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Article

Microcontroller-Based Strategies for the Incorporation of Solar to Domestic Electricity

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Abstract: Microcontrollers have been largely used in applications that include reducing power consumption. Microcontroller development tools are now readily available. Many countries are faced with energy challenges such as lack of enough power capacity and growth in energy demand. It is therefore important to introduce innovative methods to reduce reliance on national grid energy and to supplement this source of energy with alternative methods. In this study, the microcontroller is used to monitor the energy consumed by household equipment and then decide, based on the power demand and available solar energy, the type of energy source to be used. In this research, a special circuit was also designed to control geyser power and align it to the capacity of the renewable energy source. This geyser control circuit includes a Dallas temperature sensor and a triode for alternating current (TRIAC) circuit that is included to control output current drawn from a low power, renewable energy source. Alternatively, two heating elements may be used instead of the TRIAC circuit. The first heating element is powered by solar to maintain the water temperature and to save energy. The second heating element is powered by national grid power and is used for the initial heating, and therefore saves water heating time. The strategy used was by adding a programmed microcontroller-based control circuit and a low power element or one current controlled element to a geyser whereby Photovoltaic (PV) energy was used to save the energy geysers consume from the domestic electricity source when they are not in use. A microcontroller, current sensor, battery level sensor, and relay board was used to incorporate solar-based renewable energy to the commercial energy supply.

Keywords: incorporation of solar; microcontrollers for solar; solar to domestic electricity; photovoltaics

1. Introduction

Challenges can arise when photovoltaic (PV) energy is used as a primary source of electricity, such as instability, which results from this energy source and it is very difficult to predict when the sun [1,2] will give out enough energy. Atmospheric conditions such as dust, fog, cloud cover, etc. can change spontaneously and therefore affect the availability of solar energy [3]. Consumers can only increase the capacity of PV energy by purchasing high power solar panels in large numbers and batteries to be prepared for longer periods with less sun irradiance, thus increasing the system cost. It is for these reasons many people are still not using solar power as a source of electricity [4]. Solar energy is described as one of the cheapest, cleanest and easily obtainable energy sources [5]. However, the initial cost of PV energy systems is much higher when compared to that of non-renewable sources [6]. PV systems can be categorized as grid-connected and standalone systems. Grid-connected PV systems are characterized by a connection to the local grid, and their loss of power in the absence of the sun unless they are used with a backup source [7]. The continued monitoring of several parameters in photovoltaic devices will lead to effective usage of solar energy [8]. The microcontroller has been used to acquire various signals for monitoring purposes or to control activities such a battery charging and solar tracking [9]. PV energy was used to optimize the performance of auxiliary power source by employing an automatic transfer switch [10]. A study to employ PV energy for landing crafts and therefore reduce their gas emission and fuel consumption was conducted in [11]. Microcontrollers were also used to interface PV-derived energy with the grid supply as a way of providing a reference point for synchronization [12]. A multi-control single-input switch was used to select between diesel, wind and photovoltaic sources in [13]. PV energy was integrated to the smart grid system by using energy management systems that shifted load connections from one energy system to the other during certain time slots [14]. Fuzzy logic was also used to manage energy consumed by loads as means of reducing electrical bills [15]. The application of solar-derived electrical energy directly to DC water heating element has been studied in [16]. There are ongoing studies for the continued improvement of photovoltaic/thermal (PV/T) in water heating applications as in [17–19]. Although energy management techniques are available and several strategies are used to reduce energy consumption in water heating, a research gap is available to study methods of incorporating off-grid PV systems into the domestic supply irrespective of the PV system size or the load capacity. The developments in sensors and microcontrollers formed a good support base and their broader application was demonstrated [20].

In our research, we have used sensors to detect the available solar resources, water temperature and load current. The microcontroller selects utility supply for cold-water temperature and/or higher load currents. Energy produced by a standalone photovoltaic system is selected when its capacity matches the load condition. As a result, any PV system size can be incorporated to a domestic supply where high power applications (where energy is consumed at a faster rate) are reserved for a non-renewable source. A renewable energy source will be then used to supply low power devices or operate when energy consumption is at a slow rate. The microcontroller also chooses the geyser current profile to be used based on the selected energy source. High current is used for initial heating and low current to increase the water temperature at a slower rate to ultimately keep the water warm. Irrespective of the PV system size and load capacity, the research still offers benefits that includes reduction of carbon emissions, prevention of complete blackouts during the absence of utility supply and partial powering of electric water heaters by using photovoltaic energy.

2. Similar Studies

Previous researchers studied electrical energy consumption from commercial sources to support the regulations of consumptions. A survey to study the consumption of electricity by small and medium enterprises was conducted [21]. The aim in this study was to enforce a mindful electricity usage by using campains, elevated energy prices and rebates for lower consumptions. In [22], other authors presented on how law can be used to impose the regulation of energy consumed from the national grid. ISO 50001 is the standard that governs the use of supplied energy. Ineffectiveness of electricity usage was studied for a municipality in [23]. In this study, various legislation used for the regulation of energy consumptions are listed.

This research is aimed to encourage a reduction in energy consumption from the national grid; however, a technical solution is used whereby the solar energy is incorporated to supplement grid supply as opposed to legislation.

The study has attempted to unify several aspects that can bring along one solution to enable simultaneous use of both (renewable energy source) RES and domestic electricity supply source. The microcontroller continuously monitors the battery level, water temperature and load current. The monitored parameters influence a choice of electrical energy supply source. For these reasons, individual studies discussed in this section can only cover fewer aspects; however, collectively, they will cover most of them.

2.1. Microcontrollers and Energy Management in PV Systems

Other researchers designed an embedded low-cost microcontroller-based logger for the PV system in [24]. In their research, an Arduino microcontroller is used to control activities of the modules such as current sensors, temperature sensors and analog-to-digital convertors that were interfaced by using a variety of protocols. This prototype has 18-bit resolution and provides eight analog inputs that can be used for measurement of up to eight photovoltaic modules within an array or string. Measured current can be either DC or AC, and shunt resistors were used for the detection.

Other researchers have accomplished remote monitoring of PV currents by using a hall current sensor that is interfaced to the Arduino board [25]. Zigbee-based communication is a protocol used for the transmission of data to the receiving system that has a LabVIEW-based application. In this application, data is received via the USB port connected to the wireless signal circuit. A DC current of 1.5 amps has been detected and transmitted for monitoring.

A system that uses a microcontroller to disconnect a load that consumes power that exceeds the set limit of 500 W was prototyped in [26]. Here, the system is also able to protect generators against excessive load currents. In [26], the relays that are driven by NPN transistors are employed to do the switching and a current transformer is used to perform the current detection.

