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Microcontroller-based Control and Data Acquisition System for a Grid-connected Renewable Energy System

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Abstract

There has been a significant increase in the exploitation of renewable energy systems. To be able to efficiently utilize grid - connected renewable energy sources, there must be a reliable control and monitoring system. In building a control and monitoring system for this system, a power analyzer connected to a microcontroller was used. The microcontroller was linked to touchscreen display where a graphical user interface (GUI) was programmed to able to display and log the data recovered. Relays were used to reconfigure the system by shifting the load's source of energy between the grid and renewable energy system. The energy generated by the renewable energy system may be delivered to the load or be fed to the grid as needed. This operation will be done through either an external device or through a computer which was built to manually operate the control system and view the status of the system as determined by parameters such as cost and energy consumption. This system provided residential buildings with their own renewable energy system with a simple yet reliable control and monitoring system. The system was able to accumulate accurate and real time data. It also provided a continuous supply and switching application simultaneously

***Keywords**: Renewable energy, Control system, Data acquisition, Microcontroller*

1. Introduction

The energy demand is increasing as the world's population increases. Coupled with the dependency on conventional type of power plants to generate electricity, the supply for energy decreases steadily. As a result, these commonly used fuels are becoming more expensive due to high demand. Most of the power generating systems in the world are operated using non – renewable resources which includes: coal, petroleum, natural gas, nuclear energy and others. Due to the immense amount of usage of these resources, it is depleting rapidly and will eventually run out [1].

Also, the use of these resources endangers the environment living beings live in. Greenhouse gases are produced when these resources are burned to generate electricity. Greenhouse emissions are increasing due to carbon emissions from power plants which causes global warming which makes the weather more unpredictable.

With this, researches has focused on the use of renewable energy sources which could provide continuous supply of energy without direct negative impact to the environment [2]. The aim of utilization of renewable energy is to decrease the gap in the energy balance and to reach out to the rural areas in energy production with minimal emissions [3]. There are numerous ways to harness renewable energy through the use of wind turbines, solar panels, and other devices depending on the source or prime mover available.

Utilization of renewable energy technologies is clean because it does not produce noise and pollution. Different renewable energy systems also make use of control systems in order to perform operations in monitoring and instrumentation. The utilization of renewable resources can help balance or negate the crisis that is currently enveloping the world. Renewable resources is also considered to be clean energy and offers minimal risks with regards to the well-being of the environment. There are different forms of renewable energy such as wind, solar, biomass, geothermal, biofuels, hydroelectricity, and others. This research is centered on harvesting these sources of renewable energy as an alternative resource.

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This system which consist of several input and output devices combined with the renewable energy system can be controlled using a microcontroller [4]. An external touchscreen display and a programmed software in a computer is present in the system that can retrieve data accumulated by the microcontroller. Data accumulated by the microcontroller mostly came from the power analyzer. The software component was incorporated in the design mainly as the control center where a microcontroller was the center of this control system. It can be compared to Supervisory Control and Data Acquisition (SCADA) system typically used in massive power grids.

Existing control system using SCADA was used in several application that needed supervision of power flow running through the system. Acquiring SCADA system is beneficial due to its high accuracy in measuring data. An accurate measurement of data gave decent similarities to the actual value of the power flow. Similarly, the whole process can be controlled and managed in both manual and automatic modes depending on the instruction that have been set. Automation performs an important role in the current set-up of the economy and industries [5].

The purpose of this research work was to create a microcontroller-based control system which supervised the power output by the grid-connected renewable energy system. The system provided monitoring system that recorded power flowing through the load and the grid from the renewable energy system. Power flowing from the grid to the load was also monitored. This only occurred when the renewable energy system could not meet the demand of the load. This system is manually controlled and requires a personnel to be able to perform control operations. Monitoring however is continuous once the system starts. This system is designed to provide residential buildings a monitoring and control system accurate enough to predict and manage their monthly or annual electricity consumption.

