International Journal of Recent Engineering Science (IJRES)
ISSN: 2349 – 7157 / doi: 10.1445/23497157/IJRES-V7I4P102

Volume 7 Issue 4, 7-13, Jul-Aug 2020

Design And Implementation Of A Smart Prepaid Solar Inverter System

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Abstract

The emergence of alternative power systems was of great cheer and anticipation for consumers to utilize optimally as it came to solve the issue of instability and unreliability on the part of electricity supplies. This project, as designed, is to provide an alternative source of supply that offers a cost-friendly, flexible, and practicable method for consumers in all sectors of the economy. Consumers of energy had earlier faced with challenges such as inflexibility in power subscriptions and unaccountability of consumption rate, even after the solutions that some power-oriented companies had earlier proffered. With the designed prepaid meter interfaced with the inverter system of use, consumers will be able to monitor their consumption rate, and with an energy-saving technique incorporated, the consumption is controlled and channelled to critical loads only when a battery is running low and anytime balance is low. The pay-as-you-go method of operating this system power and the ability to own the systems without interference from unauthorized persons were all made feasible through some added tools such as Arduino, IR remote, and Receiver. This project presents a micro approach of a broader scope to eliminating the country's power problems.

Keywords - *Smart Inverter, EMS, prepaid metric system, Current Sensing, Voltage Sensing*

I. INTRODUCTION

Inverters, by definition, are electronic devices that provide an AC voltage from DC power sources, and they are solely used for powering electronic and electrical equipment rated at the AC mains voltage. Direct current flows in one specific direction, using this conventional current flow, the electrons in the direct current leaves the power source from the positive terminal and flows through the circuit and then ends at the negative terminal of the power source. Direct current is usually gotten from battery cells, solar panels, etc.

Besides, they are widely used in the switched-mode power supply inverting stages. The input voltage, output voltage, frequency, and overall power handling depends significantly on the design of the specific device and circuitry. The circuit is classified according to the switching technology and switch type, the waveform, the frequency, and the output waveform.

The power supplied is usually pure sine waves. But commercial inverters can give out outputs ranging from square wave to sine wave, although for electrical equipment sine wave is preferable, it is expensive because of the technology involved. The modified sine wave is commonly used in households. Before now, the inverter system has been in use just to substantiate the alternative energy sources and methods, by way of using solar panels, to optimally harness the power coming from the sun. Engineers, individuals have made advancement towards the improvement of alternative power, and companies in the power development sector to modify and improve the efficiency of the inverter system by way of integrating remote monitoring as well as metering systems. In [1], energy meter is a device designed to quantify or measure the volume of electricity consumed at a given point in time by an electrically powered device, residence, commercial premises or an industrial complex.

Utilization and monitoring of power have been a thing of practice in the line of power distribution companies using prepaid energy meters [1][2]. Now, in the line of inverter power supply, prepaid metering is recently being adopted by manufacturers of inverter systems to regulate and account for power consumption, just as in grid supplies. Looking at this from the angle of a consumer acquiring a solar system for use that is equipped with a recharge mechanism and prepaid metering all agree with the advancement in innovation and solutions to power.

II. MATERIAL AND METHODS

The solar inverter system is a system that comprises of the Inverter, battery, solar panel, and a charge controller [3]. Prepaid metering included in this system is to address the area of monitoring for the billing system that will be realized, as shown in figure 1.

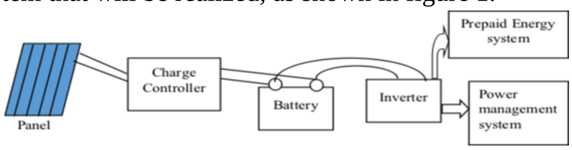

Figure 1: Power Transmission Process from Solar Panel to the Inverter

The solar panel works to convert solar energy coming from the sun into electrical energy, which is needed to charge the deep cycle battery. The Charge controller, as shown in figure 1, is connected between the solar panel and the battery to regulate the power coming from a solar panel with the right voltage and current before going into the battery. It regulates the fluctuating output of the solar panel at any point, be it at the sun's high intensity or low. To ensure that batteries do not overcharge during the day and that power does not run back to the solar panel overnight and drain the batteries.

