IoT based Renewable Energy Management and monitoring system for the Frist Passive House in Newfoundland

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***Abstract-* This paper presents a prototype of an Energy Management and Monitoring System (EMMS) for the first house in Newfoundland built under PHIUS+2015 standards. The proposed Supervisory Control and Data Acquisition (SCADA) system is based on the Internet of things (IOT) and is designed to minimize electricity usage through self-consumption. It comprises of PZEM004T current and voltage sensor with ESP32 as the first layer controller. The controller also has control relays and a web-based monitoring and controlling platform using Ubidots development platform. The overall system can be controlled and monitored remotely with advanced web-based systems powered by Ubidots and set up triggers for excess usage of electricity by the boiler system. The user can then manually load the wood into the boiler to reduce electricity consumption. Overall, this system is scalable and can be implemented to transform the house into a smart home, which will eventually generate cost savings and promote sustainable living.**

Keywords— Internet of things, SCADA, home automation, ESP32, instrumentation and control, energy management.

I. INTRODUCTION

Electricity is the most useful form of energy, and the current lifestyle has been dependent on electricity. Recent trends have shown that solar electricity generation, with the help of a Photovoltaic (PV) system, is one of the most economical sources of alternative energy. PV Self-consumption methods have proven to be the only way to efficiently utilize electricity produced from solar energy [1]. Not only this, but there are multiple other reasons why monitoring and controlling energy produced from solar energy could be highly beneficial in both domestic and commercial environments. Several data acquisition and monitoring systems have already been developed, which are either expensive or not customizable. To address this problem, a low-cost Supervisory Control and Data Acquisition (SCADA) has been designed and produced, which can take input from multiple things (sensors, controllers, etc.) and present on a dashboard to analyze and perform specific tasks according to the requirement.

Supervisory Control and Data Acquisition (SCADA) is a technology that provides users with real-time data exchange in a control center and things/devices working in the field. The proposed SCADA system has been implemented to monitor and control components of the already designed renewable energy system. So, this proposed system can be considered as a master controller to the existing renewable energy generation grid-tie system. The design of the system mainly consists of an examination, collection and processing of data in real-time and the overall energy management system consists of three main components;

- The Master Logic Controller (MLC)
- Remote Terminal Units (RTU)
- Human Machine Interface (HMI)

The logic controller can also be considered as a master control for all components involved. This controller also helps create a bridge between the FID and RTU. FID consists of sensors, actuators and intelligent signal processing modules, and there can be multiple FIDs communicating with the central controller, which is ESP32 development kit in this case. These FIDs can include but are not limited to sensors such as power measurement, in this case, relays acting as actuators, and other switches/devices installed. RTU can also be a part of each device and has its own Human Machine Interface (HMI) system to give control to the user. All these devices send data to MLC, and then data is communicated to the SCADA system through a secure SCADA communication channel and stored on the cloud and used by the central HMI system, which is powered by Ubidots in this study. Eventually, the user can use this SCADA system to monitor and control all connected devices remotely using either a computer or mobile app using an HMI platform where all the variables and controls are displayed in real-time and chart can also be observed to view the history of the data. This HMI sends instructions back to the MLC to either turn on or off.

II. LITERATURE REVIEW

SCADA systems are one of the most important parts of solar energy and renewable energy production systems.[2] The main problem with the advanced SCADA system is the associated high price tag and compatibility issues, which makes it difficult for small-scale users and research communities all over the world to strive to develop more accessible and advance SCADA solutions [3] with each having different functionalities and varying cost. For a low-cost, open-source SCADA system using the Arduino Uno controller with the Zigbee radio module to transfer the data has been studied. The data is collected from different devices such as temperature sensors, flow sensors, pumps and control valves and software developed in java. This data is used to generate reports with an overall system that is not compatible with a number of low power controllers. Another study [4] uses a slightly different approach by using a system developed in Python. This system uses three layers approach similar to our proposed system but using Python Open Platform Communication Unified Architecture and MySQL database language. Raspberry Pi3 and PLC are also added for control and supervision layers, respectively. This system design has greater power consumption than the proposed system. There have also been attempts to use low power electronics ESP32 boards to develop the SCADA system [5]. This study uses a subscription-based HMI system that limits the number of devices for free users, and pricing depends on the number of devices added to the system. Other studies using SCADA technology for devices/things connected through the Internet have been found to have a similar concept with implementation using Honeypots [6]. Cloud-based Amazon Web Services (AWS) have also been reviewed [7] in comparison to the private network-based system [8], which does not give a whole lot of flexibility to the end-user for IoT management.

