professions. The study further recommends the option of using machine intervention to reduce error, is common in many applications such as timers in microwave, ovens, temperature control in electric irons. Provisions of an automatic control for street lighting system will eliminate errors and eradicate all inconveniencies associated with manual operation of such system because it comes on automatically in the hours of darkness and goes off by itself when it senses the sunlight coming out in the day time. Authors in this study concluded that these lightings expose the activities going on within and around our premises at night time when the natural source of light is no more effective.
Keywords: Optimize Energy Management: Eliminate Human Effort & Errors: Monitoring and Controlling: Street Light: Efficient Outdoor Lighting: Less Maintenance, Nigeria.
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1.0 Introduction of the Study

This study examined the design and installation of an automatic controlled street light system for some outdoor spaces at Bells University of Technology, Nigeria. The study was birthed as a result of the Department of Electrical and Computer Engineering's response to the security challenges arising due to dark spots around the campus that may attract and harbor criminal elements of the society. The area covered by the street lighting system are the perimeter fencing and work way spanning from the Campus bakery towards the food court down to the male hostels and towards the far back exit gate leading to the chapel. The system was carefully designed based on the recommendation of Abrol (2013). However, in other to be automatically controlled, energy efficient lamps that require less maintenance were used. The lamps used were carefully selected to minimize power consumption (Light Emitting Diode - LED technology), have wide beam angle of projection for increased pole span, and of adequate IP (Ingress Protection) to withstand outdoor weather conditions. In order to reduce cost of installation, existing power distribution poles and conductors along the perimeter paths were utilized and the design was made without altering the span between existing poles, and the size of the ancillary conductor. Yasmin & Sarkar (2014) reported that the control unit was built with high Ingress Protection. It is a free standing cubicle for outdoor installation which helped to eliminate the extra cost of providing a shed for the control unit. The scope of the study includes the design of the system, procurement of parts, fabrication of mounting bracket, assembly of the control panel component, installation of units, testing and commissioning. Phases of the study execution include System design phase, Assembly of parts, Fabrication phase, the Installation phase and the Testing and Commissioning phase (Yasmin & Sarkar, 2014). Manually operated system is limited by human judgment and errors. Human perception of sensation such as light, temperature, heat, smell taste etc can vary very significantly among individuals.

Kumarrath (2016) argued that designing a system to be solely controlled by humans will most probably suffer from limitations such as, individual's level of sensitivity, forgetfulness, inaccuracy, inconsistency etc. In other to overcome these challenges, systems such as electric systems incorporate automatic controls to enable electronic components, devices and machines perform human like function in the operations of such systems (Abrol, 2013; Lavric et al., 2018; Saad et al., 2020). These types of systems are more efficient, consistent, more accurate than human operated ones, but may also be susceptible to malfunction when faulty. Largely, thermostats, thermocouple, thermistors etc are incorporated in temperature controlled circuits; light sensors are incorporated in ambience monitoring circuits, piezometers, manometers pressure transducers are incorporated in pressure control circuits, sound detectors are also available to detect sound, even there is now an electronic nose that can detect odor. Automatic controlled systems have been found to be far more consistent over manual controlled systems (Prabu & Rajendra, 2016; Kumarrath, 2016). The aimed of this study is to design and install a medium power (15KVA) automatic controlled streetlight system provided with manual override.

1.1 The objectives of this study are:

1. To design the lighting system and the automatic control unit
2. To assemble and construct the automatic control panel
3. To install the control panel and its earth protection
4. To install the streetlights and terminate to the low voltage (220V AC) distribution conductor
5. To test and commission a working Automatic Controlled Street Lighting System

