Development of a Low-cost LoRa based SCADA system for Monitoring and Supervisory Control of Small Renewable Energy Generation Systems

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***Abstract*— This paper presents the design and development of a low-cost, open-source LoRa based Supervisory Control and Data Acquisition (SCADA) system for monitoring and control of small-sized microgrids located in remote locations. The proposed system is based on the 4th SCADA generation (IoT based), which features the combination of connectivity of components for data sharing. The proposed system employs LoRa physical level communication as the communication channel, and comprises of voltage and current sensors that act as the field instrumentation devices to acquire electrical parameters from the system. It also features LEDs that represent actuators for control. An Arduino Uno microcontroller is employed as the Remote Terminal Unit (RTU) to receive the parameters and process them for ttransmission. The Chirpstack IOT server, Node-Red, Influxdb, and Grafana are all installed locally on the Raspberry Pi (Master Terminal Unit, MTU) for data processing, storage, monitoring, and remote control of the actuators. The proposed system was set up in the Electrical Engineering Laboratory of the Memorial University to monitor a 130 W, 12 V solar PV panel with batteries Connected for energy storage. The acquired data is published on dashboards created on Grafana for monitoring and control.**

Keywords—LoRa, Low-cost, Open-source SCADA, Node-Red, Grafana, Raspberry Pi, Arduino, Internet of Things (IOT)

I. Introduction

With increasing need for energy and reduced carbon emission, increased renewable energy source penetration for energy generation such as wind, solar and hydro is taking place. To achieve this, various generation and storage systems are deployed at different locations due to reasons such as diversity of resources, availability of land area for installation, and also isolation from areas of human inhabitation. This, therefore, means that for continuous normal operation of the various units, there has to be a reliable supervisory and monitoring system. Supervisory Control and Data Acquisition (SCADA) can be used for effective monitoring of various distributed systems spread out at varying locations [1]. This function is normally achieved through data acquisition from the various remote systems being monitored with the use of sensors and data transmitted to SCADA hosts for observations and possible control using actuators [1]. Owing to the fact that most of the systems are located in geographical locations with possible harsh weather, which are often inaccessible. While there may be a necessity of local means of assets operation management, it is also of importance to have a reliable, flexible, cost effective and robust coordinated monitoring and control. This function can be achieved using a SCADA system [1]. With a SCADA system in place, the need for personnel to be stationed at the site is drastically reduced. The basic functions of a SCADA system include: data acquisition, data transfer, data presentation and remote monitoring and supervisory control [1]. The SCADA system performs these functions using its basic elements [1]: field instrumentation devices such as the sensors and actuators, the Remote Terminal Units (RTU) such as the microcontrollers, the Master Terminal Units (MTU) that coordinate the data processing, presentation and the communication channel that links the RTUs to the MTUs [2].

SCADA systems can be either proprietary or open-source [2]. For proprietary SCADA, the major components are from a single manufacturer. Therefore, the standards and codes for the proper operation of the SCADA system is the sole responsibility of the manufacturer, which entails total dependence on the manufacturer for troubleshooting and repairs. The flexibility of the system is also in check as there may exist some compatibility issues. On the other hand, the open-source SCADA systems are developed with the combination of various low-cost components from manufacturers with very good compatibility, and ability to achieve secure and proper function. In the open-source systems, these functions are achieved at low-cost and better interoperability of components [3]. For communication, SCADA systems in existence have used various communication technologies for data transfer between the RTUs and MTUs. The existing communication systems include Wi-Fi, Zigbee, internet or a combination of the above. LoRa which stands 'Long Range' communication is known for its long range and low power consumption characteristics. These features of LoRa have earned it the present versatility as it entered into the internet of things (IOT) industry. In this paper, an open-source LoRa-based SCADA system is proposed.

II. Literature Review

SCADA systems have developed through four generations of system architecture: The first Generation (monolithic), the second generation (distributed), the third generation (networked) and the fourth generation (IOT-based) [3]. The concept of IOT is based upon the interactions of devices such as sensors, actuators with electronic hardware and software for data interchange in a private network or the web [4][5]. The various Generations of the SCADA systems is as shown in Fig 1.

