Energy Management System for Solar And Grid System

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Abstract
Electricity is an important resource both in domestic and industrial environment. The rise in electricity demand has led to conventional resources being exhausted and possibly lead to rise in electricity prices. since conventional resources are being exhausted, there is need to search for alternative energy sources to supplement the conventional sources. Use of green energy as an alternative to generation of electricity from conventional sources is currently on the rise. This study aims to design and implement an Energy Management System (EMS) in a grid-tied solar Photovoltaic (PV) system. The aim of this EMS is to reduce the grid electricity need to an ordinary consumer in Kenya and create dependency on renewable energy sources. One of the major expenses of the ordinary consumer in Kenya is the cost of electricity. Murang'a University of Technology was chosen as the case study. Arduino Uno was chosen to switch between the micro sources and the utility grid with the micro sources given priority over the utility grid. With sufficient solar irradiation, the solar PV supplies the load power provided the load demand is met, the excess charges the battery through charge controller. With a drop in irradiance, the battery storage system supplies the load provided the load demand is met. The grid supplies the load when the battery power drops below the load demand. With the drop in supply current drawn from the micro sources below specified thresh hold value, the load with the highest current rating was disconnected first and immediately reconnected to the utility grid.
Keywords*:* Arduino Uno, Energy Management System(EMS), Micro Grid

1. Introduction

Renewable energy as an alternative to the generation of electricity from conventional sources of is currently on the rise. The factors leading to this rise are attributed to the fact that the conventional sources are being exhausted, green energy legislation policies are being implemented, rise in technological innovation among researchers and the drive to address climate change (Polanco, Carreño, Martínez, & García, 2018). To integrate renewable energy into the utility grid, Micro-Grid system is necessary. In (Sedighizadeh, 2018) a Micro Grid is a low voltage distribution network consisting of distributed generations, loads and storage devices and are controllable. Solar PV and wind turbine systems are the commonly installed distributed generations. In the equatorial region, the sun's intensity is very high and because of this, solar energy if harnessed well can be the most convenient form of energy in homes and industries. Environmental pollution resulting from the use of solar energy is minimal as compared to other conventional sources. End wastes resulting from its production is manageable by applying engineering controls. Little maintenance is required for a PV plant for the panels can operate for many years in healthy state. The cost of operation of a PV plant is also minimal as compared to a conventional plant operation of equal capacity. Solar radiation changes with changing weather pattern and time of the day. Because of this change, battery energy storage system is used to store surplus energy generated from PV panel and release it when the necessary environmental parameters i.e. irradiance and temperature drop in their value. For efficient and effective power flow within the Micro Grid, an Energy Management System is necessary. A number of studies conducted on Micro Grid energy management as in the literature are mostly by simulations, real-time studies are less.

This study aims to design and implement an Energy Management System in a grid-tied solar PV system. The energy sources are managed in real-time using Arduino Uno. In this study, the main Micro Grid players are utility grid, solar PV, battery storage system and three incandescent lamps connected in parallel. The electric power demanded by the loads is supplied from either the utility grid or the micro sources. The micro sources considered in the study are solar PV and battery storage system. The micro controller uses instantaneous method of calculating voltage and current to switch between the micro sources and the utility grid to meet the set thresh hold limits specified. The sensitivity of the system depends majorly on the current sensors used in the study. The energy flow between the utility grid and the micro sources are monitored to determine the specific energy source that supplies specific load at any given time. The consumer's electricity bill is expected to significantly reduce with the proper application of the proposed EMS in a smart house.

The organization of the remaining parts of the study are as follows: section 2 presents literature review, section 3 presents the methodology used, section 4 presents result of the study and in section 5 conclusion and future work of the study is presented.