The DC output from the battery will be sent into the Inverter, which does the conversion from DC to AC and to supply to the AC loads. The output from the Inverter gets fed into the prepaid energy metering system and the power management system, which is serving as the control unit and finally to the various loads connected to the system. The power management system has a way of detecting the heavy load appliances (50% greater than the normal load) immediately and can stand the test of a few seconds before cutting off outputs to those ends.

III. DESIGN OF ENERGY METERING SYSTEM

The metering system was designed with the ACS712 current sensor, AC-DC adapter with a voltage divider, the main Arduino board, and the 16x2 LCD. A watt-hour meter is designed to measure energy or power consumed over time.

Energy = Power * Time

The execution of a fundamental watt-hour meter includes two hardware modules, as shown in Figure 2. These modules are represented by the voltage measurement module, the current measurement module,

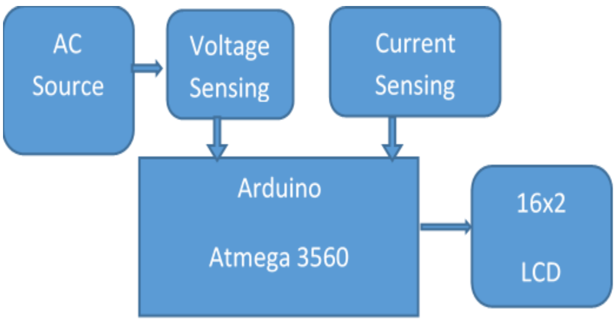

Figure 2: Energy Metering Design

The simplest type of prepaid energy meter consists of 2 EEPROMs interfaced to a microcontroller [3][4]. One EEPROM contains the recharged balance amount. The microcontroller reads this balance and stores it in the other EEPROM along with the tariff.

For the usual prepaid billing scheme, the recharge card is an EEPROM in which the balance amount along with the allocated energy units is stored. The energy meter gives an electric signal to the optoisolator, which consists of an LED and an Opto-transistor combination such that the LED glows and emits light for every electric signal received by the energy meter (which sends an electric signal for every unit consumed) [3][4]. The Opto-transistor starts conducting and sends high and low pulses to the microcontroller. The microcontroller is programmed such that a counter is kept incrementing for every pulse rate, which gives the value of the energy consumed [3][4].

Another EEPROM is interfaced to the microcontroller where the balanced amount and the energy units consumed are stored. For every increment in the count, the balanced amount in this EEPROM is deducted [4]. Finally, when the balance amount is zero, the microcontroller sends a low signal to the relay driver to give a high signal at its output, which switches off the relay. Usually the microcontroller gives a high signal to the input pin of the relay driver, which develops a logic low signal at its corresponding output pin, and the relay coil is energized, thus connecting the load to the main supply. If you want to keep the data stored for future use, you need to use the Arduino EEPROM. This stores the variable's data even when the Arduino resets or the power is turned off.

IV. DESIGN OF THE CURRENT SENSING CIRCUIT

A current sensor circuit is a circuit that can sense current going through it. If the current reaches a certain threshold, then an indicator, LED in this case, will turn on. We built a current sensor circuit, by merely exploiting ohm's law (Ohm's law states that, I= V/R, where I is the current, V is the voltage, and R is the resistance) [4].

This design was typically selected to eliminate ground disturbances of any kind, and short circuit detection as monitoring and control, overcurrent protection and supervising circuits, automotive safety systems, and battery current monitoring. The significant components of use were the CT Transformer, Resistor, and Capacitor.