Studies have also been reviewed, which are using artificial intelligence for automated control of all the devices connected in a house, which can also be called the Internet of Things (IoT). In this methodology, less control to the end-user is given for manual control of the devices [9], which can be programed afterward using hybrid simulation system prototypes that has been studied [10]. Transferred data of the daily usage and patterns can be stored in huge databases to train and optimized machine learning algorithms [11] for high accuracy and automated control to save energy expenditure for cost saving in an IoT based smart home system.

An advance approach seen in the previous study [8], which has also adopted in our project, is to combine different small scale RTUs to communicate to a central SCADA system [12] and using an open-source SCADA system can save cost and time for development and gives flexibility to the end-user to add more functionality on the later run. Mayur et al. [13] and Ikhsan et al. [14] has proposed an open-source system using micro-controller AtMEGA 2560 with SCADA Vijeo Citect and ArchestrA System Management Console, respectively. As the RTU operates independently operated with either own controller collects data from sensors and using Modbus protocol as the communication channel between the MLC and the RTU. Similarly, authors in recent studies [15][16] have developed a low-cost SCADA system based on IoT technology, where RTU is communicating through TCP/IP to the field devices, which eventually is management by a data traffic management system process. The major problem with these types of designs is as the system gets complex with multiple devices, it would be difficult for an end-user to troubleshoot.

III. PROPOSED SCADA DESIGN

The system proposed system architecture is based on a SCADA system that incorporates IoT using a low-cost ESP32 microcontroller and implementing recent research SCADA architecture discussed earlier [5,8,12,15]. For a general understanding of the system, Figure 1 presents a high-level description of where the proposed approach is represented as an Energy Management System (EMS). PV array inputs the inverter MPPT, which is then converted into pure sine wave AC to supply to the grid as well as house load, including a water heating system. There is a gird-tie inverter that supplies excessive energy to the grid as well as takes the energy from the grid when there is not enough solar irradiance to produce enough power for the connected load. This DC generated power is fed to the battery bank and also provided to the energy management system. There are current sensor and voltage sensor, which gives the analogue signal to the Master Logic Controller (MLC) with a built-in analogue to digital converter. MLC consists of KeeYees development board 2.4GHz Dual Core with WLAN WiFi capabilities with Microcontroller ESP-WROOM-32 Chip CP2102 for ESP32.

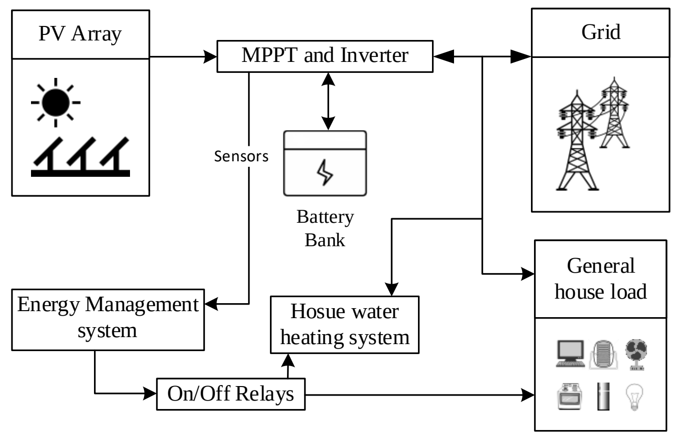

Figure 1 High level design of the complete system.

The other task for the MLC is to get energy consumption data for the water heating system and display it on the HMI system. Part of this HMI system consists of a dashboard board powered by Ubidots IoT platform and free for educational use. This HMI system will let the user see the historical data and control specific home appliances which are categorized under non-critical load for the house. The overall approach is explained in the following section.