2.0 Background of the Study

This study examined several journals on automated street lighting systems. Analysis of the designs, outcomes and implications gained in the study shows that automated, error detection LED lights are more cost-effective, energy consumption and fault detection than the usual lighting system (Rajput, 2013; Rubananth & Kavitha, 2012; Suganya et al., 2014). It also indicates that due to lower physical workload, maintenance costs are reduced. The major objective of the system suggested is to enhance energy management and efficiency of road lighting systems and to create a more trustworthy and effective long-range control and control system with dependable self-immunization. It utilizes a sensor combination to regulate and ensure the system parameters you want. Otaru & Haruna (2022) reported that public sector lighting systems are still designed to meet the old standards and often do not benefit from state-of-the-art technological development, the use of new technologies in light sources and the use of the sensor combinations to achieve high street lights efficiency, and efficiency can easily be combined to maximize efficiency at each stage. It is the ideal option as it provides advantages, including conserving electricity and extended life, for Light Emitting Diode (LED) technologies instead of sodium vapor lamp and Compact Fluorescent Light (CFL). Given the long-term advantages and the initial expense, maintaining the time spent for return on investment would never be an issue (Achana et al., 2015; Amin et al., 2013). The idea may be used in several different applications, such as lighting in industry, campuses and parking areas in big retail centers. This can also be utilized in corporate and industrial monitoring.

Smart street light management and monitoring system that combines modern technologies are easy to maintained and are energy efficient (Yasmin & Sarkar, 2014; Abdulazeez, 2015; Harshitha et al., 2017). With the usage of the solar panel on the lamp post utilizing LDR, energy efficiency is possible by using the Graphics Application to display the status of lights on streets or highways, monitoring and managing the street lights (Ruchitha et al., 2016; Anand & Jain, 2015; Ramli et al., 2015). Design of the Energy Efficient Street Light Automation Wireless Framework recommended an intelligent control of the lamps by transmitting Zigbee Wireless communication data to a central station. Maintenance from the central station can be simply and effectively scheduled, providing further savings with the proposed method (Nithya et al., 2014). The streetlight management system helps to save energy, identify defective lights and maintain time and enhance system life. In addition, GSM Basic high-efficiency remote control system Smart street lighting system that uses the Zigbee devices and sensor network are also a perfect fit (Srikanth, 2014). New smart and intelligent street light system has been built using wireless maintenance technology and a network of controller sensors. They have utilized high efficiency LED lamps, which consume less energy for a long life and are powered by solar panel renewable energy (Devi & Anila, 2014; Rubananth et al., 2012).

Abdulazeez (2015) investigated energy efficiency in street lighting with the use of six components. In controller PIC16ff877A, LCD display, current transformer, GSM module (DTMF). Microcontroller PIC16ff877A; used to link all other elements together, GSM module; used to show load value for SMS transmittal to the control station, LCD for Dim, Brighten LED for DTMF and DTMF, DTMF specifies times to move the LED (Yasmin & Sarkar, 2014; Harshitha et al., 2017). The main goal was to manage the lighting of the street (dim at morning and also to radiate at night) (DTMF). The street light was regulated by engineers based on the Electricity Board. During transmission of the information to the power system through GSM, a disconnection occurred in the case of an overload. Data was forwarded to the power board using an RFID reader to be placed in a street light pole in which the tag was issued to every consumer in the case of consumer complaints. GSM transmitted an error message to the EB server (Ruchitha et al., 2016; Anand & Jain, 2015; Ramli et al., 2015; Patil et al., 2015). Finally, a novel approach for decreasing the energy usage was presented. The recovery duration was decreased after electricity failure. The GSM module suggested streetlight maintenance, load maintenance and other electricity concerns. The writers stated that this approach would be embraced by the electricity divisions in order to remember that the final objective is to preserve power and time (Patil et al., 2015).