A unit that can alter the load connections between the generator, PV energy source and domestic utility was designed in [27] and ATMEGA16L uses the relay board to select the appropriate supply based on the availability. The prototype also includes a LCD screen to display the status.

A home energy management system was used to switch DC and AC load connections between the installed PV system and utility supply [28], and a mathematical approach was used to formulate the prediction algorithm.

A home automation based on DC load-matching technique was studied [29]. A strategy to remove DC–AC converters and AC–DC converters was investigated in order to reduce losses.

A battery management system based on the Internet of Things (IOT), where a Raspberry Pi model 2 acquires battery information as well as PV information and sends it to a cloud for distribution is discussed in [30]. The Raspberry Pi uses various sensors to acquire temperature, voltage and currents. Computers and mobile devices can be used to access the acquired data by connecting to the cloud database. The PV system consisted of battery bank (8×100 Ah), PV array (20 modules $\times$ 50 Wp), grid tied inverter and the load.

A switching system between the grid and PV system was implemented by using the PIC16F877 microcontroller [31]. Automatic switching is done in order to avoid over discharging of the battery. The switching circuit was made of a Darlington pair transistor configuration and a relay. The prototype has been tested by using a 3-W photovoltaic panel, which produced an output voltage up to 10.5 V.

2.2. Strategies of Supplementing Grid Power with PV Energy and to Control Electric Water Heater (Geyser) Power Consumptions

A microcontroller was used to implement a water heater that uses both solar and the domestic energy supply [32]. An electric heater is used when the solar radiations become insignificant and the installed thermostat sets the highest water temperature. The microcontroller automates the process and controls the activities of the circulation pump.

AC–DC hybrid and PV generation with a battery backup using a smart grid system was designed by other experts to ensure continuous supply of electricity in a cost-effective manner [33]. The system's algorithm checks the availability of solar energy and then connects to it whenever it can provide a required capacity, if not, it utilizes the local supply. The system also predicts weather conditions and reschedules high power consumption tasks to the period with high-energy production. Backup batteries are kept at charge level, which is above 50 percent.

The demand response strategy used in [34] clarifies that the thermal loads account to huge energy consumptions from the grid. If the thermal loads are not properly controlled, they create overloading when operating in great numbers at the same time. In this study, information and communication technologies are used to support the potential of renewable energy source.

2.3. Novelty and Contribution

Although microcontrollers were used for entirely different purposes, for instance, for switching between grid and PV as in [31], battery management system as in [30] and for developing solar trackers as in [9] by other experts, this research is novel. In addition to switching between a domestic energy supply and PV energy, a special circuit was designed to control geyser power and align it to the capacity of the renewable energy source in this research. Two options were used to control the geyser current; the first option uses the microcontroller select between one of the two types of heating elements as influenced by the available energy source. In the second option, the geyser control circuit uses a Triode for Alternating Current (TRIAC) circuit, which is included to control output current drawn from a low power, a renewable energy source when is in use. Therefore, our contribution further enabled the development of a programmed microcontroller-based control circuit for a geyser high current and low current heating profiles. In this research, PV energy was used to save energy when entire domestic power requirements match the available solar resources.

3. Objectives

The objectives of this research are:

- To prototype and test the microcontroller-based electric water heater (geyser) that utilizes both PV and domestic energy supplies. We propose two ways to do this; the first option is to use two elements where the calculation for the size of each element is based on capacity of the corresponding input and the second option is to include a current-limiting circuit, which will regulate current accordingly.
- To prototype and test the microcontroller-based circuit that changes the connection between PV-derived energy and domestic supplied energy based on energy supply availability and load consumptions.

4. Methods

4.1. Hardware Components

In Figure 1, a solar array that produces 200 W output is located at the rooftop. The solar panels output current charges the 12 V, 100 Ah battery via a 40 A solar charge controller designated here as MPPT (maximum power point tracker). The charge controller manages the charging process. Three sensors are connected at the input of the microcontroller, namely: current sensor (used for load management), battery level sensor (used to check when to connect and disconnect from RES) and a Dallas temperature sensor (for geyser water temperature monitoring). Several microcontroller outputs are connected to the relay circuit as illustrated on Figure A1 in Appendix A. As explained in Section 1, the software in Appendix B is used to control the relay circuit outputs.

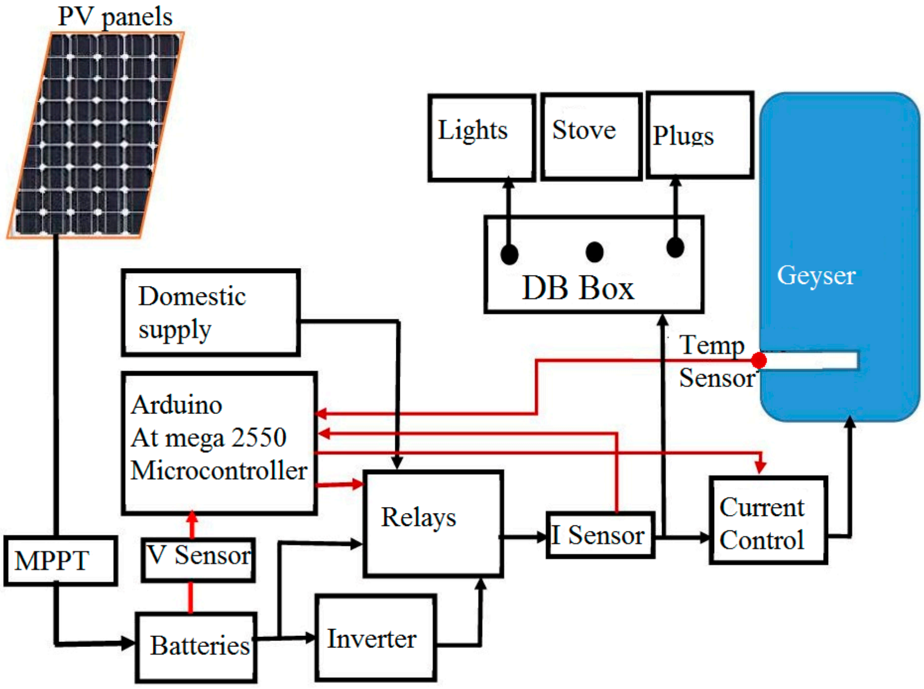

Figure 1. Hardware layout.

