

Development of a Distribution Transformer Substation Anti-vandalism using Dual Surveillance Monitoring Technique

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ABSTRACT

Power system encounter losses such as commercial, non-technical and technical losses. These losses often create serious damages to the power system by reducing the quality of power that is deliverable to the customers. Distribution substations are the most accessible power substation to customers for the supply of electricity. These substations based on their packaging in Nigeria are susceptible to vandalism. This vandalism is becoming a daily occurrence because of high demands for copper and sale of transformer oil in the black market. To minimize the vandalism, this paper presents a development of distribution transformer substation anti-vandalism using dual-surveillance monitoring technique. The method involves a circuitry design that incorporate a PIR sensor to detect human presence in the vicinity of the transformer substation perimeter fencing, a buzzer to sound as an alarm, a GSM module to send out a call/message alerting the operator in charge and a video/camera for surveillance purpose. The system was configured to send video to a dedicated web server in real time when the sensors sense any human presence and also captures image on detection which is sent via email to the operators. A flowchart that illustrates the procedural steps was developed and presented. The device was tested and found perfectly working.

KEYWORDS: Distribution transformer substation, Dual-surveillance, GSM Module, PIR sensor, Transformer substation vandalism.

1. INTRODUCTION

Power system network comprises of three sub-sectors, generation, transmission and distribution. The distribution being the last segment is closer to the consumers and are often put in charge of Distribution companies (DISCOS) in Nigeria. There are basically two types of substations in DISCOS, the Power injection substation (PIS) which often comprises of power transformers in range 2.5 to 30 MVA, 33/11 kV transformers. This type of transformer receives power supply from the nearest transmission substation. The second category of substation is Distribution Transformer Substations (DTS) and sometimes called public transformer substations (PTS) that receives electric power supply from PIS. The categories of transformer ratings obtainable in such stations range from 100 to 1000 KVA, either 33/0.415kV or 11/0.415kV voltage ratings. A typical DTS is equipped with 150mm² X 4 Core cable to serve the customers and Single core cables to take supply from the secondary of Transformer to a Feeder Pillar Unit.

Nigerian in recent time witness's transformer substation vandalism which is increasing on daily basis. These phenomena create losses and such losses often create serious damages to the Nigeria economy and thus reducing the power getting to the customers. Distribution transformer substations (DTS) are the access point (AP) for the electricity

power consumers to get electricity supply from utility. These AP often face a high threat of vandalism due to demands for copper and transformer oil in black market. Statistical data shows that large number of distribution transformers (DT) have been lost. The extents of this vandalism cover draining away of transformer oil as well as removal of single core armored cables, 150mm² x 4 core cables, and the removal of DT. Consequently, consumers are in black out while DISCO loses money due to re-installation of the vandalized components. This paper is aimed at developing a distribution transformer anti-vandalism using dual-surveillance monitoring technique.

To handle the project effectively, reasonable number related work was reviewed so as to know which work has been done on the subject matter. The review centers on technical approach, the strength and weakness of the methodology used. It also examined the success of the research work. For example, Kwarteng *et al.* (2021) observed that distribution substation transformers are not regularly monitored. Thus, an IOT-based DTS health condition monitoring system was researched on to assist in monitoring the health conditions of DTS remotely at a specific time. It involves the system determination of the health index by monitoring the variation in DTS parameter like oil level moisture. The aforementioned are achieved by using sensor and Arduino as the microcontroller while the sensed data are transmitted through GSM module to the designated people. The system is helpful in prolonging the life span of a transformer. The major limitation with this system is that it is limited to areas where Wi-Fi is available.

Kirunguru, *et al.* (2017) worked on 'Design and Implementation of a Transformer Vandalism Monitoring System'. The article focused on the design and the output is capable of detecting vandals near the transformer, raise an alarm and sends message to the nearest security post. This device also utilizes the use of an Arduino microcontroller, sensors and a GSM module for wireless communication [1]. Observation revealed that the researcher only worked on design and implementation but no construction work is done.

Kabanda & Ttondo, (2018), proposed a technical strategy to curb vandalism through only monitoring of the oil level of the transformers using a float switch which is open when the level of the oil is normal and closes when the level of the oil falls. This sends a signal to the buzzer to scare off the vandals and also condition an input signal to the GSM module through the microcontroller. The GSM module then sends a text message to the people in charge so that they can take action. This system also helps to monitor and notice if there is leakage in oil. The limitation is that float switch easily gets stuck. Also, there are delays in relaying the SMS to the mobile phone majorly due to inconsistencies in the GSM Network and incompatibility of local networks' service providers' SIM cards with the GSM Modem [2].

Panasa, (2017) presented a design of embedded circuit and control. Coordination of systems which monitor and diagnose the transformer condition was presented. The proposed system integrates both the GSM technology and IR - Sensor to detect the coming nearer of persons to distribution transformer substation. Each time the microcontroller receives a return signal from IR - Sensors, the programing is made such that it initiates GSM modem. However, a GSM consist of a SIM card where a text message is assigned and sent to the concerned mobile numbers [3]. The major drawback is that the system is just a proposed one it has not been put into practice.