Sumathi et al. (2013) suggested that on a street light system enhanced management and efficiency, sensors were used to improve and operate the system efficiently. The authors found that there was a movement felt by the IR sensor. When a human was spotted in detection, street lights were turned ON. The system has employed a GSM module for effective administration and control of street lamps. The road light condition was verified and a problem notice was sent to the control centre. The GSM module method helped to save considerable electricity. This increases the system's performance and maintenance by creating an integrated street light energy saving system (Vinitha et al., 2012). This study provided an excellent alternative for wasting electricity. Manual lighting system operation in this research was completely destroyed. Two sensors used for indicating day and night dependent resistance and IR sensors used for detection of street motion (Meihua et al., 2012; Natu & Chavan, 2013; Salem et al., 2015; Akash et al., 2015). The street light control used PIC16F877A microcontroller. The language utilized in this programming was C. On a prototype version the system was implemented. The two sensors utilized to operate the circuit were the LDR sensor and the IR sensor. The automation of each lighting column was controlled by each sensor. A microcontroller was applied effectively to the street light recorded that a GSM module may be utilized to monitor and operate the street lighting system with the wireless sensor network (Chaitanya et al., 2013).

2.0 Methodology of the Study

The method used in the achievement of this study from design to implementation is discussed in this section. However, the purpose and design of street lightings is quite different from other lighting systems, street lights do not have the same appearance as normal day light from the sun, but must quite be sufficient for people (pedestrians & motorist) to continue their movement on the road at night. It is expected to provide sufficient light to see important objects on the road or street. Street lights assist in discouraging vandalism, creating a secure environment for commuting and habitation, assisting in protection of buildings and properties, discouraging crime, reducing the risk of night time accident etc. A basic street light should have the following characteristics; Should be mounted horizontally or slightly at an angle and should aim vertically, should concentrate its flux to the ground with total reflection towards the floor, should have a wide look angle and fair distribution on the sides, existing power distribution poles were used for the installation of the street lights. The distance between adjacent power poles is 50 meters. Pole arrangement should be one sided, average usable height of each pole is about 6.5meters, existing ancillary conductor of gauge 35mm is was used; this to a far extent determined the maximum lighting load that was placed on the conductor, the road to be illuminated is considered a type E road (connector road between residential areas & low traffic with limited speed), length of covered area is about 2 kilometers (2,000meters).

However, for outdoor illumination design, the first consideration is to determine the kind of lamp that will provide the required flux for proper luminance, other considerations are; beam angle requirement, energy efficiency, low maintenance, durability, and cost effectiveness, the Lumen method was used in the determination of type of lamp to produce the needed illumination. The geometry of the space illuminance describes the amount of luminous flux falling on a surface. Illumination is measured by the light meter in lux. Illumination values decline with lamp distance and are typically not relevant to describe lamp performance unless a distance is specified. The control circuit utilizes a photocell sensor and photocell relay combination to sense the ambient light level and consequently controls the automatic switching ON or OFF of the power supply to the load (LED lamps circuit in this case).

The power supply to the system was obtained from existing Three Phase and Neutral Low Voltage power distribution line on the campus. Power flows to the control panel through a circuit isolator/breaker. It is fed to the switching unit, which is a contactor controlled by the control switch "Auto or Manual" for the manual operation, the switch by-passes the automatic control and energizes the contactor to provide an output to the loads connected on the other side of the contactor. For the automatic operation, the photocell relay monitors the ambient light level in combination with delay settings (ON-Delay, and OFF-Delay) to switch the contactor. When the environment is dark and the ON-Delay time has elapsed, the photocell relay switches ON the contactor, also when it is daytime the photocell switches off the contactor once the OFF-Delay time is elapsed. Care must be taken in positioning the photocell so as not to cause the street lights throwing light on it as this may lead to cycling ON and OFF of the system. The energy analyzer continuously monitors the input voltage and load currents giving appropriate display of system parameters and also keeps record of some selected parameter. In this study the contactor will switch the power supply ―On or ―Off from the Mains to the street light circuit depending on control signal from the photocell control circuit. A current transformer is used to reduce or multiply alternating current, but mostly used to transform current from higher value to lower value in instrumentation devices. For this study the STEL ―CT with 100/5A transformation ratio and burden of 2.5VA is selected to work with the circuit monitoring and analyzing device.