The system has three major sensors: battery level sensor, inverter-output current sensor and the Dallas temperature sensor [35] for the monitoring of water temperatures. A maximum charge current of 16 A has been measured. If the software never allows the battery level to drop below 50% of its maximum capacity, i.e., 50 Ah, it will therefore take a minimum of about 3 h to fully restore the battery charge to its maximum level. To create about 50 Ah from 16 A, you need only about 3 h of sunshine from a day with a potential to give six peak-sun hours. At the same time, when ignoring losses, where a maximum load power of 600 W is permissible for a PV source—a fully charged 12 V battery can supply the load for a duration of about 1 h (50 Ah). For a maximum connected load, this system will therefore charge battery for 3 h to supply continuous energy for 1 h and have a potential to provide domestic electricity savings of about 1 kWh per day, as influenced by the available sunshine duration. To produce more savings, one will have to increase the size of solar panels, battery and a charge controller. If the load requires about 120 W to operate and the system in Figure 1 is used to give backup power, it will work for about 10 h and still save 1 kWh of energy per day.

Figure A1 is a schematic diagram that represents the overall circuit that has been discussed. In this schematic, sensors discussed on the previous sections were excluded. The LCD used to monitor the load controller status and activities is shown in Figure 2.

Figure 2. LCD display.

From the LCD, it can be seen that the battery level capacity is at 55.9%, the equipment consumes only 110 W of solar power and that the status is "SOLAR", meaning solar energy is available. On the LCD, three statuses can be displayed: charging, idle, and solar (PV usage).

4.1.1. Battery Level Sensing

Upon powering on, the microcontroller will check the battery level by reading the voltage across the current limiting resistor (R_1) illustrated in Figure 3, where a 1 W, 9.1 V Zener diode has been used. The Arduino ATmega2550 microcontroller analog to digital converter supports a maximum of 5 V at a 10-bit resolution. Even though a fully charged battery gives about 12.7 V, by using this sensor the microcontroller will withstand up to a maximum 14.1 V (9.1 V + 5 V) across the battery. A Cotek SK1000-212 inverter with specifications outlined in [36] was used. Therefore, based on its specifications, this inverter will operate properly over the voltage range between 10.5 V and 15 V. To avoid excessive battery discharging, the battery minimum level is kept at 12.1 V, which is a represents 50% of its maximum charge. The microcontroller never allows battery usage by the load when the level at its analog to digital converter input becomes lower than 3 V (12.1 V − 9.1 V) or less. When this occurs, the load is diverted to the domestic electricity supply.

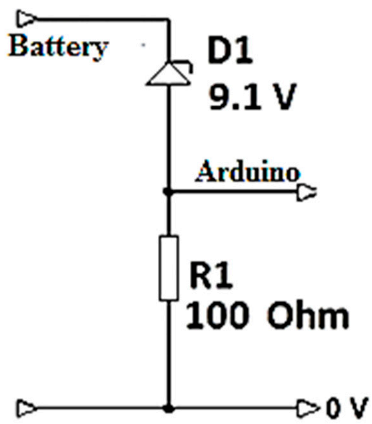

Figure 3. A simple voltage sensor circuit.

4.1.2. Output Current Sensing

A circuit shown in Figure 4 was used to detect a high load current by using the current transformer (CT) illustrated. The current transformer used can deliver up to a maximum of 141 mA peak to peak output current through the 33 Ω resistor.

By using ohm's law; this will translate to a maximum peak to peak voltage of 4.65 V applied to the input of' the microcontroller. From the 1000 W invertor used and excluding any form of calibrations; the maximum output power was restricted to 600 W at 230 V output, which then produced the peak-to-peak current of 7.379 A. The CT current ratio is 100 A: 50 mA.

Therefore a 7.379 A peak-to-peak current will produce 3.689 mA through the load. By using Ohm's law, a peak-to-peak voltage of 3.689 mA × 33 Ω = 121.764 mV results. The Microcontroller will suspend any connections to PV energy source and connect all loads to the commercial electricity supply after reading 121.764 mV or higher.

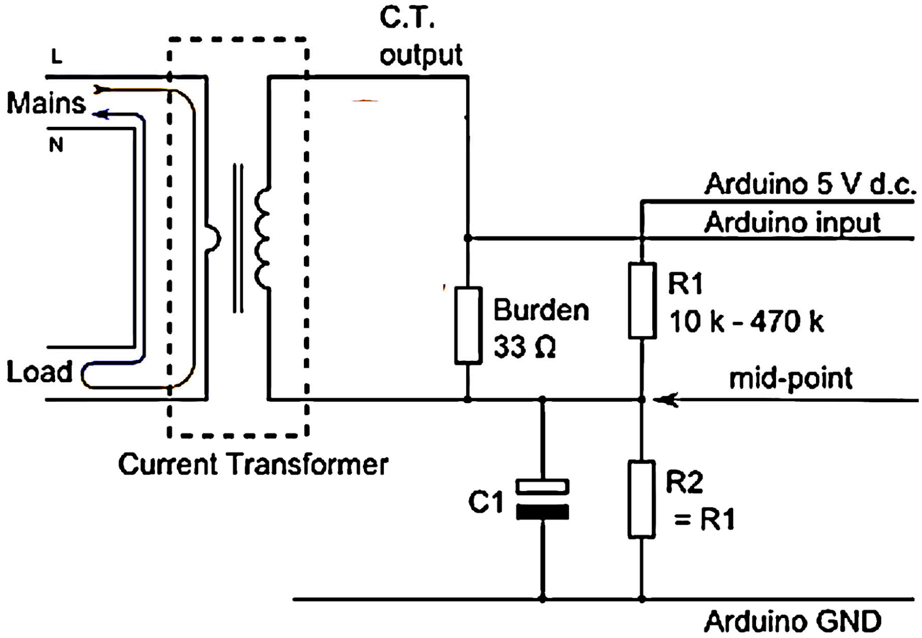

Figure 4. Current sensor circuit [37].

4.1.3. Geyser Water Temperature Sensing

A temperature probe and connection diagram as in [38] was used as a guide for this research for the detection of water temperature. Before using it, one must download software library from an open source. The library software is then included as a header file in the source code (see Appendix B). In source code, the sensor is initialized to prepare it for temperature reading. The existing geyser thermostat can also be used for extra protection, but it will have to be set to the value, which is slightly higher than maximum preset cut-off temperature of the sensor in [38].