Mazikana (2019) conducted a research study on strategies to curb vandalism using Zimbabwe Electricity Transmission and Distribution Company (ZETDC) as a case study. The research was undertaken because of the increasing vandalism

of transformer. The research aim is to gain an understanding of the cause of vandalism at ZETDC and to come up with various strategies to curb vandalism of transformers. Using the quantitative approach, questionnaires were circulated and the analysis in the response shows that the vandalism is caused by unemployment, poor security, low standard of living etc. and it can be curbed through strategic implementation of security and alarm systems. One of the suggested strategies is to secure pole mounted transformers with steel cages others include use of sign post, employing more security guards, use of cameras etc [4]. The limitation of this study is that confidentiality of some document and information related to the topic and lack of fairness by some of the staffs to give cooperation concerning the topic. .

Onchoka,, (2015) clearly presents the problems of transformer vandalism and its impact on power distribution systems, and then discusses the IoT and its potential applications in this area in detail. One of the strengths of the document is that it highlights practical solutions, such as using sensors and cameras to monitor transformers and detect vandalism in real time. The author also emphasizes the importance of data analysis to identify vandalism patterns and develop effective prevention strategies. However, there are several areas where the document could be improved. First, the author could provide more detailed information on the technical aspects of implementing IoT, such as: the types of sensors and devices that could be used and how they would be integrated into the existing energy infrastructure. Additionally, the author could address the limitations and potential challenges of IoT-based solutions, such as: the cost of implementing and maintaining these systems and potential privacy issues. In terms of presentation, the article would benefit from clearer headings and subheadings to guide the reader through the different parts of the article. Overall, I think the article supports the use of IoT to prevent transformer vandalism and provides valuable insights into implementing such solutions. With a few small corrections and clarifications, the article could be even stronger [5].

2. MATERIALS AND METHOD

This project aims to implement a superior approach compared to the previous methods for safeguarding the transformer from vandals. The implementation of this system will provide a 24/7 security monitoring system, ensuring a continuous power supply to consumers unless there are power operations and maintenance. This is of great importance as it will save millions that would have been lost due to transformer vandalism.

The monitoring system will be designed and programmed to capture pictures of vandals, alert the operator in charge, and sound an alarm through the buzzer when necessary. The project consists of a motion sensor that detects the presence of vandals around the transformer. Once triggered, the sensor sends a signal to the GSM module to call the operator in charge while also activating the camera to capture an image of the vandals. The image is saved to a memory card, and the camera also streams live footage to a web server where the entire substation condition can be viewed.

Additionally, the buzzer receives a signal from the motion sensor, causing it to sound a loud alarm to alert people. The ESP-32 CAM microcontroller controls all operations of the system.

2.1 Power Supply

The electrical devices that are going to be implemented in this research work such as the microcontroller, GSM module etc., can only operate on a voltage supply of approximately 5vdc [6]. The power supply circuit is the circuit from

which the desired dc voltage to operate other devices in the circuit can be gotten from. To supply voltage to the whole circuit, the voltage from the ac mains (220vac) is stepped down by passing it through a 220K ohms resistors. The reduced ac voltage is then passed through a full bridge rectifier which converts it to dc. The output will be a pulsating dc voltage with significant ripple. To smooth out the voltage, a large capacitor is connected to the circuit. The filtered dc voltage obtained from the capacitor is then rated down to 5vdc through the (5.1v) Zener diode which serves as a form of voltage regulator [6 – 12]. The output voltage (5vdc) is made to serve as an input to the dc charging circuit. For the purpose of charging the battery we need to reduce the voltage to a lower dc voltage, so the 5vdc is passed through a voltage divider circuit which output a voltage of 3.7vdc to charge the battery.

A transistor is connected to the circuit to serve as a switch that turns on and off the circuit to charge the battery when its low and to prevent over discharging of the battery. The diodes (D1, D2, D3 and D4) helps to prevent back emf while the diode led is just to indicate whether the battery is charging or not. The implementation circuit is presented in Figure 1.