The Klemsan Powys Energy analyzer selected for this study has the capability of measuring the parameters listed in this study. It is also capable of performing some analysis, storage, relay output, accepts digital input, capable of Modbus Interconnection e.t.c. Light Emitting Diodes are semiconductor materials that emit lights when current are passed through them. At earlier stage of development they were used as indicator lights in equipments. With advancement in technology, LEDs are now used for high powered lamps up to thousands of wattage. After careful design and economic consideration, the 100watts, pole mount, wide beam angle was selected to be mounted on each pole to provide the required illumination. The mounting arm and bracket for securing the lamps to the poles are made from galvanized steel, threaded rod & nuts, and steel sheet. The mounting arms are made from 50mm diameter steel hollow pipes having thickness of 2mm, cut into 90cm lengths and bent into curved shape with hammer over large anvil. The bracket is designed to form a hook and lock around the square cross- sectional area distribution poles.

In this study, galvanized steel sheet of 3mm thickness are cut into smaller rectangular sheets (3cmX30cm) with two holes of 10mm diameter drilled at both ends. 8mm diameter threaded rods are cut into 30cm long pieces provided with a set of nut and washer on both ends. Two set each of the flat sheets are welded into the lower part of the curved hollow pipes having a distance of about 15cm between them. Another two set each of the flat sheets are formed into a canoe shape and two threaded rods slotted into the holes at the ends of the sheets. The canoe shaped sheets are to be worn around the poles and to be locked unto the sheets welded to the hollow pipes by the threaded roads and nuts. By this the mounting arms (curved hollow pipes) are secured to the power distribution poles while the LED lights are fixed to the other end of the mounting arms. Electrical cables are made from conductive materials enclosed in an insulation sheath/cover mostly of aluminum and copper conductor. They come in different forms, shapes, sizes, insulation material, number of cores etc. they are selected after careful consideration of relevant parameters which may include; current carrying capacity, voltage limit, insulation type, shielding, number of cores, form (stranded or solid), temperature limit, cost, protection (armoured or non-armoured) etc. The cable used in the study include; **2.5mm 3core flexible cable:** used to extend connection from the LED Lamps to the street light distribution lines on the poles.

4.0 Discussions of the Results

4.1 Construction and Installation Tools

For the execution of construction and installation jobs, quite a number of tools and equipments were used in the process, some of these tools are highlighted below;

 **Digital Multimeter:** for voltage, current, resistance and other measurements	 **Cordless Drill:** For drilling & Screwing	 **Power/Impact Drill:** For drilling
 **Cordless Electric Crimper:** For crimping lugs and terminals	 **Hand Grinder:** For cutting and grinding metal surfaces	 **Tape:** for measuring

 **Live Tester:** test potential	 **File:** To remove tiny unwanted particles/chimps from metals or others	 **Table Vice:** To hold work objects in place
 **Hammer:** For driving nails, bending or shaping metals etc	 **Cable Stripper:** To remove small cable insulations	 **Screw driver:** for driving screws
 **Pliers:** For Holding, pressing, twisting, cutting etc.	 **Long nose Pliers:** can access confined spaces	 **Contact live tester:** To test for presence of live voltage
 **Hacksaw:** For cutting metals	 **Spanner:** For driving bolts and nuts	

A layout plan for the components installation in the panel was developed as a guide for the component arrangement in the cabinet.

i) **Drilling of hole for passage of cable to the external photo-sensor:** 10mm hole was drilled to the top left side of the of the control panel by using a drilling machine and 10mm steel drill bit. The hole is to serve as a passage way for cable from the photocell relay to the external sensor.

ii) **Cutting of rectangular cable entry path for cable intake:** the intake path for supply cable, earth cable, and load cables is created by cutting out a 10mmX20mm rectangular hole out from the base of the panel using a cutting/grinding machine with a 2mmthick cutting disc.