4.1.4. Controlling Geyser Element Current

Special attention was given to geysers since they consume huge amounts of energy. In this research, it is proved that geysers can be configured to draw high current only to heat up water when the temperature is less than the pre-defined value and thereafter uses less current to bring water temperatures to even higher values. It was already proved that a significant amount of energy savings would result in reducing geyser connection time to the domestic electricity supply source. Instead of fully disconnecting geysers to the power source, in this research, we bring down their power consumption and thereafter connect it to low power PV energy source. By doing this, the domestic energy savings is further improved as the water temperature will be increased slowly to even higher temperatures. Two methods of doing this were evaluated. It may be done by using two elements or a TRIAC-based circuit that operates like a high-power light dimmer. Various low power light dimmers are discussed in [39].

4.1.4.1. Using Two Water-Heating Elements

In Figure 5, two elements are used. The low power element can be connected directly to the batteries or DC to AC inverter output but not directly to the solar panels: The high-power element will raise water from its lowest temperature to 50 °C, thereafter, the low power element ensures that the water stays warm by raising its temperature further to 72 °C. To do this: The microcontroller reads the temperature sensor. If the water temperature is below 50 °C, it then connects the high-power element to the domestic electricity supply to raise the water temperature to 50 °C. Once the temperature of 50 °C has been reached, the microcontroller checks the level of the battery shown in Figure 1. If the battery level is more than 50%, it then keeps the water warm by connecting the low power element to renewable source until the battery level is just below 50% or the water temperature reaches about 72 °C. When the battery level becomes less than 50%; the low power element is kept off until the battery recovers to a level of 75%. The battery charging and water heating process will be repeated until the water temperature of 72 °C is reached. At the water temperature of 72 °C, all geyser elements are disconnected from their corresponding energy source to avoid geyser overflow. If it happened during the battery charging phase whereby water temperature drops to a temperature below 50 °C, the high-power element takes over.

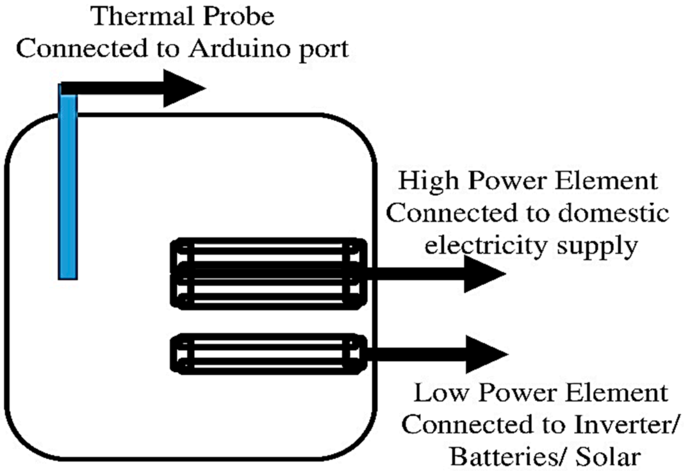

Figure 5. Two-element water heating system.

4.1.4.2. Using TRIAC Circuit to Control Geyser Current

In Figure 6, a special switched TRIAC circuit is used to control geyser current. A TRIAC is a device that can be used to regulate output current by controlling its on/off periods.

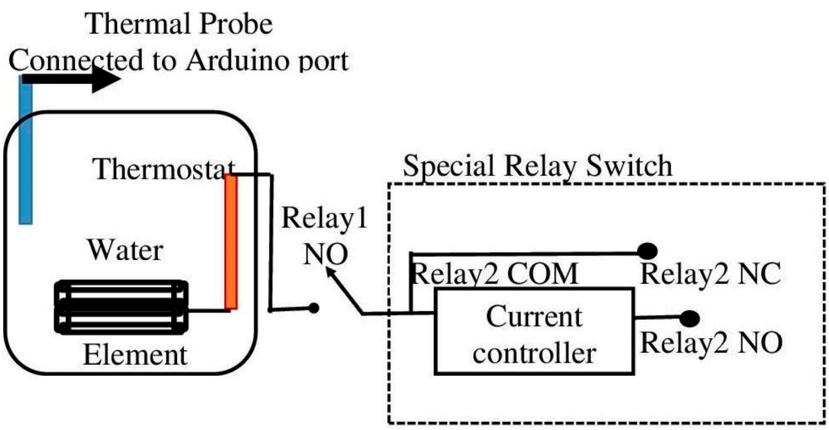

Figure 6. One current controlled element.

This setup is well suited for conventional geysers since it requires less modification to them. The difference between the operations explained in Section 4.1.4.1 and the one for the setup in Figure 6 is as follows:

- One element is used instead of two.
- Current control circuit regulates current from source.
- Relay1 is used to switch off all elements.
- Relay2 normally closed (NC) contact connects to the national grid whilst the normally open contact (NO) connects to renewable energy source.

4.2. *Software Component*

The Geyser and a load controller (a circuit that switches between solar energy and the national grid supply) were tested independently using separate software as represented by the flowcharts that will be discussed later. Appendix B gives a complete source code that was used to control geyser operations. Since there is greater similarity between the software used to control the load and that of the geyser, it is unnecessary to attach both sets of source codes. Overall, the source code can be organized to have a main program that can either call the geyser control or the load controller's software algorithm. As a result, the source code in Appendix B can be rewritten to become a function.

4.2.1. Geyser Controlling Software

The flowchart in Figure 7 uses national grid energy to raise the initial water temperature up to 50 °C and thereafter uses solar energy to keep water temperature between 50 °C and 72 °C.

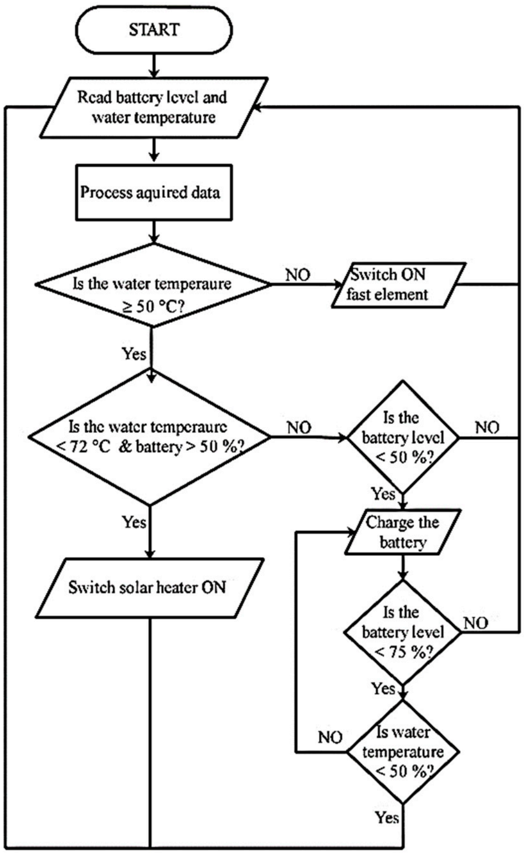

Figure 7. Geyser control software algorithm.