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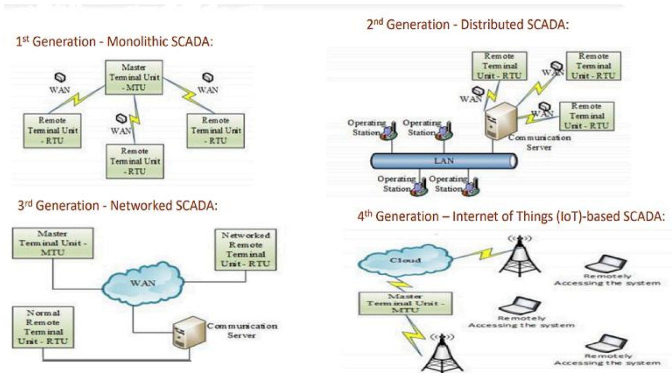

Fig 1: SCADA system generations [4]

Various IOT based SCADA systems have been developed by researchers throughout the world. In [1], the authors proposed and developed a prototype low-cost, open-source SCADA system for solar photovoltaic system monitoring. The work implemented a system that comprises of sensors that measure electrical parameters off a PV system, and the data is transferred to a locally installed EMMON CMS server for monitoring and control actions. The communication system implemented for data transfer in this work was Wi-Fi. The work in [6] implemented a web-based monitoring and control system for real-time electrical data measurement of a hybrid power system using web-based inTouch system for the graphical user interface. The research in [7] describes the functions of a LoRa-based SCADA system. This work focused only on the security of the communication system employed such as the data encryption algorithm and security of LoRa – in the conext of communication in microgrids. In [2], a low-cost SCADA system was implemented for CO_2 enhanced oil recovery, which uses sensors and actuators connected to the wellhead and data stored in MYSQL DBMS database and displayed on a graphical user interface. Recently, researchers in [8] designed and developed a low-cost, open-sources IOT-based SCADA system using Thinger.IO and the ESP32 microcontroller board. This system has voltage and current sensors connected to a PV systems. The electrical parameters were measured and parsed using the ESP32 microcontroller board. The data is then transferred to a Raspberry Pi that hosts the Thinger.IO server platform for data presentation, monitoring and control activities. This system also uses Wi-Fi as the communication for data transfer. Publications such as [9][10][11][12] are also examples of various categories of IOT-based SCADA systems. In the above works, it is observed that the main SCADA communication channels are internet based. Although in [1] and [8] the servers are locally installed on the Linux machine and Raspberry Pi, respectively, the measured data was transferred using Wi-Fi.

LoRa, is the physical layer or wireless modulation used to create long range communication link [13]. Most of the known wireless communication technologies achieve communication using the frequency shift keying (FSK) modulation at the physical layer [13]. This allows low power consumption. LoRa, on the other hand, makes use of the chirp spread spectrum (CSS) modulation technique, which also has the capabilities to achieve low power and long range communication. CSS works with chirps whose frequencies increase or decrease linearly over a period of time [14]. LoRa operates in the free spectrum band (i.e., ISM) of various regions such as 868 and 915 MHz band for Europe and USA, respectively [15]. This communication technology has a low data rate of up to 50 kbps [15]. LoRa has bandwidth capabilities of 125 KHz, 250 KHz, and 500 KHz [16]. LoRa uses CSS for message modulation. Conventionally, this technology uses a sweep tone that increases (up chirp) or decreases (down chirp) in frequency over time for message encoding instead of the pseudorandom binary sequence used by the well-known direct-sequence spread spectrum (DSSS) [17]. The modulation technique employed in LoRa spreads the message (signal) over a wide bandwidth, which makes it less affected by noise and interference [17]. Other low power communication system do not have this feature by default. A LoRa transceiver can decode transmission 20 dB below the noise floor, making very long distance communication possible, even on low power consumption.

In this paper, LoRa machine-to-machine communication between RTUs and MTUs, and a locally installed LoRaWAN server based on the Chirpstack IOT server system are employed for the development of the proposed SCADA system. Node-Red is incorporated in the system for data processing on the MTU. A time series database known as the Influxdb is incorporated into the system for more robust data storage with the ability to access data with easier queries than a typical SQL databases. The data is displayed for monitoring using Grafana IOT dashboard. The proposed system is deemed to be robust, and can be employed for SCADA applications for systems deployed in harsh remote areas without needing other forms of communication system such as the cellular. The LoRa communication system employed for data transfer in this work can attain a commendable communication distances of up to 10 km in rural areas, and about 5 km in urban areas with high number of obstructions. The design and development of the proposed LoRa-based SCADA system will be discussed in the remaining parts of this paper.