iii) **Installation of component base (35mm DIN rail):** The DIN rails are cut into sizes and affixed to the panel using riveting machine and rivet pins.

iv) **Installation of cable tray:** cable paths are created for routing of cables from component to component by the installation of cable trays. They are run in vertical and horizontal positions to make suitable paths and routes. The cable trays are also affixed to the panel using the riveting machine and pins.

v) **Mounting of components on the DIN Rail:** the various components of the automatic control system are assembled and mounted on the DIN rails. They are arranged strategically, physically by separating the switching circuit from the control & monitoring circuit components. Most of the components are manufactured to 35mm DIN rail standard and easily snap unto the rails and lock into place using locks provided on each component. The current transformers are not DIN rail mountable and as such located close to the incoming supply cable and braced horizontally to the side of the cable tray using cable straps/ties. They are positioned in such a way to enable easy passage of the line cables through them from the input connectors to the mains isolation switch

By following the circuit and panel layout diagram developed for the system, each control and monitoring connection is made from component point to point using the single core 1.5mm cable; cut into individual sizes and run through the cable tray, and terminated at the device terminals. At the device terminals each connection is well labeled for easy identification and sorting. Cable tags are used for the control connection labels; they come in different sizes, color codes and or printed numbers. The power connections are made with the 16mm single core stranded cabled, terminated at the device terminals and fitted with color coded ferrules to identify the line and neutral line. Location point for the installation of the outdoor IP65 control panel was situated close to one of the distribution poles. This point provides proximity to the distribution lines and secures it away enough from physical mishap. A shallow pit of 0.9m X 1.5m to a depth of 30cm was dug into the ground for the foundation of the base. Two layers of brick were laid with mortar (mixture of sand, cement and water), the inside of the brick structure was filled with clay sand and the top finished off with concrete (mixture of sand, gravel stone, cement and water). A conduit was created in the structure by pre-inserting a 5inches L-shaped PVC pipe network opening up at the top and back of the base structure; this is to be used as passageway for the incoming, outgoing power cables .The base structure was allowed 5days to cure. The completed foundation block measures 0.7m X 1.2m with a height of 0.4m from ground level. After allowing for 5 days curing of the brick – concrete work, four foundation bolts were fixed in the concrete. The positioning of the bolts was made to match the slot holes on the base of the free standing control panel. These holes were drilled using an impact concrete drilling machine with a 10mm concrete drill bit, the bolt-peg were pushed into each holes and the bolt locked into the pegs in the concrete work with a spanner leaving about 6cm protrusion. The panel was erected on the concrete platform by sliding its base holes through the protruding bolts on the concrete work and secured in place with a 13mm nut and washer set. The cable entry cover at the bottom had been removed before the mounting of the panel.

4.2 Earthing

Earthing can be defined as the process of connecting the metallic but usually non- conducting parts of an electrical system, equipment or devices to the general mass of the earth for the purpose of providing protection in case such parts come in contact with live or attain dangerous high potentials. For this project the T-T type of earthing was used; (where earthing is solely provided by the consumer as the power supplier provides no earth. Earthing rod/pits is used by the consumer to earth the electrical system). The purpose of the earthing for this project includes; To provide safe path to dissipate currents due to lightning, transient over-voltages, leakages and earth faults to the ground. In the event of voltage surges, the surge protective device provided in the system will dissipates the excess energy to ground through the earth connection. To protect control panel under fault conditions. To ensure that the metallic control cabinet/panel does not reach a dangerous potential in case of earth fault. An earth conductor (6mm copper cable) was bonded to the earth rod and led to the control panel through the conduit provided in the concrete base of the panel. The pit is back filled with earth conditioner (aggregate mixture of wood charcoal, industrial salt and soil).