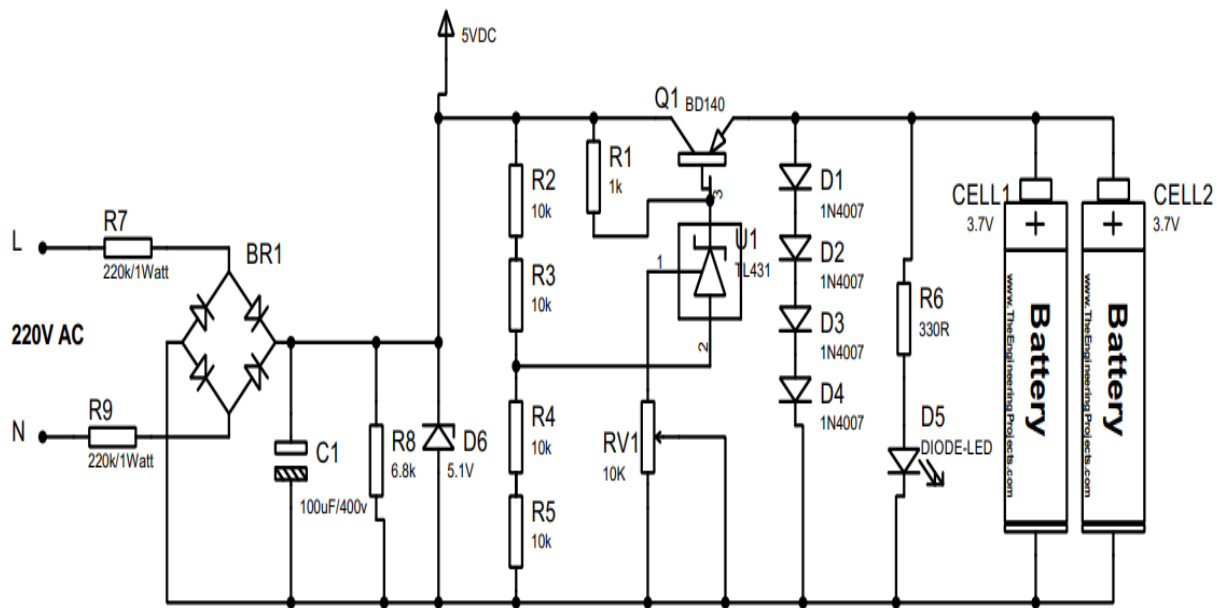


Figure 1: Circuit Diagram for the Power Supply

2.2 Motion Sensor

The project will utilize a passive infrared sensor (PIR) shown in the figure below. This electronic tool measures the emission of infrared light (IR) within its field of vision. The sensor will be placed near the transformer to monitor any movement in the area.

The PIR module has three pins: one for the +5V power input, another for ground, and the third for digital output. The PIR itself does not emit energy into space, but rather receives infrared radiation.

The trig pin is utilized to initiate ultrasonic sound pulses, while the echo pin listens for the reflected signal. The ground pin is labeled as GND.

The outdoor detection range of the PIR sensor ranges from 10m to 150m. Normally, the detection distance of a pin sensor is not very long, so a lens is used as a focusing system for infrared radiation to increase the detection range.



Figure 1: Diagram of a PIR Motion Sensor [13]

2.3 Microcontroller (ESP32-CAM)

This project opted for the esp32-Cam due to its capability to handle resource-intensive tasks, particularly video processing. Additionally, it was chosen for its compact size and low power consumption. The device also features an ov2640 camera, supports both Wi-Fi and Bluetooth, and includes an onboard TF card slot that accommodates up to a 4G TF card for data storage. The esp32-Cam's central component is the esp32-s system-on-chip (SoC), which contains a complete computer.

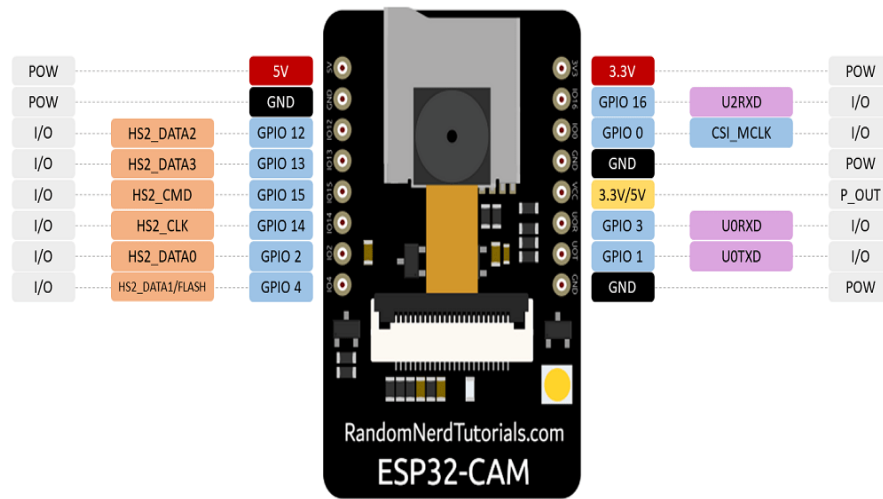


Figure 2: ESP32-CAM pinout [12]

2.4 GSM Module (SIM800L)

The SIM800L GSM module is used in this project. When the motion sensors detect activity near the transformer, the module contacts the pre-programmed phone number.

When power is applied to the entire circuit system, the GSM module takes 45 seconds to connect to the network. As a result, a for-loop software is used to display a progress bar on an LCD for 45 seconds before calling the programmed phone number to signify that the module has gained access to the SIM network provider's network.

The microcontroller and the GSM module communicate via a USART (universal synchronous/asynchronous receive transmit) mode.

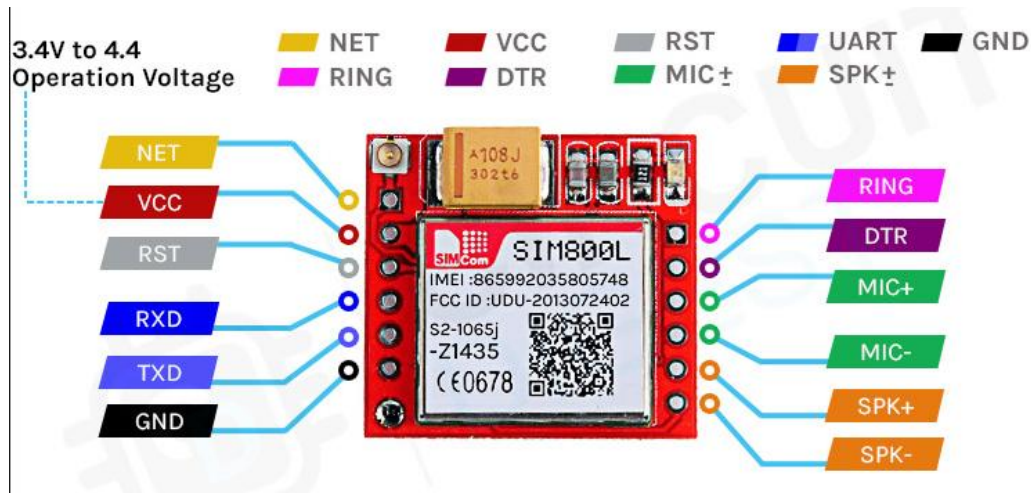


Figure 4: SIM800L pinout [14]