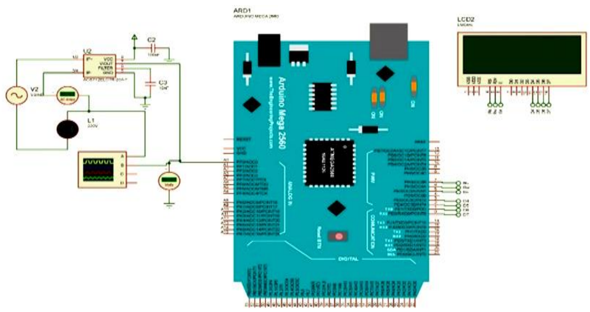

Figure 3: Circuit Diagram of Arduino and Current Sensing

The output signal from the CT sensor needs to be conditioned, so it meets the input requirements of the Arduino analog inputs, i.e., a positive voltage between 0V and the ADC reference voltage. This was achieved with the following circuit, which consists of two main parts:

1. The CT sensor and burden resistor

2. The biasing voltage divider (R1 & R2)

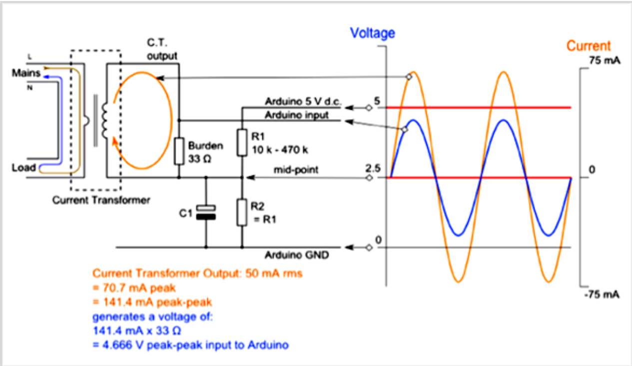

Figure 4: Connecting a CT Sensor to Arduino (learn.openenergymonitor.org)

Calculating a Suitable Burden Resistor Size

The CT sensor is a "current output" type such as the YHDC SCT-013-000; the current signal needs to be converted to a voltage signal with a burden resistor. If it is a voltage output CT, you can skip this step and leave out the burden resistor, as the burden resistor is built into the CT.

(i) Choose the current range you want to measure

The YHDC SCT-013-000 CT has a current range of 0 to 100 A. For this project, we choose 100 A as our maximum current.

(ii) Convert maximum RMS current to peak-current by multiplying by √2.

Primary peak-current = RMS current × √2
= 100 A × 1.414
= 141.4A

(iii) Divide the peak-current by the number of turns in the CT to give the peak-current in the secondary coil.

The YHDC SCT-013-000 CT has 2000 turns, so the secondary peak current will be:

Secondary peak-current = Primary peak-current / no. of turns
= 141.4 A / 2000
= 0.0707A

(iv) To maximize measurement resolution, the voltage across the burden resistor at peak-current should be equal to one-half of the Arduino analog reference voltage. (AREF / 2) using an Arduino running at 5V: AREF / 2 will be 2.5 Volts. So, the ideal burden resistance will be:

Ideal burden resistance = (AREF/2) / Secondary peak-current
= 2.5 V / 0.0707 A
= 35.4 Ω

35 Ω is not a common resistor value. The nearest values either side of 35 Ω are 39 and 33 Ω. Always choose the smaller value, or the maximum load current will create a voltage higher than AREF. We recommend a 33 Ω ±1% burden. In some cases, using two resistors in series will be closer to the ideal burden value. The further from ideal the value is, the lower the accuracy will be.

V. DESIGN OF VOLTAGE SENSOR CIRCUIT

Voltage Sensing Unit, the Voltage Sensing module, contains Three AC Voltage Sensors (ZMPT101B). This module uses a pulse transformer with a transfer ratio of 1:1 used for isolation purpose, and it uses a simple op-amp circuit for isolation and stepping down the voltage from (0–250) Volt to (0–5) Volt that is used by the input of the Arduino microcontroller. Calibration of the sensors for the control of electrical capacity is one of the most important things that must be taken into account in order to obtain high accuracy in device measurement. The sensor calibration is achieved by comparing the sensor reading (Vrms) with the reading of ordinary voltmeter. The Arduino Voltage Sensor Interface was pretty straight forward. By simply connecting the voltage under a measure to the screw terminal of the Voltage Sensor, and with the output of the voltage divider to the Arduino, we were able to determine the input voltage under the module. After which the results were viewed on the serial monitor of the Arduino IDE and the 16×2 LCD Display.