III. Proposed LoRa-Based SCADA System

The proposed LoRa based communication system is an IoT approach to data transfer within microgrids. As such, it involves the interaction between LoRa communication devices and sensors that are connected to various components of the microgrid for monitoring and data transfer.

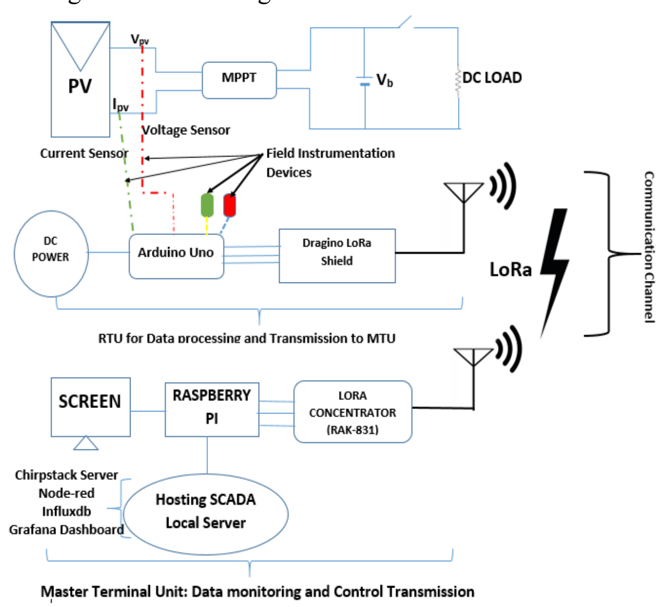

Fig 2: Architecture of the proposed LoRa-based SCADA system

In this work, the sensors are programmed to obtain data from the monitored components. Then, the data are processed and sent by the LoRa nodes to the gateway, the gateway forwards these data to the server for processing, storage, display and possible control. Fig 2 shows the full configuration of the proposed LoRa-based SCADA system.

The proposed SCADA system in this work is composed of sensors to obtain data, Arduino Uno and the Dragino LoRa Shield as the RTU for data parsing and transmission, RAK831 LoRa concentrator and Raspberry Pi 3 B+ model as the MTU for hosting the server for data processing, storage and display on the user interface.

A. Sensors

Generally, sensors are always connected to the systems that are to be monitored due to their abilities to measure various desired parameters. For this work, two sensors are connected to the PV setup to measure voltage and current.

1) Voltage Sensor: The voltage sensor is employed to measure the voltage across the units of the microgrid. The voltage sensor used in this work is built based on the voltage divider principle. The sensor is made up by a series connection of two resistors of values 10 kΩ and 4.7 kΩ. The voltage sensor's output pin is connected to the pin A2 on the Arduino Uno micro-controller, and the measured data is drawn from this pin. The ground pin is connected to the ground. The principle above is such that the voltage drop across the second resistor is measured to scale down the voltage to a value that is allowed to be interfaced into the Arduino. During processing, it is scaled back up with the expression shown below such that the Arduino ADC obtains the proportional and accurate voltage value.

$$vin = \frac{vout}{\left(\frac{R2}{R1+R2}\right)}$$

Where;

$vout$ = Sensor measure value * Vpp

Vpp= Arduino ADC Value = $\frac{5.0}{1024.0}$ = 0.004882813

2) Current Sensor: The current sensor employed in this work is the ACS712 Hall effect current sensor, by Allegro Micro-systems. For this work, a 30 A current sensor is used. This sensor is employed to measure the line current in the various microgrid components to be monitored by connecting Vcc and GND to 5V and GND on the Arduino, respectively. The data pin is connected to A0 on the Arduino for data acquiring. The input lines are connected in series to the line to measure the DC current .

B. Arduino Uno Microcontroller

Arduino is an open-source platform used for building electronic projects [18]. This is made up of both a physical programmable circuit board and a software (IDE) where the programming is done and uploaded. This system has been popular over the recent years for applications for IOT due to its low-cost and low power consumption. The Arduino Uno board is coded to function through the IDE, which is installed on the PC. The interface allows for easy processing of the coding for various projects, and is uploaded to the board through the USB. For this work, the Arduino Uno is used to process data that has been measured by the sensors. The sensor data are now displayed on the serial monitor on the IDE with a baud rate of 115200.