2.5 LCD Display

The I2C 16 x 2 LCD DISPLAY module, which is based on the HD44780, was used to implement the operating status display. The LCD display has 16 pins: eight data pins (D0–D7), four control pins (Rs, E, Vee, R/W), two power lines (Vdd, Vss), and two led pins (LED+ and LED -). When there is little light, the led serves as a backlight to read the data on the display.

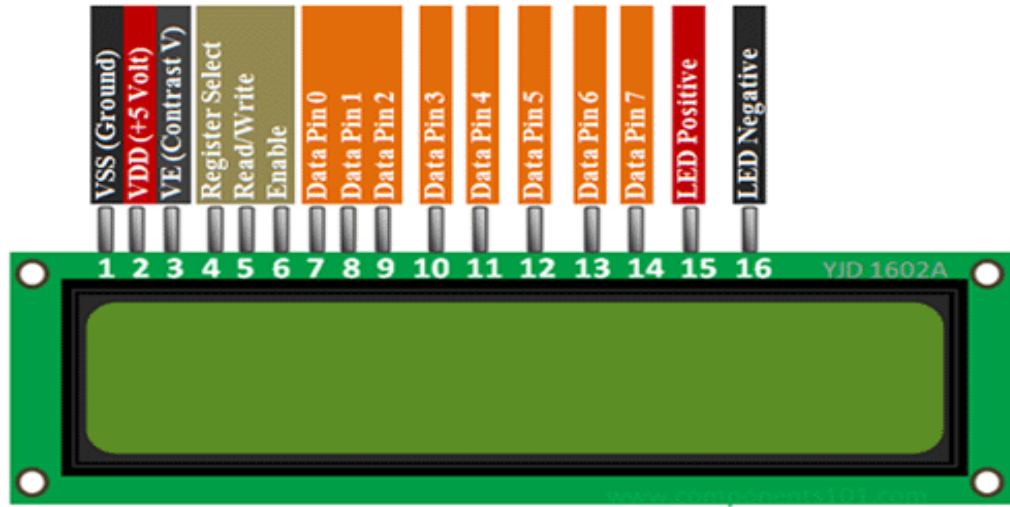


Figure 3: LCD pin out [15]

2.6 Buzzer

The buzzer is an electronic device that emits a loud continuous tone when activated. When activated, the buzzer emits a loud tone that can be heard from afar, alerting security personnel or nearby residents. This shortens response times and avoids possible theft. In summary, using buzzers in conjunction with transformer anti-theft is a useful way to improve transformer security and deter theft. The buzzer acts as an effective warning system to alert authorities or security personnel to unusual activity, reducing response time and preventing potential damage.



Figure 4: Diagram of Buzzer [16]

2.7 Arduino IDE software

The Arduino IDE (Integrated Development Environment) software tool is used to program and upload code to Arduino boards. A code modification is necessary for the ESP32-CAM board to interface with other device in the circuit. The Arduino IDE open-source software makes it simple to write code and upload it to microcontrollers. Evidence of coding implementation is shown in Figure 7.

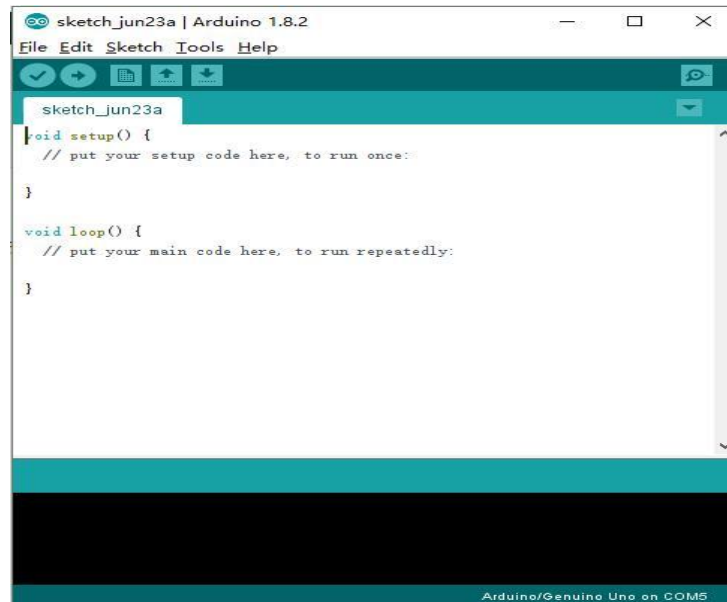


Figure 7: Arduino IDE software

2.8 Theoretical Framework

The theoretical framework is shown using the system block diagram of Figure 8. Distribution transformer (DT) is an important equipment in DTS. They are used for the distribution of electricity at low voltage to the final consumers. In Nigeria, the DT modify the high voltage to the standard output of 240V and 415V for single phase and three phase supply respectively. For the DT to work effectively, some apparatuses are required to be installed along with it. These apparatuses include single core cable (available in sizes) depending on the capacity of DT, 4-core cable (available in different sizes) depending on customer's loads to be carried. Other important apparatus are Lightning arrestors, XLPE cable, Johnson & Phillip Fuses, Feeder Pillar, and feeder pillar fuses. Figure 8 illustrate the theoretical framework