2. Literature Review

For quite some time, several studies have been conducted on Micro Grid Energy Management System. In (Zia, Elbouchikhi, & Benbouzid, 2018) , the authors provided a critical and comparative analysis on decision making strategies and solution methodologies in Micro Grid Energy Management. The research conducted in (Tabaa, Chakir, Moutaouakkil, & Medromi, 2019) performed Optimal Energy Management System in a grid-tied solar PV system using MATLAB/Simulink software. The research conducted in (Butt, Dilshad, & Rauf, 2020) simulated a home load management system using Proteus software. The system was to automatically reduce the load during peak hours. In (Abubakar, Khalid, Mustafa, & Mustapha, 2018), the authors designed and implemented an EMS for a home to automatically switch off the loads one at a time when the total load current exceeds the threshold value. The switching off of the loads was based on the relay numbering. The system is disadvantageous because after discrimination, the load remains off until the condition is restored. No alternative source of power supply is provided for the discriminated load.

2.1 Main Objective

To design the electrical and electronic system to aid in energy management operation of different system connected to grid and solar, with solar given the authority hence minimizing the consumption of the grid supply hence saving on the cost.

2.2.1 Specific Objectives

a) To achieve switching of loads from solar to grid using control signals from Arduino
b) To monitor the current flowing in the system
c) To display the loads that are active on either the grid or the solar system

3. Methodology

3.1 System Sizing

The importance of PV System sizing is to provide enough energy for the demand

3.1.1 Demand Estimate

This study uses a total connected load of 200 W. Considering that the load operates for 6 hours a day, then the total energy is given by equation (1)

$$Total\ energy = 200 * 6 = 1200\ Wh \tag{1}$$

3.1.2 PV Module Sizing

The solar resource maps are used to get a rough estimate of the site's annual mean daily insolation. Nairobi is located around 5.6 peak sun hour contour on such maps. Therefore, Nairobi has an estimated annual mean daily insolation value of about 5.6 peak sun hours. PV module loss of 80% and system voltage of 12 Vdc is considered for this study. The PV wattage is then given by equation (2).

$$PV\ wattage = \frac{Watthours}{Sunshine\ hours * Module\ efficiency} \tag{2}$$

$$PV\ wattage = \frac{1200}{5.6*0.8} = 267.86W$$

Choose capacity of the module to be 300W.

The global formula to estimate the electricity generated in output of a photovoltaic system is:

E = A * r * H * PR (3)

E = Energy (kWh)
A = Total solar panel Area (m2)
r = solar panel yield or efficiency (%)
H = Annual average solar radiation on tilted panels (shadings not included)
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75

3.2 Battery Sizing

The solar battery is used to store solar energy from the solar panels. This is the energy which after conversion by solar inverter is used to power the entire system.

Taking the efficiency of the battery to be 80%, the depth of discharge to be 60% and the nominal battery voltage as 12 V, then the battery capacity as given by (Leonics.com, 2013) is represented in equation (4).

$$Battery\ capacity = \frac{Total\ energy}{Battery\ efficiency * DoD * Nominal\ battery\ voltage} \tag{4}$$

$$Battery\ capacity = \frac{1200}{0.8*0.6*12}\ 208.33\ Ah$$

Choose battery capacity of 220 Ah

3.3 Charge Controller Sizing

To protect the battery against over-charge and over-discharge, a charge controller is needed. Over-charge protection disconnects the PV module from the battery and the charging stops. Over discharge protection disconnects the load from the battery and the discharging stops.

The charge controller capacity depends on the maximum current of the PV module. It is advisable to have some margins about 25% on maximum current. Required capacity of charge controller is given by equation *(5)*

$Charge\ controller\ capacity = I_{SC} * 1.25$ (5)

From electrical characteristics of Yungli Energy (China)YL210P-26b solar panel, charge controller capacity is given by;

$Charge\ controller\ capacity = 5.28 * 1.25 = 6.6\ A$

3.4 Inverter Sizing

A power inverter converts the variable direct current output from the solar panel into alternating current at 240V rms.

Considering inverter efficiency to be 80%, the approximate inverter wattage is given by equation (2)

$$Approximate\ inverter\ wattage = \frac{1200}{0.8} = 1500\ W \quad (2)$$

Choose inverter capacity of greater than1500VA, 12 V

3.5 Microcontroller

An Arduino microcontroller board is a single microprocessor board based on the ATmega328 that is used in so many intelligent projects that include; computing, controlling, logical and sensing applications. The hardware and software of Arduino are easy to use in designing and prototyping, with a simplified version of C/C++ as the programming language. It has 14 digital input and output pins: 6 pins used PWM outputs and 6 pins is analog input such as the clock speed is 16MHz, the ceramic resonator, the USB connection, the power jack, the ICSP header and the reset button

Figure 1: Arduino uno (https://store.arduino.cc/arduino-uno , n.d.)