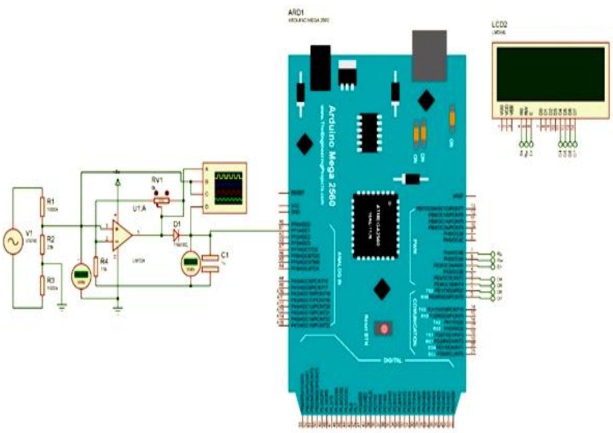

Figure 5: Voltage Sensing Circuit.

The voltage sensor circuit is a precaution taken to avoid voltages up to 12V (i.e. voltages greater than 5V) as we couldn't use the Analog Input Pins of the Arduino, which indeed would have fried the ATmega2560 IC on the Arduino Mega board. The voltage sensor can determine, monitor, and can measure the supply of voltage.

VI. RECHARGE MECHANISM

The electricity balance, as intended, can be recharged through this system by dialling a recharge code using the remote. It can also disconnect the home power supply connection if there is low or zero balance in the system. And this system will take the unit readings and automatically send some updates as low balance alert (orange led), cut off alert (red led), resume alert (green led), and recharge alert (blue led) [5].

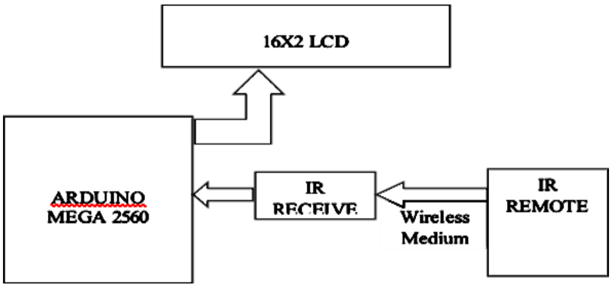

Figure 6: Block Diagram of Recharge Mechanism

IR Remote

Each time a button is pressed on the remote control, a unique hexadecimal code is generated. This is the information that is modulated and sent over IR to the Receiver. In order to decipher which key is pressed, the receiving microcontroller needs to know which code corresponds to each key on the remote. We saved the code for the buttons that we want to control the LEDs in the Arduino code [5]. First, the four LEDs were connected to the Arduino. The positives of the four LEDs to the pins 7, 6, 5, and 4 and the negative of the four LEDs to GND on the Arduino through the 220-ohm resistors. The longer wires on the LEDs are positive, and the shorter wires are negative, after which the IR sensor was then connected to the Arduino. Whenever a button is pressed on the remote, it sends an infrared signal in encoded form. This signal is then received by the IR receiver and given to the Arduino [6]. The Arduino, upon receiving this code, will compare it with the codes already saved, and if any of them matches, the Arduino turns on the LED connected to that button [7].

The connections for the IR sensor with the Arduino were as follows:

(i) The negative wire on the IR sensor was connected to GND on the Arduino.

(ii) The middle of the IR sensor, which is the VCC, was connected to 5V on the Arduino.

(iii) The signal pin on the IR sensor was then connected to pin 8 on the Arduino [8].

Transmitting and Receiving IR

There were two circuits, as set up; the first circuit uses a TSOP382 IR photo sensor to receive and demodulate the IR signal from a common remote control [6][7]. The second circuit uses a 950nm IR LED and current limiting resistor to transmit IR codes to the inverter system [5].

Figure 7: TSOP382 IR Remote

Generating Codes for System Recharge

The codes for recharging were simply generated by way of initializing a secure coding approach in the Arduino. Using program codes, we were able to interface the serial port pins of the Arduino as tied to the IR receiver, and some values were chosen at random with a range of digits specified. The button of the IR was pressed alongside to recognize these values as 'Recharge Codes' and units assigned. Whenever the codes are recharged, it loads a particular unit in the system. This thus increments the units stored in the EEPROM and decrements as the user keeps consuming power. Table 1 shows the codes generated and the unit charge they represent.