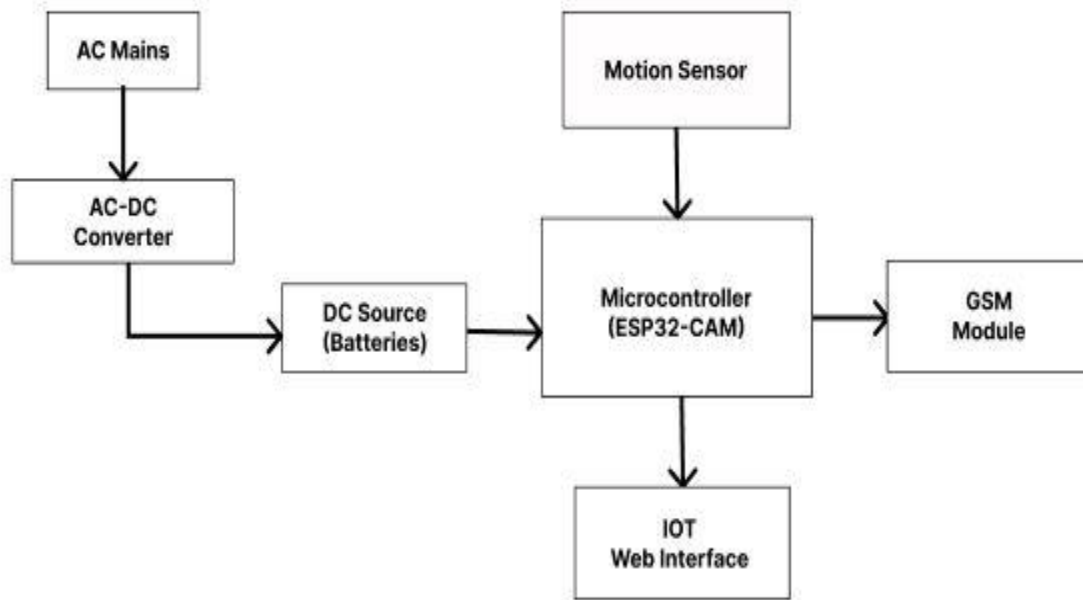


Figure 8: System Block Diagram of Distribution Transformer Anti-vandalism using Dual - surveillance Monitoring Technique

3. RESEARCH AND METHODOLOGY

3.1 Flowchart Diagram

The approach to this research work is summarized by the algorithms displayed in the flowchart diagram of Figure 9.

3.2 Programming the ESP32-CAM

Programming the ESP32-CAM may be a bit difficult due to lack of built-in USB connector. Because of the nature of the system design, additional hardware is needed to upload programs via the Arduino IDE. A USB-to-Serial adapter (an FTDI adapter) or an ESP32-CAM-MB programmer adapter is required for programming the ESP32-CAM. This is shown in Figure 10

3.3 ESP32-CAM with Piezo Buzzer

The piezo buzzer is an electrical component that can emit sound or beep. The gadget contains two pins (positive and negative). In this project, the buzzer is attached to an ESP32 digital output pin, and a code is developed and uploaded to the ESP32-CAM board via the Arduino IDE to control the pin's state. The ESP32-CAM generates the control signal to the positive pin, while the negative pin is connected to the GND (ground). This is also shown in Figure 11

3.4 ESP32-CAM with Sim 8001 GSM

The sim 8001 GSM module is a 12-pin module device that can perform everything a typical mobile phone can do, including text messaging, making and receiving phone calls, and connecting to the internet via General Packet Radio Service (GPRS). It also supports quad-band GSM/GPRS. The sim8001 is a 2G modem. In this project, the sim8001 module is configured to transmit a warning notification to a preset monitoring number, alerting the transformer operator to the presence of potential attackers in the proximity of the transformer. The module includes a TCP/IP stack that may be accessed using AT commands.

Through its serial pins, the ESP32-CAM communicates with the sim8001 GSM module.

RXD: The module's RX pin.

TXD: The module's TX pin.

The module's power supply should be between 3.4v and 4.4v. If connected to any voltage over the specified range, the module may be damaged; if attached to any voltage below, the module may not function at all.