3.6 Current Sensor

For measuring current in a circuit, a sensor is required. ACS712 Current Sensor is the sensor that can be used to measure and calculate the amount of current applied to the conductor without affecting the performance of the system. ACS712 Current Sensor is a fully integrated, Hall-effect based linear sensor IC. This IC has a 2.1kV RMS voltage isolation along with a low resistance current conductor

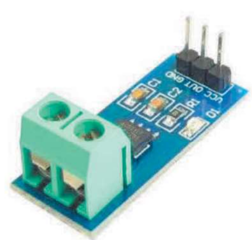

Figure 2: Current sensor

ACS712 Current Sensor uses Indirect Sensing method to calculate the current. To sense current a liner, low-offset Hall sensor circuit is used in this IC. This sensor is located at the surface of the IC on a copper conduction path. When current flows through this copper conduction path it generates a magnetic field, which is sensed by the Hall effect sensor. A voltage proportional to the sensed magnetic field is generated by the Hall sensor, which is used to measure current

The current sensor is used to monitor the current from the solar panel and convey the signal to the microcontroller which takes actions as programmed to monitor the loads connected to it through relay modules

3.7 Voltage sensor

Figure 3: Voltage sensor

The voltage sensor module works on the voltage divider principle. A voltage divider is a circuit made of two resistors connected in series. An input voltage is connected to the circuit. The applied voltage is then passed on between the two resistance and division takes place in direct accordance with the resistances. The output analog voltage is taken from the second resistor and measured. The general equation of the output voltage is

$$V_{out} = \frac{R2}{R1+R2} \times Vin \qquad (6)$$

The output of the voltage sensor is analog, so it has to be connected to the Arduino analog pins to be interpreted by use of inbuilt ADC. In the EMS the voltage sensor is used to monitor the voltage and hence making it easy for calculation of power. The schematic diagram of the voltage Sensor module which is a resistive voltage divider is shown below:

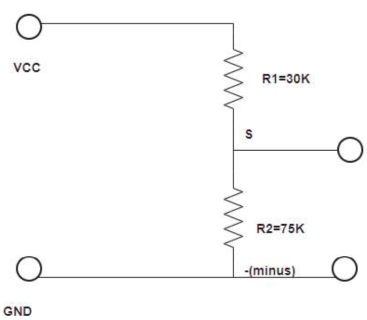

Figure 4: Voltage sensor schematic diagram

3.8 Display (16 by 2 lcd with i2c module)

The LCD helps in displaying the current and volage of the system and also displaying the state of the loads i.e., whether the loads is on the grid or on the solar part.

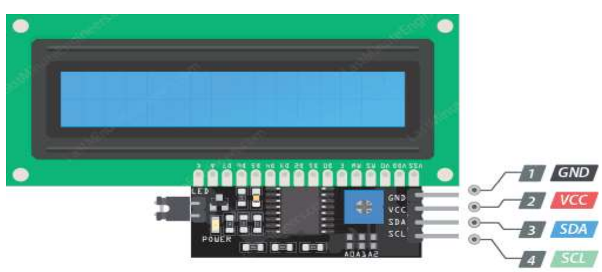

Figure 5: LCD with i2c

The i2c module interfaced in the LCD display reduces the number of connection lines and also no digital pins are used. This makes it possible for many components which require digital pins to be connected in one project

3.9 Relay module

Relays are switching that open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing in another circuit. In the EMS the 12-channel relay module is used in the discrimination of loads from solar to grid system and vice versa. The relays replace the old changeover switches. The module gets the signal from the microcontroller and takes the required actions (discriminating loads or switching back the loads from grid system to the mains) as per the program.

The module gets the signal from the microcontroller and takes the required action

3.10 Loads

One 100w, one 60w, one 40w bulbs are used to represent loads of different ratings. Figure. 6 shows the schematic diagram of the proposed system.