Table 1: Recharge Codes and Units

Code	Unit
517568199	100
133835997	200
547890754	300
355273736	500
666544489	1000

The codes are inputted anytime the recharge is running low, by using the remote control and through the following steps;

1. The user activates the IR remote controls by pressing the CH+ (ON) button on the remote
2. The user dials the codes as shown above and see as they appear and disappear on the LCD screen.
3. Enter the codes by pressing the EQ button on the IR Remote
4. This automatically increments the balance on the EEPROM and displays the available unit on the LCD [9][10][11][12].

VII. ENERGY MANAGEMENT SYSTEM

The Energy Management System (EMS), as earlier devised, is to take charge of controlling the electrical system. Its primary tasks are to ensure that the electrical system is safe and efficient [8][9]. It adopts the idea of 'Load Shedding' to avoid a blackout.

When there is an imbalance between the electricity available and the electricity demand, Load Shedding helps to stabilize the balance between the available generation and the demand, in this way reducing the risk of system faults and battery drainage. This system also offers features as automatic start and stop of power consumption by users as the load varies. The Relays in Figure 8, work on electromagnetism when the Relay coil is energized it acts as a magnet and changes the position of a switch [13]. Because the circuit which powers the coil is completely isolated from the part which switches ON/OFF, it is feasible to control the relay using 5V from the Arduino, and the other end of it will be running the 230V appliance which was completely isolated from the 5V Arduino circuitry. The first two connections were the ground and power pins, where the Arduino +5v was connected to the 4 Relay board VCC pin and the Arduino GND to the 4 Relay board GND pin. The communication pins, labelled IN1, IN2, IN3, and IN4, were connected next to two 4 data pins on the Arduino. The default state of the Relays was normally closed (NC); the transistor worked as the trigger mechanism. The relay is triggered when the Arduino sends a high signal through the signal pins [13][14][15].

The battery is connected one leg to the Relay board and the other to the collector pin of the transistor, to complete the circuit [15].

At low recharge balance and battery voltage of 11.5V, as read by LCD, the Arduino sends a low signal via the signal pins, the transistor upon receiving this trigger the relays (3&4) [15][14] to cut off output supply. In order to preserve and not to waste available power, the EMS periodically checks the battery percentage when it's no longer receiving power from the sun, and that's major during the night hours. When the percentage level of the battery gets to 11.5V, the system will automatically cut-off the heavy load line of circuitry (loads above 30W), which are controlled by the other two relays (3&4). For Prepaid meters, they can count the flow of electricity used in KWH. As the meter balance decreases with increased power usage, the indicator light, which serves as a primary means for visual monitoring and control on the meter blinks continuously [13]. The EMS also performs load sharing function when there exists constant but low supply from the solar panels, alongside main supplies.

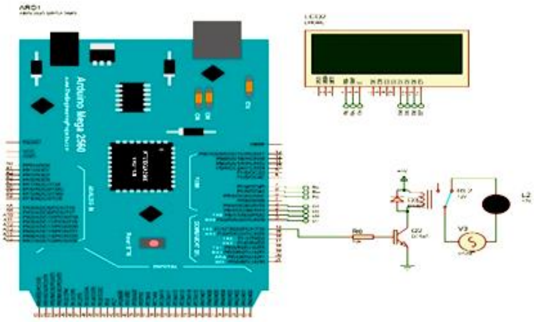

Figure8: Circuit Diagram of Energy Management System

VIII. DESIGN ANALYSIS AND OVERALL SYSTEM IMPLEMENTATION

The realized functional system is as represented in the simulation diagram below. Here, the Inverter, designed prepaid energy meter, recharge mechanism, and EMS are working as connected where the deep cycle battery and solar panel are sources of power to the overall system implementation.