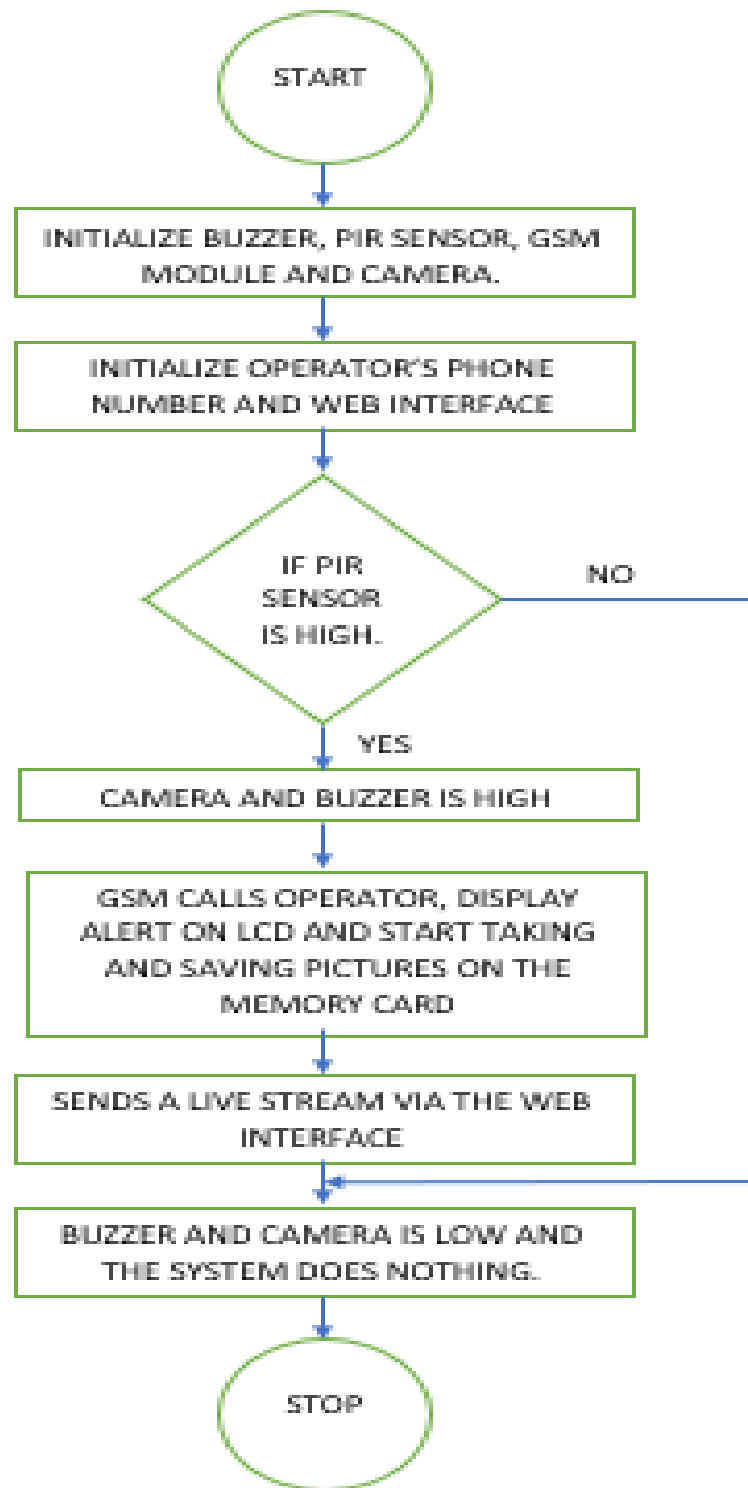


Figure 9: Flowchart of Distribution Transformer Anti-vandalism using Dual-surveillance Monitoring Technique