2. Research Method

This research study was composed of two systems, namely: Control System and Monitoring System. In the control system, the component used to perform switching operations was a double-pole double-throw (DPDT) relay. The relays were controlled via touchscreen interface which was linked to the microcontroller. Relays may also be controlled using a computer wherein a software is developed using processing. The microcontroller used was Arduino which was programmed using C++ programming language and it acted as the brain of the system which processed several inputs and outputs. In the monitoring system, a power analyzer was used to measure parameters such as voltage, current, power, and energy. This component is compatible with the microcontroller which made it efficient for data retrieval and storage. Depending on the user, supply of the load can be transferred between the renewable energy system (RES) and grid. Also, depending on the user, power generated by the RES or grid can be fed to the grid (electric cooperative) or used to supply the load. The only mode not available in the control system is the grid to electric cooperative configuration. Monitoring system was present to determine power consumption from grid, power sold to the grid, and power consumption from the RES.

Electricity rates for the RES and grid are manually entered by the user in the settings tab in the interface via keypad. Another way of entering rates is through the GUI developed in the computer. The GUI is developed through processing software. Rates entered must have a unit of peso per KWh. All of these functions and operations can be accessed through touchscreen display or computer software. With this, monthly electricity consumption and cost can be determined and compared to the monthly electricity bill. Both systems are integrated in the external touchscreen display and computer software. Designing was a crucial stage in building the foundations of a system and the design of the control and monitoring system determined the overall performance of the whole system. The design implemented in this research project is shown in Figure 1.

The renewable energy source, battery, and inverter represented the renewable energy power generation system. The cooperative represented the grid wherein power was sold or fed. The microcontroller served as a channel wherein the user, through the meter module, communicated with the output devices to shift the flow of energy as needed. Power analyzers were the monitoring components. The microcontroller retrieved data from these components and displays it through the touchscreen display or graphical user interface in a computer. At default, control of the system is initially on the graphical user interface on the computer. Control can be transferred to the external touch screen device through the graphical user interface. Computer and external device is linked via cable, data transfer is possible due to this. Before initializing, user will be prompted to enter the username and password as an added security feature. As shown in Figure 1, the system built is self-sustaining. The microcontroller is tapped directly to the output of the renewable energy system making it possible to run 24/7. This microcontroller consumes a very small amount of energy which makes its power consumption negligible.