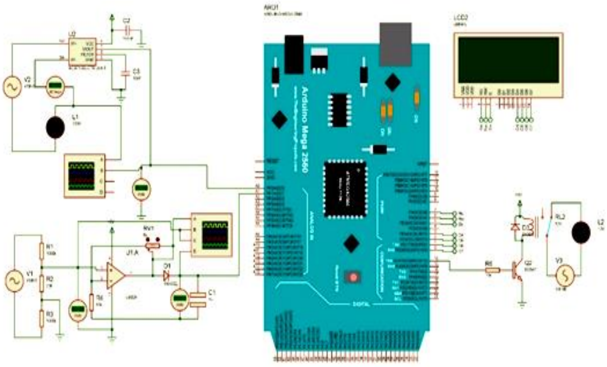

Figure 9: Circuit Diagram of Prepaid meter and Energy management system

RESULTS

After connections of components used and description of work very well implemented, we were able to provide a functional sound system of Inverter, interfaced with prepaid metering and monitoring. They were taking energy-saving, recharge mechanism, and user remote control into account. As estimated, the costs of the project were covered as earlier analyzed.

Load under test: 300W load

Table 2: Result for Solar Inverter System

V_{AC}	V_{DC}	Load AC In Watts	Time In Hour
220v	14.14v	300	Start
220v	13.42v	300	1 hour
220v	12.76v	300	2hours
220v	12.44v	300	3hours

Table 3: Result for Prepaid Metering Section

UNIT RECHARGED	TIME INTERVAL	UNIT BALANCE
1000 unit	Start	1000unit
1000 unit	1 hour	825 unit
1000 unit	2 hours	644 unit
1000 unit	3 hours	465 unit
1000 unit	4 hours	293 unit

200 units were recharged 5 times to realized 1000 units recharge. At the hourly intervals, varying units between 174 – 179 units have been consumed at that particular load.

Testing:

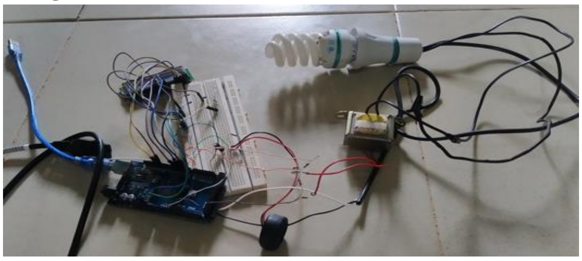

Figure 10: Circuit on Breadboard

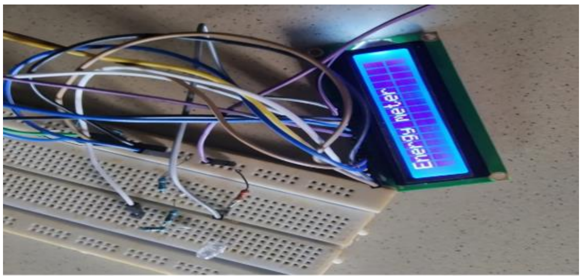

Figure 11: "Energy meter" on Setup

Figure 12: Voltage, Current and Energy Readings at no Load

Figure 13: Testing the Inverter and Battery with Loads.

CONCLUSION

The whole idea of this project is to offer a more reliable source of power in the most efficient and practicable way, and the aim was achieved using the best approach and the most efficient means. It will be of significant impact to the power sector in the society and encourage users of alternative energy to purchase and exercise ownership of these systems, as this practice when taken further will emerge beyond the scopes mentioned and proffer a more realistic attempt to resolve unreliability in inverter systems and giving out some more useful information about advancement in energy.

Although the objectives and scope of this project have been covered, the system can be upgraded by implementing a cloud computing system whereby data and records of customers can be stored and monitored by the company providing the system.

GSM network provides global coverage across countries, thus enabling communication to every nook and corner without the need to implement a new communication infrastructure solely for this purpose. A more remote communication and plant configuration can be implemented based on GSM modules.

Apart from seamless coverage, the GSM technology also provides services like SMS (Short Message Service) and GPRS (General Packet Radio Service) for requesting, retrieving, and reading from individual houses back to the energy provider wirelessly.

Moreover, the GSM network is a more efficient, reliable, and secure communication standard that is being widely used for more than several years now without any technical issues. The low cost, simple SetupSetup, vast operating distance, less human intervention are some of the other salient features of this GSM based system.

One of the recommended for this system's implementations is a GSM modem and a PPP connection to offer solutions based on ground PPP, LANs, or the Internet when needed and at a less expensive rate.

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