A. Working of the SCADA system:

To understand more in-depth, EMS shown in Figure 1 can further be expanded into Figure 2, which represents a more detailed version of the proposed system. Here it can be seen that power consumption from PV is monitored with ACS172 current sensor and voltage divider circuit for a level of voltage. This parameter is later used to monitor the power supplied by the grid. If there is a significant drop in power while it is still daytime, it is clear that there is snow blocking the PV panels, and the manual process of snow clearing is initiated by sending an email to the house owner. This HMI system is flexible enough to give freedom to an end-user with other ways of notification since the data is already being monitored.

Secondly, power consumption by the water heater is also monitored by the MLC with the help of PZEM-004T 3.0 version TTL Modbus-RTU power meter. This power meter has a measurement accuracy of 0.5% and can measure AC current up to 100A with other variables like voltage, power and frequency. This water heater uses both wood and electricity for water heating, so there is a potential to monitor and save electricity if it is being used more than usual. Also, other house loads can be controlled and monitored from the Dashboard of the SCADA system. Instead of publishing the value on the Dashboard, Ubidots and Arduino library for ESP32 let you subscribe to the variable for continuous monitoring and control of the variable. As this variable changes values from the Dashboard when the user decides to turn off/on a switch remotely, ESP32 fetches the value of the respective variable, and an immediate signal is sent out to the output pin of the ESP32 controller. This whole process activates the relay to turn on/off the appliance.

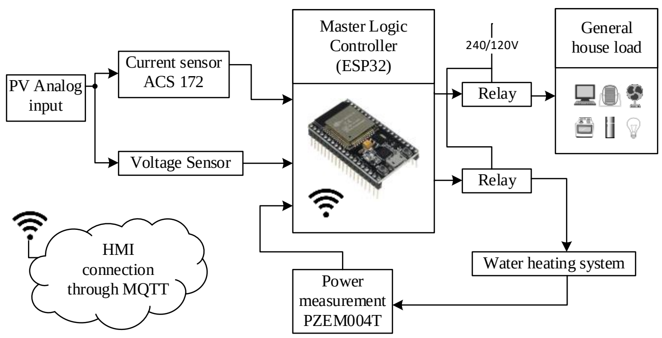

Figure 2 Detailed structure of the Energy Management System (EMS).

B. Description of SCADA

Sensors feeding information to the SCADA system are the FIDs for the RTUs to get real-time data for users which can be remote to monitor and control the system. The EMS follows a three-layer SCADA system [17], where the current and voltage sensors are at the base layer. There can be temperature or humidity sensors added to the system using a similar framework.

For analogue signals coming out from the PV generation system, a step-down resistor arrangement has been used, which can be seen in Figure 3. Equation 1 is used to calculate the voltage, which uses a voltage divider circuit. A similar circuit is used for voltage sensing. ACS712 takes 5V input to operate and uses series connect for power in and power out to generate the voltage ratio accordingly.

$$V_{out} = \frac{R_1}{R_1 + R_2} \times V_{in} \quad (1)$$

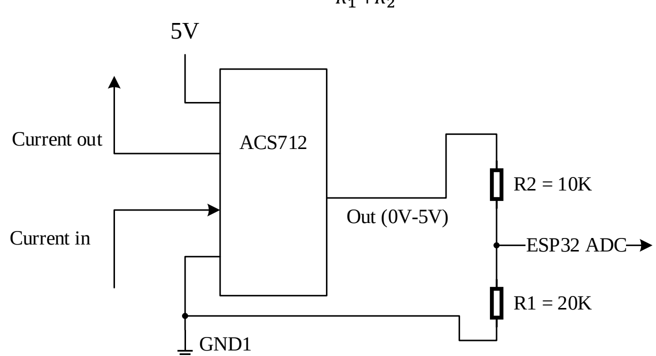

Figure 3 ACS 712 Pin configuration.