C. LoRa Shield (Dragino V1.3)

The LoRa Shield is a transceiver module that achieves long distance communication with low data rates using the LoRa communication technology [19]. The module is programmed with open-source codes from GITHUB, which makes it a low-cost system. The LoRa Shield is based on the Semtech SX1276/SX1278 chip, which has attained enormous growth in IOT applications [19]. Dragino Shields have good sensitivity of over -148 dBm and +20 dBm power, which has been combined into its technology to achieve a very high link budget of 168 dBm [19]. This has made LoRa Shields suitable for robust and long range applications [19]. This transmits the data obtained from the sensors, which is processed into LoRa data format by the microcontrollers to the gateway.

D. RAK 831 LoRa Concentrator

A RAK 831 concentrator is manufactured by RAK wireless group. The board is a high-performance transceiver module with design for the reception of LoRa-packets at 8 different frequencies simultaneously [20]. The concentrator is based on the Semtech SX1301, half-duplex gateway module, which supports up to 10 channels, 8 downlinks, 1 uplink and 1 FSK channel [20]. The above channels are supported in the various ISM bands of respective world regions. RAK 831 is normally employed as the front-end of a multichannel LoRa gateway to receiver LoRa packets from the nodes that are locked to its range of frequencies. In this work, RAK 831 is used to receive data from the nodes as LoRa packets. RAK 831 has no processing capabilities to decode the received data. Hence, RAK 831 needs a host system that can either be a Raspberry PI (MCU) or a PC that is connected through USB or SPI connections [21].

E. Raspberry Pi Microcomputer

For this work, a Raspberry Pi 3 model B+ is employed. This is a single board microcomputer that operates on the Broadcom BCM283730, Cortex-A53 (ARMV8) 64-BIT SoC processor with a 1.4 GHz clock frequency [22]. The Raspberry Pi is employed to be the host to which the concentrator is connected. To achieve a fast and reliable system. The IOT server (Chirpstack LoRa server), Node-Red, Influxdb and Grafana are all installed on the host Raspberry Pi.

1) Chirpstack LoRaWan IOT server

ChirpStack is an open-source LoRaWAN Network Server stack previously known as the LoRa Server [23]. It is an IOT low-cost solution for the development of various IOT systems. Its components include the bridge, network server and the application server. The Chirpstack server is hosted on the Raspberry Pi, and serves as the platform for integration of other components. This server works out-of-the-box with a modular structure that easily integrates with existing infrastructures [23]. The Chirpstack server has some features that are in line with the LoRaWan Protocol such as support of classes A, B, C devices. This also allows for bidirectional communication for monitoring and control purposes [23]. The Chirpstack server also allows adaptive data rate and provides live frame logging of the arriving data with a decoding ability to make the data readable to the observer.

2) Node-Red

Node-Red is an open-source visual editor for connecting and communicating with IOT elements supplied by IBM [24]. Node-Red eliminates the cumbersome job done by programmers, which involves significant amount of manual coding for wiring of various components used for monitoring [24]. Node-Red consists of various components majorly known as "Nodes" that simply look like icons that can be dragged and dropped in an editor interface, and can be wired together [24]. In this work, the Node-Red is used to process the data that arrives at the server.

3) Influxdb Time-series database

Influxdb is a time-series database designed and developed by InfluxData. This database is used to store any data involving large amount of time-stamped data that may include monitoring applications such as IOT sensor data for real time analysis. This data base features custom high-performance data storage written specifically for time series data. In this work, Influxdb is installed on the Raspberry Pi to store the sensor data for easy data accessibility.

4) Grafana Graphic User Interface

Grafana is a multi-platform open source analytics and interactive visualization web application that provides charts, graphs and displays. This can be integrated to various databases for visualization of stored data. In this work, Grafana is employed to visualize the various electrical parameters that were measured and stored in the Influxdb database. Grafana also has plugins that allow for control commands to be sent back to the nodes at the unit being monitored.

IV. EXPERIMENTAL SETUP

A test-bed was set up in the Memorial University's Electrical Engineering Laboratory to achieve a physical implementation of the proposed system. The setup is shown in Fig 3. The laboratory houses a PV semi-microgrid, which is consisted of 12 solar panels rated at 130 W with 7.6 A each. The system has in-built maximum power point tracking (MPPT) systems that ensure optimum operation even during periods of bad weather. This system also includes an energy storage made up of 6 batteries.