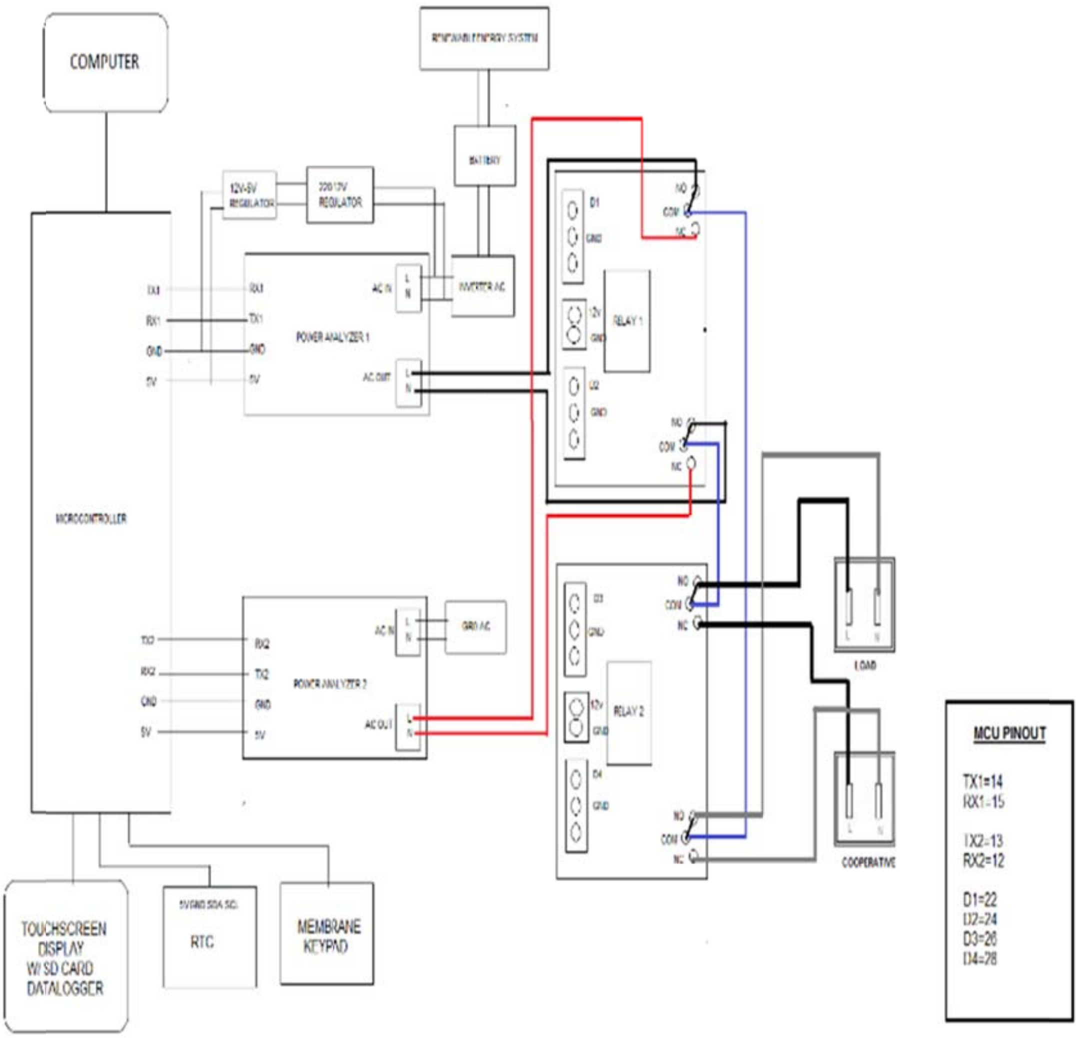

Figure 1. Block diagram of the microcontroller-based renewable energy system

The relay circuit designed was to be able to switch from two different sources of energy and two different load circuit. This was possible using two relays which are both a double pole double throw (DPDT) type. Relays are actuated by a set triggering pin in the microcontroller. Figure 2 shows how the relay system performed its switching operations. Relay 1 and 2 are both DPDT type of relay. At default, the loaded circuit is connected to the renewable energy system. If DPDT1 is triggered via touchscreen control, supply is transferred to the grid. During this time, DPDT2 should not be actuated since a grid to grid connection is not desired. The system is designed to perform only three modes: RES to load, RES to grid, and grid to load. DPDT2 reconfigures the circuit from loaded to no load circuit.

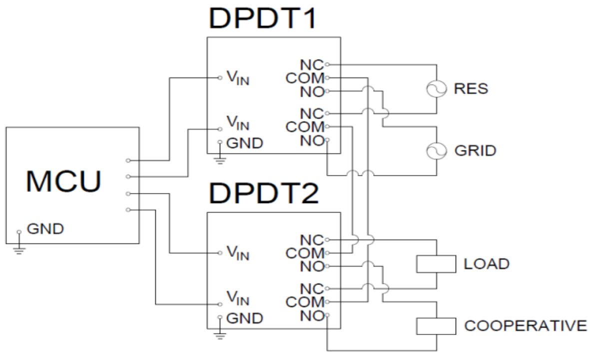

Figure 2. Relay circuit design

The system operations are done manually and requires a user to be able to function as desired. The controls wherein the user may interact with the output devices can be operated through the touchscreen display or computer GUI. This touchscreen module and GUI enables the user to trigger the relays and switch the supply or load circuit as desired. Figure 3 shows the logic for both supply and load relays.