Upon powering on, the software reads outputs from both the battery and temperature sensors. These acquired values are then translated into meaningful data that is later used for decision-making. If the water temperature is below 50 °C, domestic electricity is applied to heat the water until the temperature of 50 °C is reached, thereafter the renewable energy is applied to heat the water further if the battery level is still above 50% and water temperature is below 72 °C. If the battery level drops to a value below 50% whilst the water temperature is still above 50 °C, renewable energy is disconnected to allow battery recovery by charging it up to 75% capacity. If the water temperature drops to a temperature below 50 °C whilst the battery is recovering, the mains will connect to the element and raise the water temperature back to 50 °C. A geyser thermostat was also incorporated to protect against overflow. Connecting the mains to the element during the charging phase will never affect the battery recovery process because the batteries are always connected to the PVs via the maximum power point trackers (MPPT).

4.2.2. Load Controlling Software

Figure 8 shows the software algorithm that was used to switch load connection between the renewable energy source and the national grid power. Here, the underlying fact is that the battery must be above 50% and the connected load should not exceed 600 W for the renewable energy source to be used. The national grid power is given the lowest priority. In other words, renewable energy here is a primary source of energy that uses the national grid power as a backup source.

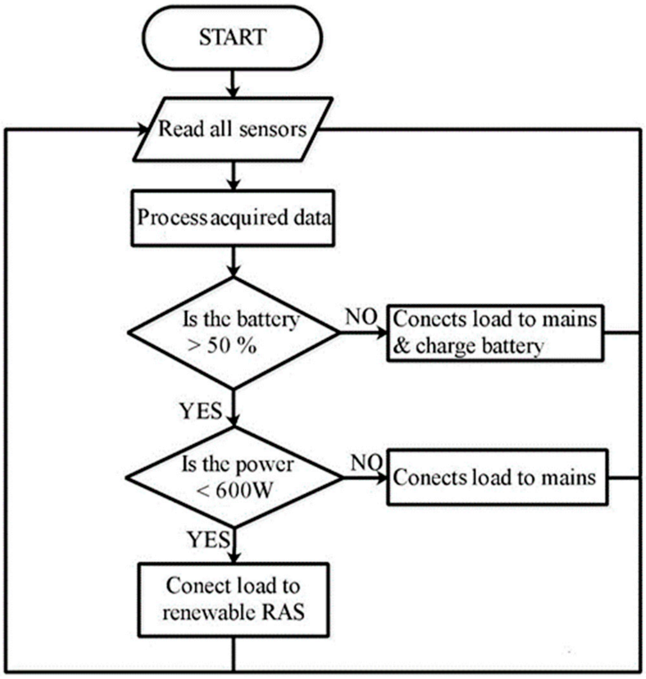

Figure 8. Load control software algorithm.

5. Results

5.1. Performance of the Geyser Prototype

The tests were conducted using a geyser that was prototyped as illustrated in Figure 9 and followed the connections shown in Figure 6. If the low-power element is not available, one high-power element can be used. The circuit that employs a TRIAC moderates the current whilst the microcontroller controlled the geyser operation. The software algorithm illustrated in Figure 7 can also be used for a two-element system as per the connections shown in Figure 6.

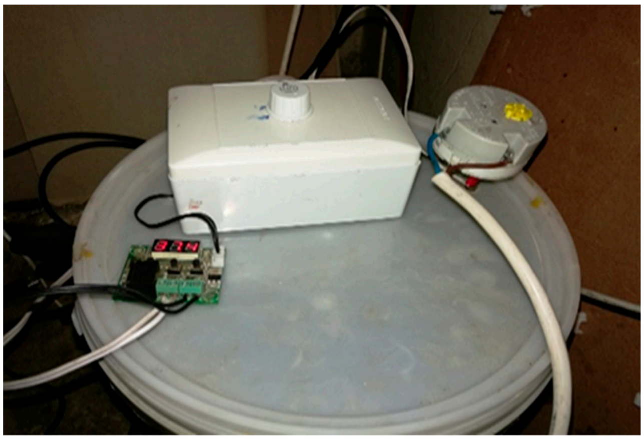

Figure 9. Hybrid geyser that was prototyped using 10-L water bucket, light dimmer, thermostat and the temperature sensor.

5.1.1. Results Obtained When Both PV Energy and Grid Energy Are Used

The values of energy consumption presented in this section were logged in by a custom-built energy logger that employs NI myRIO data acquisition card that was programmed by using LabVIEW development platform. The details about logging and tracking of renewable energy using this tool are outlined in [40]. As illustrated by Table 1, 140 Wh of energy from the domestic electricity supply source was used to raise the initial geyser water temperature of 27 °C to 50 °C in a duration of 7 min. The solar energy maintained the water temperature above 50 °C in a time period between 08h07 until 18h48. In some instances, the low power heating overlapped with the a battery levels that are below 50%, that occurred spontaneously due to high DC currents of up to 30 A, which were drawn from this battery, but never last longer than the software delays. Another challenge is to get accurate battery voltage readings (used to derive battery charge level) whilst the load is actively connected. However, in any case, a battery level of lower than 50% is not permitted. The geyser water temperature is maintained by using PV power to gradually raise the water temperature to 72 °C. At a water temperature of 72 °C, all power sources were disconnected. Table 1 also indicates that PV energy was only able to preserve the water temperature of about 72 °C during the period that ranged from 11h00 until 16h33. After 16h33, in the absence of enough sunlight, the water temperature has decayed from the temperature of 72 °C to a value below 50 °C. This is what has retriggered connections to the national grid power at 18h48. Five-hour power saving can be calculated by looking at a time span from 09h05 to 14h06 in Table 1. The saving will therefore equal to about 10 Wh (160 Wh − 150 Wh). A battery level of a percentage lower than 50% occurred around 16h33; note that even though the geyser stopped drawing current from the battery, a DC to AC inverter is still on to power the instruments that continued to reduce the battery charge further.

Table 1. Sample values that highlight the geyser performance during the presence of both national grid energy and solar energy.