Figure 4 shows the circuit diagram of the power meter IC PZEM004T. There is a potential divider logic shifter circuit that has been used to shift the voltage from 5V to 3.3V. PZEM004T provides output in the form of 5V and 0V during serial communication, and ESP32 has a standard operating voltage of 3.3V. All inputs to ESP32 should be 3.3V; for that purpose, equation 1 has been used, which gives 3.3V when there is 5V applied.

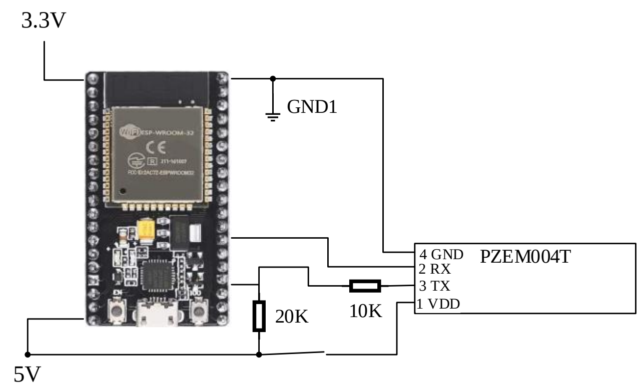

Figure 4 PZEM004T Pin Configuration .

C. Approach and methodology

After a clear understanding of the system requirement and architecture, it is time to understand the programming approach and what is going on behind the scene. Figure 5 describes the exact flow of the SCADA system's data and processes, as explained earlier.

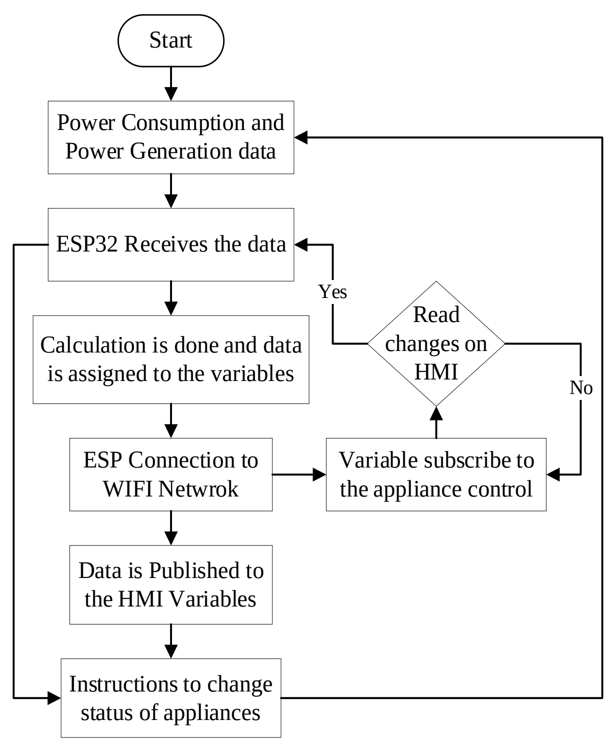

Figure 5 Flow chart of the SCADA system.

Firstly, analog and digital sensor data is read, which is collected from the PV system and water heater. ESP32 reads the sensor values on analog pin 26 and 25 for the calculation of the value of power supplied by the solar system. 27 Pin is connected to the PZEM-004T for serial communication to get the power value for later to show on Dashboard. ESP32 then connects to the WiFi, which is local TCP/IP, using a unique WiFi name and password that throughout remains unchanged. ESP32 uses the MQTT protocol to connect to the Ubidots platform, where similar variable names take the value to publish on the Dashboard. MQTT client identifies the MLC with a unique ID referred to as a Token number. The HMI system provides this Token number for security and authentication purposes and remains unchanged for the account.