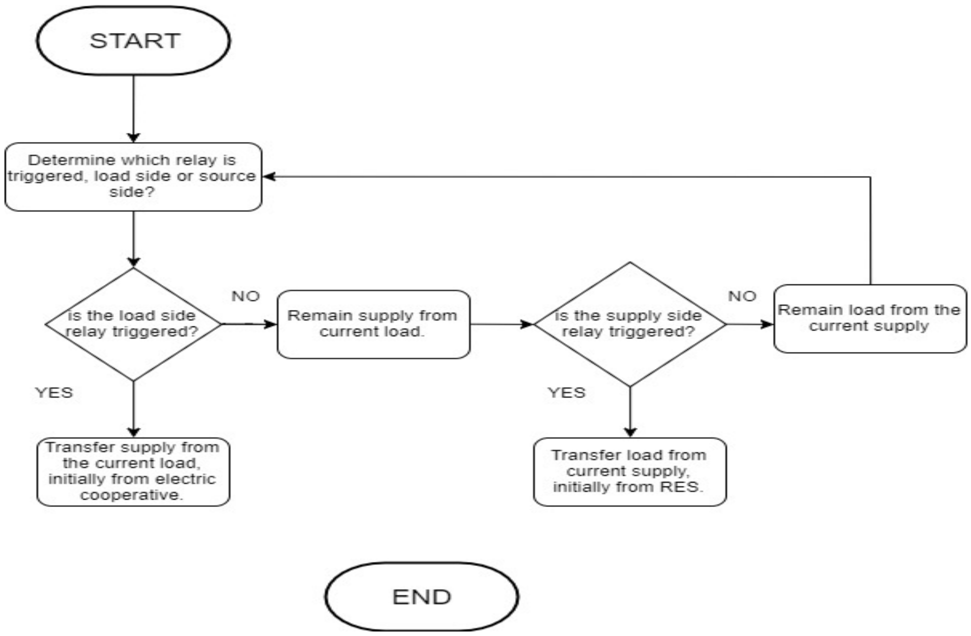

Figure 3. Relay circuit logic

Both relay have the same logic but has different circuits to reconfigure. When the system has identified that the user triggered the relay, for the supply, it will transfer load from renewable energy system to the grid. When triggered again, it will return to its previous circuit. For the load relay, if triggered, from the loaded circuit it will be reconfigured to the no load circuit. The figure shown below displays the logic of the graphical user interface programmed in the computer using processing software. It is a java-based program.

As shown in Figure 4, the GUI prompts the user for its username and password. It won't proceed to the control and monitoring system unless the user provide the correct registered details. Initially, when the system boots it is initially in mode 0. Mode changes can be done through a button in the GUI.

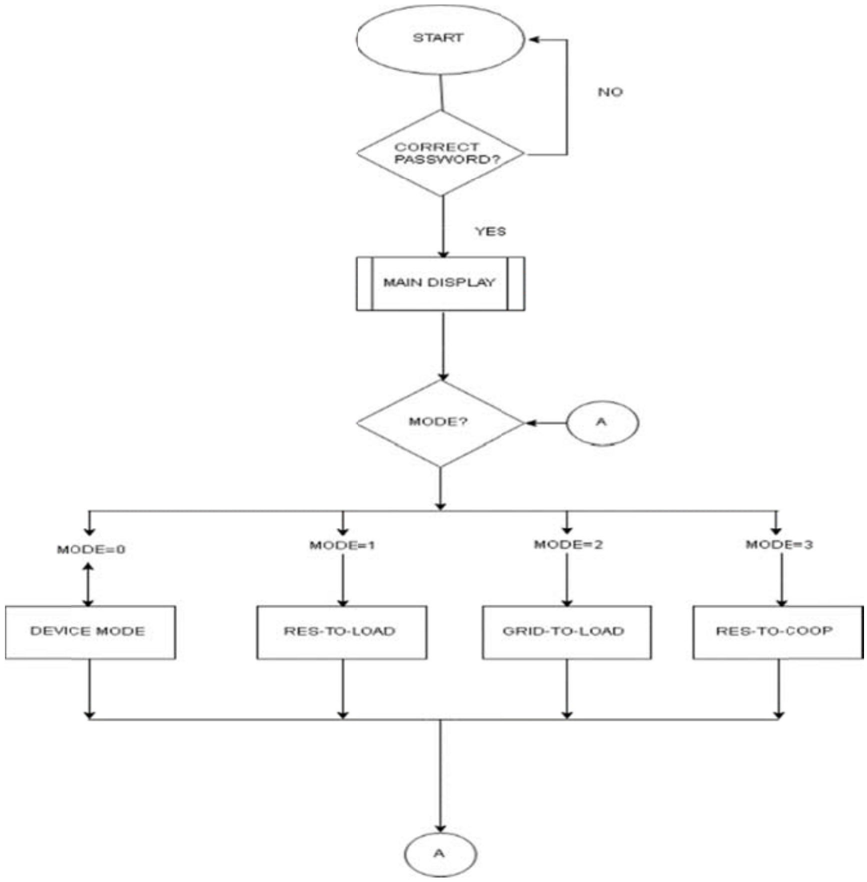

Figure 4. Graphical User Interface Logic

The components responsible for the measurements are the power analyzers. These power analyzers read different parameters such as voltage, power, and current. To be able to make these data useful, the microcontroller is programmed to retrieve data coming from these components. Data retrieved is displayed through either the touchscreen display or computer GUI, depending on which device is presently active. Data retrieval was developed by programming the Arduino using c++ code. Both interface are programmed to organize and filter data coming from other components connected to the system. The data are stored and logged in a memory card on the external touchscreen device. A memory card slot is present in the touch shield module. Data stored may be transferred and read in a computer via memory card. The interface was programmed to store data hourly, daily, weekly, and monthly. Data logged may also be viewed via touchscreen display. A real time clock module is present in the system to keep track of time even if the system experiences power interruptions. This makes the data logging more accurate and precise in accordance with time.