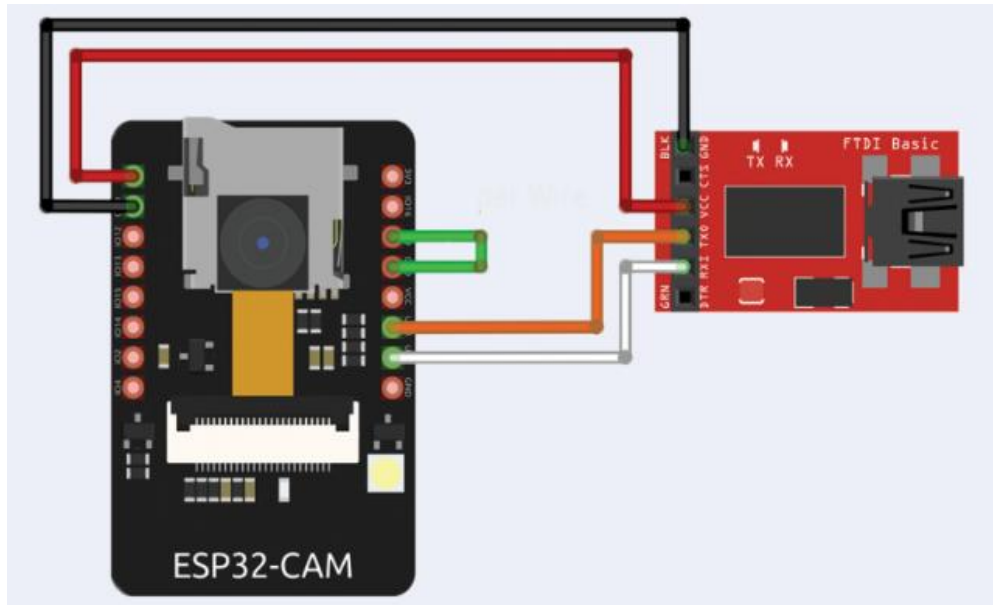


Figure 10: Interfacing an FTDI with the ESP32-CAM

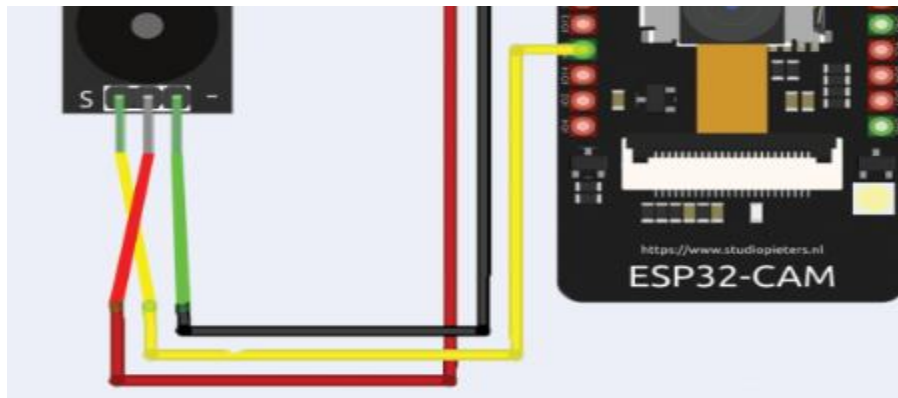


Figure 11: Interfacing a Piezo Buzzer with an ESP32-CAM

3.5 ESP32-CAM with motion sensor

The PIR motion sensor is a three-pin device that uses its eyesight to detect objects that emit infrared light. The first pin is used for 5v input power supply, the second is connected to the ground pin, and the last pin is the digital output pin. In this project, the ESP32-CAM is in deep sleep mode, with external wake-up enabled at pin 13.

When the PIR sensor detects motion inside the range, the output pin of the PIR sensor turns high. Because the PIR sensor's output pin is connected to the ESP32-CAM's pin 13, the ESP32-CAM receives the wakeup signal. The ESP32-CAM wakes up and takes the photo. After that, the image is saved to the microSD card linked to the ESP32-CAM

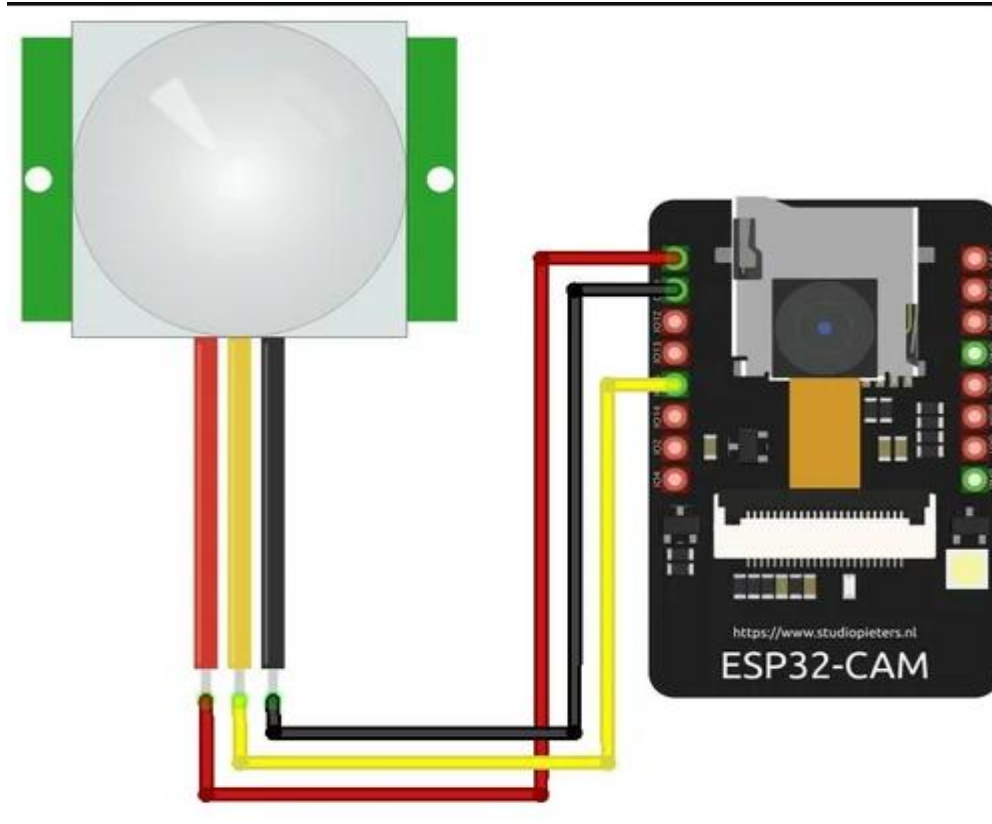


Figure 12: Interfacing a Motion Sensor with the ESP32-CAM

3.6 IOT Web Server

To establish an internet connection between the microcontroller (ESP32-CAM) and the configured webserver, an Arduino application is utilized.

Setting up the web server, configuring the WIFI settings, and creating the routes for the video streaming destinations are all part of configuring the webserver to stream video. Following the configuration of the webserver, the ESP32-CAM is connected to the computer to set and install the required drivers. In the Arduino program, a Wi-Fi SSID (Service Set identification) and password are used as an identification for the microcontroller embedded Wi-Fi module to connect to the router.

The ESP32-CAM board has a camera module that can be used to capture video footage. The camera is set up to capture video at the specified resolution. With the web server and camera module configured, we can now stream video over the internet.

3.7 Circuit System

The overall circuit system of a distribution transformer anti-vandalism using dual-surveillance monitoring technique is shown in Figure 13.