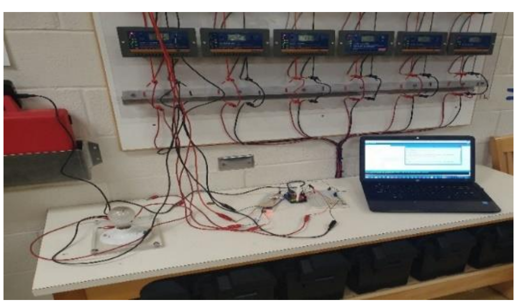

Fig 3 Experimental test-bed of the propose LoRa based SCADA system

In this work, a unit of the PV systems was monitored with voltage and current being measured. A LoRa node (Dragino Shield on Arduino Uno) with voltage and current sensors are connected to the PV systems using cables to measure voltage and current values. From these values, the Arduino microcontroller is programmed to calculate the power produced by the PV system instantaneously. The electrical parameters measured are: PV voltage, current, power, and battery voltage. These values are processed by the nodes and sent to the MTU located in another room in the Engineering building using the LoRa communication Technology. On the MTU that hosts the local Chirpstack LoRa server, Node-Red, Influxdb database and the Grafana dashboard, the received parameters are then decoded and stored in the database. The stored data is forwarded to the Grafana display dashboards for monitoring by the personnel. The proposed system also includes a downlink data transfer system that can be employed to control relays and switches at the units being monitored right from the dashboard. In this work, two LEDS are connected to the node measuring data to be turned ON and OFF to indicate control commands from the MTU using the buttons on the dashboard. This, therefore, entails that control commands can be sent from the control room to the various unit such as turning ON and OFF of various components of the unit. This will in turn improve remote monitoring and control of the system.

V. TESTING, RESULT AND DISCUSSION

The Proposed SCADA system was set up in the Memorial University laboratory to measure electrical parameters of the PV and battery generation system. The data is observed using the LoRa communication technology to the Grafana IOT dashboard, which is hosted on the Raspberry Pi, and integrated to the open source Chirpstack LoRa server, which is also hosted on the Raspberry Pi. This process is achieved right from the measuring at the node. The flow-charts of the parameter measurements at the node and processing at the Chirpstack server for storage and display are shown in Fig 4 and Fig 5.

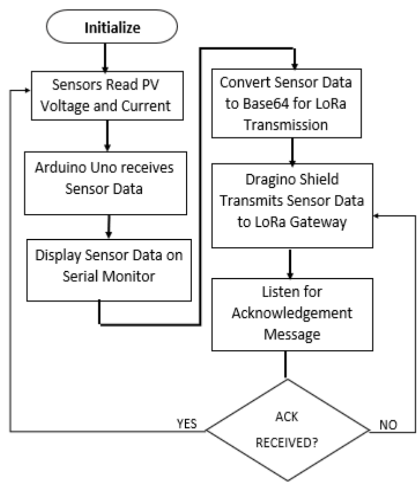

Fig 4: Flow-chart of the RTU

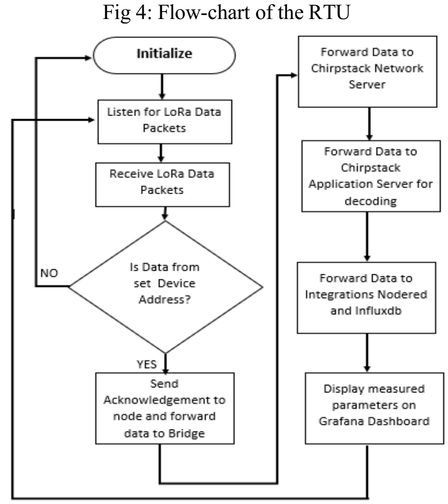

Fig 5: Flow-chart of the MTU

A. Experimental Results

The proposed system was setup in the laboratory for a period of 3 days. The parameters were measured, processed and transmitted using LoRa communication technology to the local Chirpstack local server hosted on the Raspberry Pi through the gateway. The data is then decoded and stored in the Influxdb time series database using Nodered integration and then displayed on the Grafana dashboard. The data stored on the Influxdb data based is shown in Fig 6. The Influxdb database has the ability to show data that is measured and stored up to months away. This, therefore, is very important to track the generation and operation history of the monitored system. The Grafana dashboard displays the voltages, current and power measured from the system in graphs ,which can be easily viewed by the personnel at the control plant. The real-time voltages, currents and power of the 2 monitored PV units in the lab are shown in Fig 7. The results displayed on the dashboard matched with those measured using conventional digital current and voltage multimeters. As stated earlier, the proposed system includes a control system which turns ON and OFF LEDs connected to each of the nodes which can be replaced by relays or actuators for better remote control of the unit.