Time	Temperature	Battery (%)	Energy (Wh)	Status
07:59:41	27	71.69	0	High Power Heating
08:07:17	50	87.39	140	Low Power Heating
08:07:19	50	85.94	140	Idle
08:07:21	50	83.44	140	Low Power Heating
09:05:02	65	29.99	150	Low Power Heating
11:04:40	73	39.5	150	Battery Charging
11:12:08	70	65.11	150	Idle
11:12:09	70	69.51	150	Low Power Heating
11:40:06	73	46.57	150	Battery Charging
11:41:09	72	65.28	150	Idle
1143:52	73	42.88	150	Low Power Heating
11:45:43	72	65.11	150	Battery Charging
11:45:46	72	65.45	150	Idle
11:50:59	73	51.2	150	Low Power Heating
11:55:02	71	65.62	150	Battery Charging
12:09:26	72	52.45	150	Low Power Heating
12:11:33	72	65.45	150	Battery Charging
12:12:57	73	44.34	150	Low Power Heating
12:16:31	71	66.97	150	Battery Charging
12:26:57	72	46.21	150	Low Power Heating
12:28:14	72	65.28	150	Battery Charging
14:06:01	72	51.2	160	Low Power Heating
16:33:00	72	41.69	160	Battery Charging
18:48:00	50	39.5	160	Battery Charging
18:48:45	49	39.66	160	High Power Heating
18:48:55	49	39.5	170	High Power Heating
18:49:09	50	39.33	170	Battery Charging

5.1.2. Results Obtained When PV Energy Is not Available

As illustrated in Table 2, the national grid power was connected to raise water temperature from 28 °C to 50 °C and maintain the water temperature of 50 °C for the period ranging from 09h13 until 14h06. Water temperature has been observed to drop by about 1 °C in every 20 min. This has caused the geyser to be switched on every time when the temperature drops to 49 °C. As a result, the energy consumption was raised regularly. As illustrated in Table 2, a total energy of 130 Wh (230 Wh − 100 Wh) was drawn from the national grid source in order to preserve water temperature at 50 °C for a period that is between 09h13 and 14h06. The test process has been terminated earlier to avoid excessive energy consumption.

Table 2. Sample values that highlight the geyser performance during the absence of solar energy.

Time	Water Temperature (°C)	Energy (Wh)
09:05:25	28	10
09:13:15	50	100
09:30:01	50	110
09:30:03	50	110
10:00:03	50	120
10:30:00	49	140
11:00:03	50	150
11:30:05	50	160
12:00:00	50	170
12:30:01	50	190
13:00:03	50	200
13:30:03	49	210
14:06:01	50	230

5.2. Load Controller Performance

Figure 10 shows a PV system consisting of a DC to AC inverter, real time solar power consumption monitoring unit, solar charge controller, energy logging device, Arduino-based load controller, relay board, two 3-W indicating lamps and a solar current/voltage sensor. Three sets of wiring cables were used, i.e., wires carrying large DC current from the battery and solar panels, CAT 5 network cable for the signals from sensors and AC output current cables.

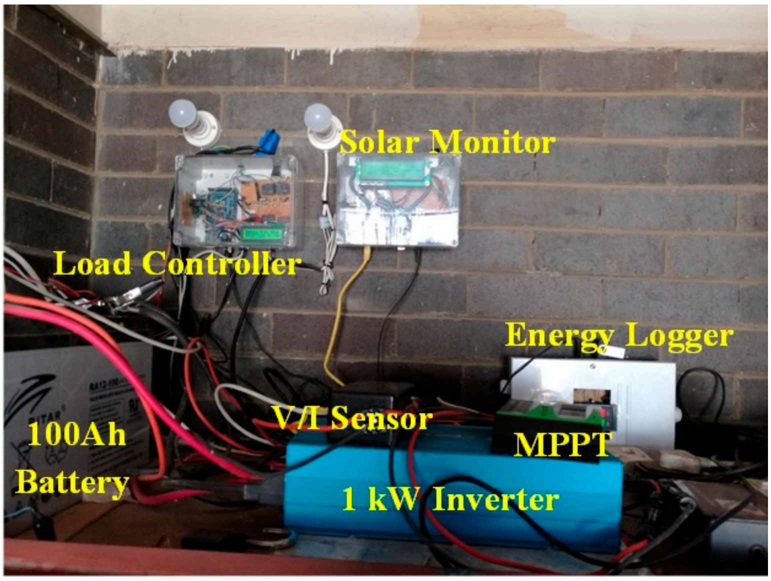

Figure 10. A hybrid renewable energy system.

5.2.1. Results Obtained When PV Energy Is Incorporated to Domestic Electricity Supply

As already described, the solar renewable energy system consists of: 2 × 100 W PVs mounted on the roof top, 100 Ah battery, 1 kW Inverter, 30 A power point tracker (MPPT), custom-built solar monitor, which shows real time power produced by solar panels, as well as the roof ambient temperature and custom-built energy logger. During a sunny day, the system illustrated on Figure 10 is seen to be active between 11h30 until 14h30. The input solar power was recorded up to the maximum of 200 W and the output AC power ranged between 150 W and 500 W. It should be remembered that the system never allows any power levels above 600 W, as previously discussed. If that happens, it connects the load to the national grid power. In Figure 11, we illustrate that most points of consumed electrical energy do not overlap with a virtual line called "reference line". A reference line represents the power that can be accumulated continuously without any form of disconnection. The actual energy curve goes below it. The space between the two lines therefore signifies the amount of energy savings.

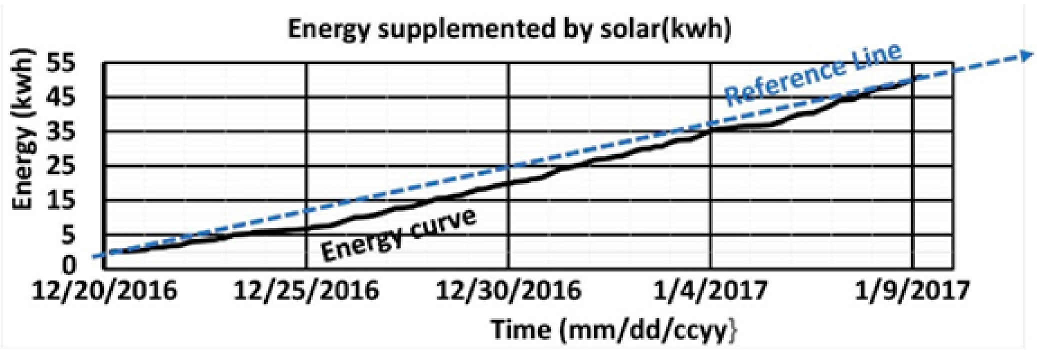

Figure 11. Accumulative energy that is consumed from the national grid source, when solar produced energy is used as supplement.