The Arduino was programmed to accept input commands from an external module which is the touch shield resistive touchscreen. A touch shield compatible for Arduino microcontroller was used so that operations may be executed without the presence of a computer. Using this module, data is monitored real time and relays may be triggered via touchscreen controls. A resistive touchscreen was used since the prototype, when implemented, is exposed. The main body of the touchscreen, however, is enclosed in a durable casing. This makes the dust and water resistance quality of the resistive touchscreen a useful characteristic. Also, a 4x4 keypad is linked to the touch shield module for numerical input of rates. Rates for both grid and RES are manually entered via keypad. Rate are not computed but given by the supplier. This can be accessed through the settings tab in the interface. A period symbol cannot be entered to the interface via keypad since it eats up too much of the microcontroller ram, therefore the system is programmed to divide the entered rate by a factor of 100. This enables the user to input decimal numbers.

3. Results and Analysis

3.1. DPDT Relay Response to GUI Command

The DPDT relay response through the interface was determined. The test conducted determined whether the system is functioning as programmed. The relay was switched between LOGIC HIGH and LOGIC LOW using the interface for a series of trials to determine the actual response of the system. The data gathered shows that the GUI developed on the computer is communicating with the microcontroller properly with its 100% accuracy and precision for all thirt (30) trials. On the other hand, DPDT relay actuation is dependent on the user.

3.2. DPDT Relay Response to External Touchscreen Display Command

The DPDT relay response in accordance with the interface was determined. The test conducted determined whether the system is functioning as programmed. The relay was switched between LOGIC HIGH and LOGIC LOW using the interface for a series of trials to determine the actual response of the system similar to the first test.

The data gathered shows that the touch shield touchscreen component is communicating with the microcontroller properly. This also means that the microcontroller is programmed according to the design while DPDT relay triggering is also dependent on the user. It was observed that the response of the DPDT relay with respect to the interface command is 100% accurate and precise.

3.3. Load Power Reading in Response to Load Configuration

This test was conducted to determine whether the output of the system is as designed. The power readings at the load was used to determine whether there is power supplied to the load whichever configuration it may be. The load used for the test was a 24 watt bulb. A 24 watt bulb was used to have greater power consumption in a short amount of time. With this, variations can be easily seen on the parameters being observed. In this test, the DPDT relay was triggered from LOGIC LOW to LOGIC HIGH and vice versa to determine if the design is being executed.

3.4. System Accuracy Test

In this test, the monitoring system accuracy was tested. With the help of a digital multimeter, actual values are determined and compared to that of the system values. Parameters such as voltage, current, and real power are measured and compared to that of the system readings. The load used for this test is rated 30W.

Using the data accumulated in Table 1, comparison from two different measuring methods was conducted. The null hypothesis for this test is that both methods of measuring real power have the same results while the alternative hypothesis is that two different methods give different results. Statistically comparing both methods, the mean equation 1 and standard deviation equation 2 for both methods were calculated. Also, the pooled estimate of standard deviation equation 3 was calculated to get the t value in equation 4. This t value is then compared to the critical t value with a confidence level of 95%.

$$\bar{X} = \sum_{i=1}^{n} \frac{X_i}{n} \tag{1}$$

$$S = \sqrt{\frac{\sum_{i=1}^{n}(\bar{X}-X_i)^2}{n-1}} \tag{2}$$

$$S_p = \sqrt{\frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}} \tag{3}$$

$$t = \frac{|\overline{X_1}-\overline{X_2}|}{S_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \tag{4}$$

$$df = n_1 + n_2 - 2 \tag{5}$$

Table 1. RES to Load connection: Comparison between System and Measured Value

Trial No.	Real Power	
	System Values	Measured Values
1	29.93	28.60
2	30.63	28.70
3	30.61	28.50
4	60.65	28.52
5	29.98	28.80
6	30.59	28.63
7	30.60	28.66
8	30.31	28.88
9	30.08	28.50
10	29.98	28.61
11	30.15	28.70
12	30.63	28.71
13	30.57	28.65
14	30.24	28.61
15	30.07	28.57

Results shown in Table 2 were calculated using equations 1 to 5. These values were used to determine whether to reject or accept the null hypothesis. Rejection or acceptance of null hypothesis is dependent on the condition that the computed t is greater than the critical t value given on the t table.