4.3 Charcoal

Charcoal ensures trapping of moisture from the soil to the pit chamber, also it is made of carbon a good conductor of electricity hence reduced resistivity, **Salt:** Aids absorption of moisture, and ensures reduced resistivity of ground water, **Soil:**

Because of its porosity permits percolation of ground water. Note: Moisture content of the ground enhances or improves its resistivity. Also there are some other readymade industrial soil conditioners that are available but expensive, compared to the charcoal-salt-soil mixture. The other end of the 6mm copper earth conductor was terminated to the body of the panel using a ring connector and looped to the surge protective device (SPD)Mounting of the lamps was highly coordinated while taking every necessary safety precautions and using the required personal protective equipments (PPEs). Two sets of ladders were utilized and at least three personnel rigged each lamp on individual pole along the installation path. The lamp and mounting arm assembly was done before erection on the poles. The lamp ends were slotted into the arms and locked in place using the allen bolt provided on the lamp fitting. Though the diameter of the lamp base was too large for the mounting arm; the fitting was packed with iron studs to allow for firm grip. The power supply connection of each lamp fitting was extended by 1m using a 3-core 2.5mm cable to enable easy connection to the distribution conductors. At the control panel end of the installation, Five cores of recline 16mm aluminum conductors laid down the pole were ran from the distribution line (Red-Yellow-Blue-Neutral-Ancillary) conductors to the panel through the conduit hole in the base of the panel and terminated at the terminal block connectors provided inside the panel. 3 wires connected to the R-Y-B phases and a common neutral are to provide the input power supply to the system and 1 wire connected to the auxiliary conductor plus the common neutral serves as the load circuit. The input supply feeds the main isolator switch/circuit breaker of the system and the load supply is fed from the output of the switching contactor.

5.0 Testing and Commissioning

Some electrical tests were carried out on the control panel before the termination of power supply cable and after electrical power was supplied to the panel .At the control panel end of the installation, Five cores of recline 16mm aluminum conductors laid down the pole were ran from the distribution line (Red-Yellow-Blue-Neutral-Ancillary) conductors to the panel through the conduit hole in the base of the panel and terminated at the terminal block connectors provided inside the panel. 3 wires connected to the R-Y-B phases and a common neutral are to provide the input power supply to the system and 1 wire connected to the auxiliary conductor plus the common neutral serves as the load circuit. The input supply feeds the main isolator switch/circuit breaker of the system and the load supply is fed from the output of the switching contactor. Following a successful test exercise with desirable results, the system was put into operation with the MCCB & MCBs switched ON, Selector Switch to Auto- Mode, photo-cell relay set to 5 lux, Photocell relay ―ON-delay timer set to 30 seconds, and ―OFF-delay timer set to 30 seconds.

6.0 Conclusion of the Study

In this study, authors found that an automatic controlled system is far more efficient than a manually controlled one. In addition, it makes the system operation seamless and stress free. The provision of the manual over-ride option makes the system even better in case of testing, troubleshooting and fault in the control circuit. The manual mode serves as a redundancy option in case of fault in the automatic control mode and allows for the continuous operation of the system till the control fault is rectified. The study also reported that automatic control of the street lighting system will save cost and reduce energy wastage that may result from human limitations such as forgetting to switch off the system soon enough in the morning when daylight is available. In this study the challenges reported are that; different cross sectional area of poles were encountered during the installation of lamps on the pole, giving rise to construction of different sizes of mounting bracket. The study also added that slotting hole/groove of the LED lamp are too wide for the mounting arm causing slack and tilting of the lamps when fixed to the arm. This was resolved by packing the groove & arm fixture with iron studs to form a firm grip. Authors in this study also added that only one phase of the power supply can be utilized as there is only one ancillary distribution conductor. This will cause load imbalance on the distribution line circuit at night time as the one phase switched to the street light circuit will appear to be loaded than the others. The study recommended that; for subsequent project of this nature the lamps mounting holes should be carefully matched with the mounting arm of the installation bracket. Consideration for different cross sectional area sizes of poles should be made when cutting the threaded rods for the mounting bracket.

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