5.2.2. Results Obtained When Solar Is not Included

Figure 12 illustrates that most points of energy consumed from domestic source overlap with a virtual line called the “reference line”. This is because the grid power is always active.

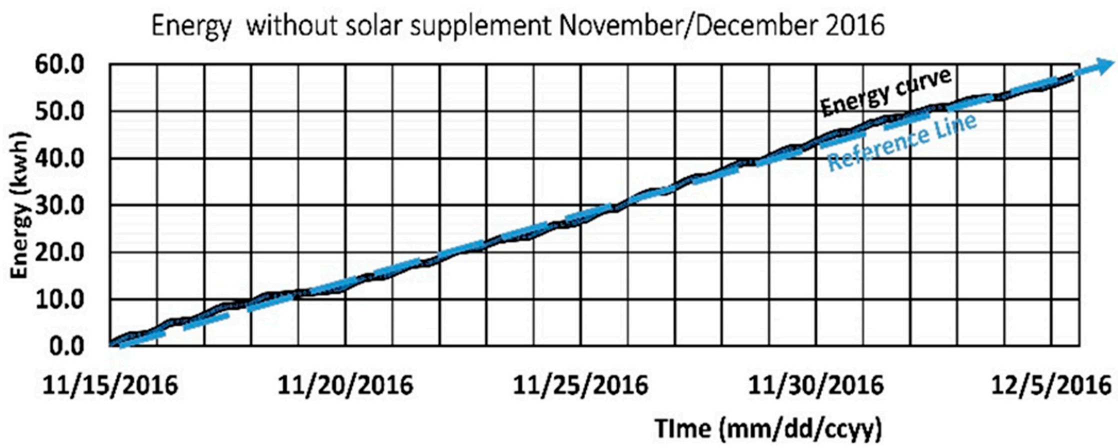

Figure 12. Accumulative energy consumed from commercial source that is not supplemented by solar energy.

6. Discussion

6.1. Geyser Control Circuitry

Please refer to Tables 1 and 2. The geyser control circuitry has managed to reduce the daylight geyser domestic energy consumption from 130 Wh to 10 Wh as calculated in Section 5.1.1. This is a good performance; however, it should be noted that the prototype geyser system used is not thermally protected has less water capacity (10 L). Also note here that the geyser energy consumption here, refers to the energy it consumes when the water is not being used. Using this control circuit with normal geysers will never affect the output that much, since both energy sources will be affected a similar manner, but the geyser control circuit will have to be upgraded to support high current levels and the renewable energy system capacity will have to be increased slightly. On a test that was conducted for two days, from 07h59 until 14h06, a geyser control system has showed to save power given by $(1 - 10/130) \times 100\% = 92\%$—a percentage that can be improved by changing the capacity of the renewable system. Besides saving energy, the system also takes away the notion of switching off geysers when hot water from it is not scheduled for usage.

6.2. Load Control Circuitry

Please refer to Figures 11 and 12. Unlike values explained in Tables 1 and 2, where energy was presented in Wh over a time domain given as hh:mm:ss, this section presents energy in kWh over a time domain that is given in days. As a result, the performance of solar-based renewable energy system is expected to depreciate since it is not capable of giving high power for longer periods as some periods will produce insignificant sun light. Refer to the components that were listed under Figure 10. On a test conducted for 20 days from each power source, Figure 11 shows that when the renewable system is incorporated to the commercial energy supply, a total energy of 50.9 kWh has been consumed. On the contrary, Figure 12 shows that when renewable energy is not incorporated, the energy consumption has risen to 57.4 kWh. The total energy savings here can be calculated as follows: $(57.4 - 50.9) \times 100\% \div 57.4 = 11.3\%$. The calculated percentage depends on the capacity of a PV-based renewable system.

7. Conclusions

In this paper, we focus on the strategies that can be used to incorporate solar-based renewable energy to the domestic supply in order to reduce energy consumption.

- We developed a prototype and tested the microcontroller-based electric water heater (geyser) that utilizes both PV and domestic energy supplies. A programmed microcontroller-based control circuit with a high-power and a low-power element or one current controlled element was connected to the geyser. That enabled a direct application of PV-derived AC voltage to geysers as a supplement of domestic energy supply, as a result, domestic energy consumption is reduced. A circuit to divert the low power load to a PV source was also included.
- Collectively, a microcontroller, current sensor, battery level sensor and relay board were used to construct a circuit to reduce electricity usage. The significance of the findings is that consumers can therefore only use the domestic electricity to supply high-power devices. This might only occur during peak consumption hours, when they do cooking, laundry, ironing, etc. However, things like low-power lighting and entertainment will automatically be diverted to PV energy sources. Geyser power is also aligned to the PV supply for connections during low-power consumption times. Consumers might not have to worry about switching off geysers when not using water from it.

As opposed to a conventional thermostat, a Dallas temperature supplies continuous temperature readings that enable the choice of geyser heating profile. In this way, both the upper and lower temperature limits are considered.

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Conflicts of Interest: We declare that there is no conflict of interest with any other organization.