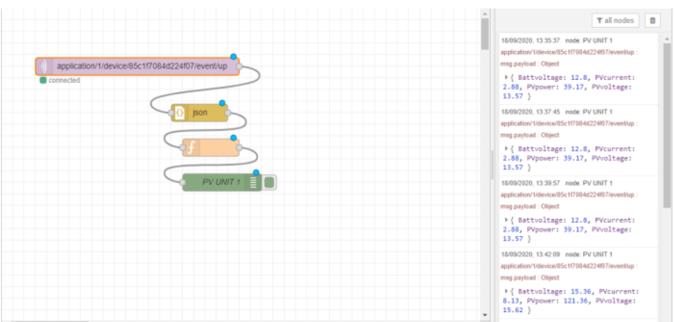

Fig 6: Node-Red flow for receiving and processing of measured data from RTU

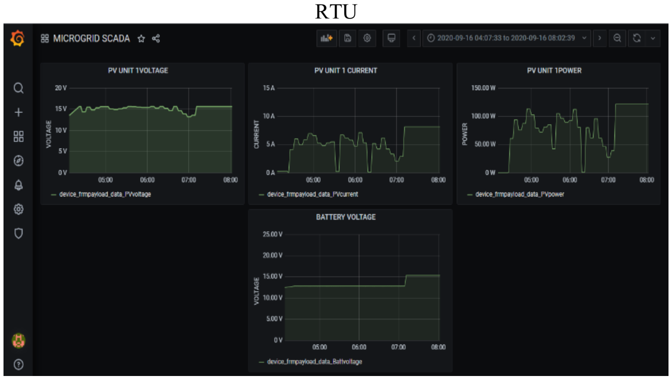

Fig 7: Grafana dashboard showing the measured values of the Unit

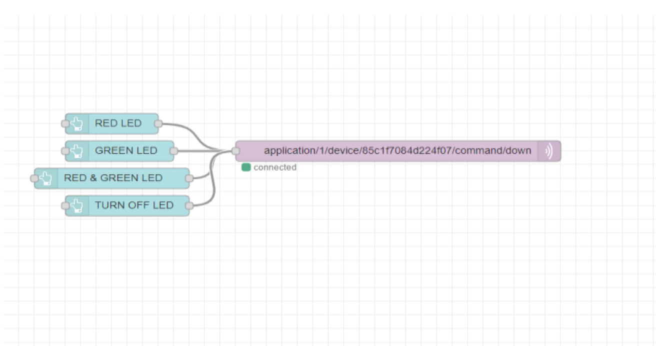

Fig 8: The Node-Red flow to control the LEDS connected to the RTU

B. Discussions

Key features of the proposed LoRa-Based SCADA system are itemized below:

- IOT-based SCADA system: Considering that the proposed system has the four basic units of the fourth generation (IOT) of the SCADA systems, it is therefore an IOT based SCADA system.
- Low-cost and open-source: This proposed SCADA system is designed and developed using a mix of various low-cost components. In addition, the software builds such as the codes and the firmware are all obtained from the GITHUB open-source code site.
- Internet independence: The communication system used for the proposed SCADA system is the LoRa physical level communication system. The server is locally hosted on the MTU. This means that the proposed system can be deployed in remote areas with no pre-existing communication technology for data acquisition and monitoring.
- Data storage: The proposed SCADA system also features the most recent IOT database Influxdb for storing sensor data with the ability to facilitate reliability analysis of the monitored system over a long period of time.
- Real time display with remote control capabilities: Grafana IOT display dashboard is used for real time display of values. It also has plugins with capability to remotely control key components of the measured system.

VI. CONCLUSION

In this paper, a low-cost LoRa based IOT SCADA system is designed and developed. Key components of the SCADA system includes: field instrumentation devices, RTU, MTU and the communication system. The SCADA system uses LoRa for data transfer due to the various advantages of LoRa communication, and its present penetration into the IOT sector. The proposed SCADA system also includes a control component which has not been observed in other low-cost SCADA systems.

The Proposed system was set up in the Memorial University Electrical Laboratory to monitor various electrical parameters. This includes: voltage, current and power of the PV system. The data is acquired, processed and transmitted by the LoRa node to the server through the LoRa gateway using LoRa communication technology. Influxdb and Grafana IOT database and dashboard are used for data storage and display, respectively. The system also incorporated an LED control system that allows remote observation and component control.

Although the proposed SCADA system has been developed for applications in electric power generating systems, it can also be deployed to any system that requires SCADA systems for data acquisition, analysis and system control.

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