Table 2. T test Results on RES to Load connection

	System Values	Measured Values
$\bar{X}$	30.334	8.642667
S	0.285577	0.106131
S_p	0.215428	
df	28	
t	21.500993	

The calculated t value was computed to be 21.500993 while the critical t value given on the t table with a degrees of freedom of 28 at 95% confidence level was 2.048. Therefore, null hypothesis was rejected. This has proven that there was a significant difference in terms of result and the system was not 100% accurate. A different circuit connection was tested but having the same process and hypothesis as the RES to load connection. Data gathered are shown in Table 3. Using these values, the t test was conducted and results are shown on Table 4.

Table 3. Grid to Load connection: Comparison between System and Measured Values

Trial No.	Real Power	
	System Values	Measured Values
1	30.15	28.50
2	30.08	28.51
3	30.12	28.50
4	30.02	28.53
5	29.98	28.47
6	30.21	28.63
7	30.33	28.57
8	30.25	28.50
9	30.03	28.66
10	29.96	28.54
11	30.12	28.70
12	30.36	28.60
13	30.42	28.55
14	30.22	28.62
15	30.09	28.50

Table 4. T test Results on RES to Load connection

	System Values	Measured Values
$\bar{X}$	30.156	28.558667
S	0.139887	0.068751
S_p	0.110216	
df	28	
t	39.689955	

The critical t value for this configuration was still 2.048 since the degree of freedom was still the same. It can also be seen in this test that the t value was greater than the critical t value. Thus, null hypothesis was rejected. The last configuration tested was the RES to COOP connection. Data gathered are shown in Table 5.

Table 5. Grid to Load connection: Comparison between System and Measured Values

Trial No.	Real Power	
	System Values	Measured Values
1	29.98	28.50
2	30.67	28.51
3	30.55	28.40
4	30.66	28.55
5	30.48	28.42
6	30.33	28.64
7	30.05	28.68
8	29.97	28.52
9	30.15	28.45
10	29.96	28.61
11	30.43	28.50
12	30.55	28.60
13	30.67	28.40
14	30.33	28.51
15	29.98	28.60

Table 6. T test Results on RES to Load connection

	System Values	Measured Values
$\bar{X}$	30.317333	28.526
S	0.278938	0.086998
S_p	0.206609	
df	28	
t	23.744119	

The same result occurred even with different configurations. With this, it was concluded that the system was not 100% accurate and there is a deviation between the system value and the true value.

4. Conclusion

The system was determined to be able to execute all of the functions of the design. Switching mechanism and monitoring are fully operational as determined through tests. Based on the outcomes of the research, the control system effectively executed its programmed function. Initially, the control system linked the renewable energy system (RES) to the load. Circuit reconfiguration only occurred when manually triggered through either of the interface as observed. The system had three modes: RES to load, RES to cooperative, and grid to load. A double-pole double-throw (DPDT) relay was responsible for both load and supply switching. The monitoring system ran continuously 24/7.

The data from the power analyzer were logged hourly, daily, weekly, and monthly which can be accessed directly through the interface of the prototype or be transferred to a personal computer via an SD card. These can be read and analyzed through Microsoft excel. The system was also able to filter data received and display only the required parameters which included voltage, current, real power, apparent power, reactive power, and kilowatt-hour. Rates at which electricity was being charged and/or sold were manually entered via keypad as designed. The last entered rate was stored even if there was power interruption. The real time clock module installed enabled the system to keep track of time even when power interruptions occur. The system was designed to be self-sustaining. This enabled the system to run 24/7 even if there are power interruptions in the grid. Lastly, the system was able to provide a reliable summary of the consumption from grid and RES. This system enabled keeps users in track of their consumption and sold energy to the electric cooperative.

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