Appendix A

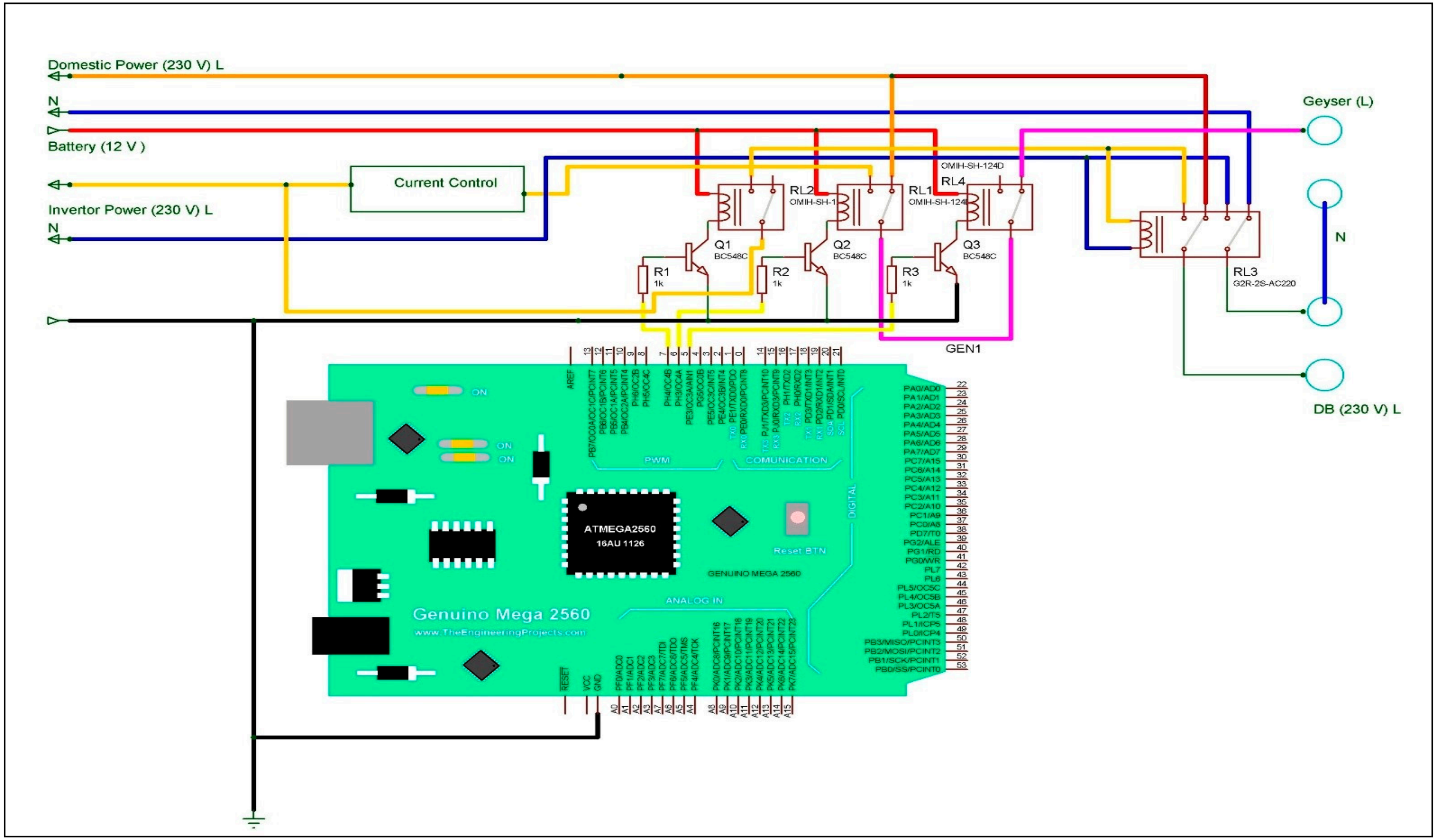

Figure A1. Schematic diagram of the complete controlling circuit.

Appendix B

```
/*
GeyserCTRL V1.00
The software can be used as a function or independently
Geyser control software code that works */

// Include the libraries we need
#include <OneWire.h>
#include <DallasTemperature.h>
#include <EmonLib.h>              // Include Emon Library
EnergyMonitor emon1;
boolean flag = FALSE;
float batt =100;
double energy = 0;
int Tempe, Temp;
int count = 100;
double Irms;
int power;

// Data wire is plugged into port 2 on the Arduino
#define ONE_WIRE_BUS 2

// Setup a oneWire instance to communicate with any
//OneWire devices(not just Maxim/Dallas temperature ICs)
OneWire oneWire(ONE_WIRE_BUS);

Pass our oneWire reference to Dallas Temperature.
DallasTemperature sensors(&oneWire);

/*The setup function. We only start the sensors here*/

void setup(void)
{
  pinMode(6,OUTPUT);
  pinMode(7,OUTPUT);
  // start serial port
  Serial.begin(9600);
  emon1.current(1, 111.1); // Current: input pin, calibration.
  // Start up the library
}

/*Main function, get and show the temperature */

void loop(void)
{
  sensors.requestTemperatures();//issue a global //temperature
    // request to all devices on the bus
    //Serial.print("Requesting temperatures...");
    // sensors.requestTemperatures(); //Send the command to
     //get temperatures
    // Serial.println("DONE");
    // After we got the temperatures, we can print them here.
    // We use the function ByIndex, and as an example
```

```
        batt = analogRead(A0) * 5.00 / 1023.00; //read battery
        batt ==(batt-2.90) * 0.016;

//get the temperature from the first sensor only.
        Tempe =sensors.getTempCByIndex(0);
        Temp = Tempe;

while (Tempe < 50)
  {
  batt = analogRead(A0) *5.00 /1023.00;//converts 5V Max
  batt =(batt-2.90) * 0.016
      sensors.requestTemperatures();
     Tempe =sensors.getTempCByIndex(0);
     Irms = emon1.calcIrms(1480);     // Calculate Irms only
     while(Irms*230 >600)         //Test for pwer > 600 W
         {
           Irms = emon1.calcIrms(1480); // Calculate Irms only
           Irms = abs((Irms - 0.0)*0.7491);
           Serial.print(energy);
           LCD();
           lcd.setCursor(12, 1);
           lcd.print("*HI*");
           Serial.println(",HIGH");
           digitalWrite(7, LOW);//switch on fast element
         }
Irms = abs((Irms -0.25)*0.7491);

energy = energy + (Irms*230)/3600000;
   digitalWrite(7, HIGH);//switch on fast element
   digitalWrite(6, LOW);// switch off slow element
   if (batt < 50) //stop and go to charging
   flag= false;
   delay (1000);
   }
while ((Temp >=50) && (flag==1)) //keep water warm
  {
     batt = analogRead(A0) * 5.00 / 1023.00;
     batt=(batt-2.90) * 0.016;
     sensors.requestTemperatures();
   Tempe =sensors.getTempCByIndex(0);
   Temp = Tempe;
   Irms = emon1.calcIrms(1480); // Calculate Irms only
   Irms = abs((Irms -0.25)*0.7491);
   energy = energy + (Irms*230)/3600000;
   delay (1000);
   digitalWrite(6, HIGH);//switch off fast element
   digitalWrite(7, LOW);// switch on slow element
   if ((Tempe > 72) || (batt <=50))
   flag= false; //cutoff at 72
   }
  while ( (Temp >= 50) && (batt < 100)&&(!flag) )
// charge battery
```

```
    {
      batt = analogRead(A0) * 5.00 / 1023.00;
      batt=(batt-2.90) * 0.016;
      sensors.requestTemperatures();
      Tempe =sensors.getTempCByIndex(0);
      Temp = Tempe;
      Irms = emon1.calcIrms(1480); // Calculate Irms only
      Irms = abs((Irms -0.25)*0.7491);
      energy = energy + (Irms*230)/3600000;
      delay (1000);
      digitalWrite(6, LOW); //switch off fast element
      digitalWrite(7, LOW);// switch off slow elements
      if (batt > 75) //stop charging
      flag= true;
    }
}// end program
```

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