4. DISCUSSION OF RESULTS

The research design integrates some technologies such as sensors, cameras, IOT and solar power connectivity to monitor the distribution transformer aimed at reducing the incessant theft and vandalism of substation equipment. Sensors detect abnormal behavior of people with bad intention around the protected transformer substation which may include unlawful entry in the substation.

The installed camera and video monitor the entire distribution substation that include transformer, upriser cables, underground single - core cables, feeder pillar, Poles, J & P fuses, etc. Once this equipment noticed movement in the substation, the camera takes pictures while the video records the activity going on in the substation. The IOT devices feed sensor data and video footage to the control center, where it may be processed and sent to the GSM phone of the selected members of the community on that transformer for necessary action. Simultaneously, the buzzer that has already been remotely integrated to a high frequency Alarm setup will raise alert to the awareness of those that matter in that community who will rise to take action.

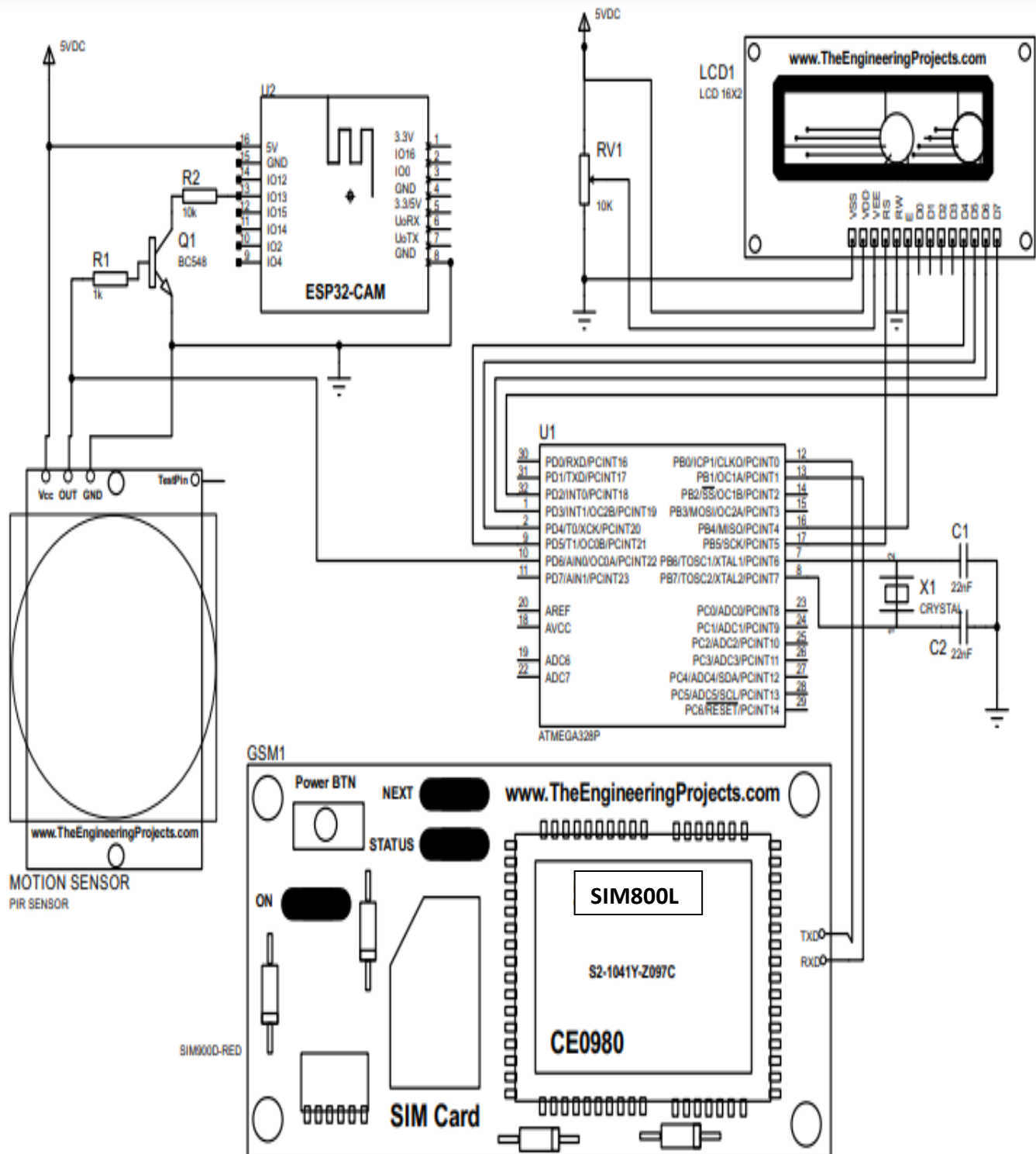


Figure 13: Circuit Diagram of Distribution Transformer Anti-vandalism using Dual-surveillance Monitoring Technique

To minimize theft and vandalism in public distribution transformer substations, a distribution transformer substation anti-vandalism using dual-surveillance monitoring technique has been developed.

transformer anti-vandalism surveillance monitoring control system built on the Internet of Things is a possible option. The system can identify and stop theft and vandalism occurrences, enhancing safety, cutting expenses, and boosting efficiency. It does this by integrating sensors, cameras, IoT devices, and a control center. Despite possible upfront expenditures, power discos may find the system to be a good investment given the potential rewards.

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