As the user interacts with the Dashboard and values changes for the on/off control of the appliances, these values are then sent out automatically to the variables subscribed for the values. Pin 12 and 13 send a signal that activates relays to turn on/off sequence for respective appliances. Figure 6 shows the prototype testing setup for the SCADA system. Two electric bulbs are being used

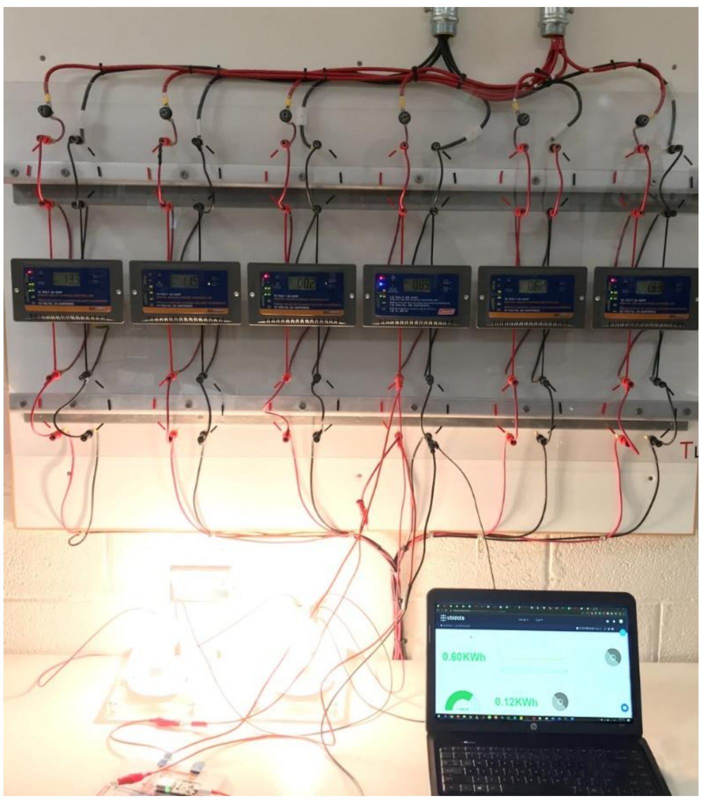

Figure 6 Experimental setup for the SCADA system testing.

IV. Simulation and Results

Ubidots IoT platform provides a user-friendly Dashboard where real-time data can be seen, and charts can be accessed remotely. Figure 7 shows a screenshot of the Dashboard for the prototype of the proposed SCADA system using Ubidots IoT platform. As can be seen, a real-time graph can be seen, which shows the historical data stored in the cloud as well. There is a demo of real-time power consumption data for the water heating system. Users can create multiple kinds of real-time visualization, and all this can be done remotely using an internet connection and an online Dashboard. Ubidots also have an android as well as an iOS app to support all kinds of environments and provide accessibility to the end-user. Finally, there can be seen two switches in a gray circle that can give live feedback to ESP32 controller's variables subscribed to these switches. An operator can also initiate automated supervisory checks and control actions where a particular script or task can be performed at the given condition. An email is sent out to the user, reminding them to clear the snow if solar power generation is less than a threshold of 0.1kWh. This alert can be changed to a text message with the option provided by the HMI system.

Figure 7 Ubidots Dashboard prototype for the proposed SCADA system.

V. Conclusion

The idea of the SCADA systems have revolutionized the industrial systems for complex automation control, visual inspection and monitoring. This idea comes in great help when there are multiple systems from different manufacturers that need centralized management and monitoring. For a futuristic house design where various appliances are connected from different manufacturers, and there is a need for efficient control and monitor of energy expenditure. The proposed system is scalable and, most importantly, affordable, with the overall cost of implementation to be below $300CAD. Moreover, acquiring real-time data from PV and water heater and remotely monitoring it on the Dashboard can improve the efficient usage of Photovoltaic electricity. Not only that, but the system also enables end-users to turn off home appliances with the ability to gain more control over the energy expenditure. This is going to be another step closer towards sustainable living.

VI. Future work:

This system has been designed as a prototype with the ability to add more devices in the future. This will enable the user to gain full control of the house and make it more smarter with an automated check and conditional algorithms. Multiple devices can be turned off when they are not being used, or multiple houses can be connected and monitored simultaneously. Most importantly, this idea is not only limited to an energy management system for a house. A lot of industries like pharmacies, traffic control systems, data centers and small businesses can implement this system with added security using encrypted communication between HMI and MLC.

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