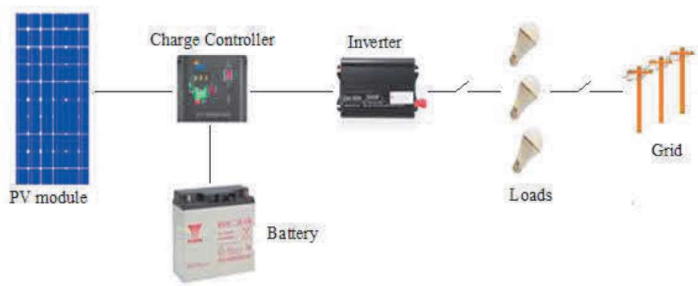

Figure 6: proposed energy management system Software Code

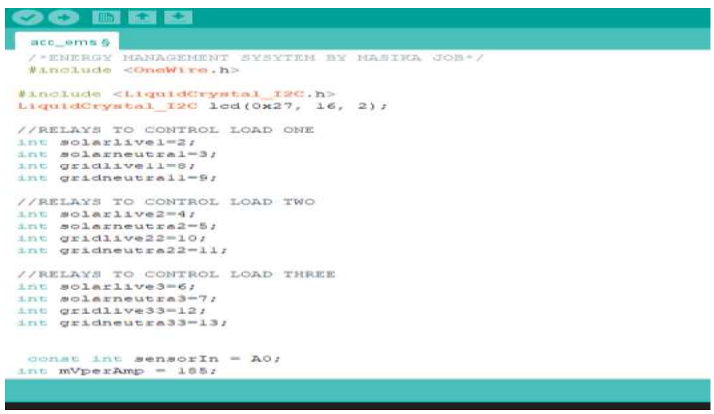

Figure 7: Digital pins declaration of devices

The first part of the program is global declaration of different objects, in this case the components i.e., the current sensor, the relay systems, the LCD. Every single Load utilizes four digital pins, two for solar power supply and two for grid power supply

Figure 8: Current calculation

In the void setup ,the Arduino pins that are connected to the modules and sensors are declared whether as output or input but on this EMS the digital pins will be used as outputs.

```
acc_ems
}

void loop(){

 Voltage = getVPP();
 VRMS = (Voltage/2.0) *0.707;
 AmpsRMS = (VRMS * 1000)/mVperAmp;

 current=AmpsRMS-0.09;
 Serial.print("CURRENT=");
 Serial.println( current);
 if(current <0.70){

 }
 if( current <0.70 ){

    digitalWrite( solarlive1, LOW);// switch off LOAD1 from solar system.NORMALLY CLOSED
     digitalWrite( solarneutral,LOW);//switch off LOAD1 neutral from the solar system.NORMALLY CLOSED
     digitalWrite( gridlive11,LOW);//switch on LOAD1 live to the grid system.NORMALLY OPEN
     digitalWrite( gridneutral1,LOW);//switch on LOAD1 neutral to the grid system.NORMALLY OPEN


     Serial.print(" LOAD1 ON grid:");//dispaly the state of the load.
     Serial.println(current);
     lcd.setCursor(0,0);
     //lcd.print("ENERGYMNGMTSYSTM");
```

Figure 9: Logical operation to discriminate loads

In the void loop, this is the back bone of the control program, this is where the current calculations are calculated by the microcontroller with the signal from the current sensor. it's here where the logical operation to control discrimination of loads from solar system to grid system and vice versa. The **ACS712 measures current** in two directions. It means that if we sample fast enough and long enough, we sure to find the peak in one direction and the peak in another direction as the **ACS712** have 5 µs output rise time in response to step input current. We are measuring AC current of 50Hz i.e., 20mSec per cycle and we get around 4000 Samples in one cycle. With both peaks known, it is a matter of knowing the shape of the waveform to calculate the current. In the case of line or mains power, we know that waveform to be a SINE wave

RMS Current = root (2) * Peek Current (7)

The flowchart controlling the actions of the system is shown in Figure 3 which shows the sequence and flow of all calculations and controls

The sequence and flow of energy, as implemented by Arduino Uno, is represented by the flowchart given in Figure. 10.

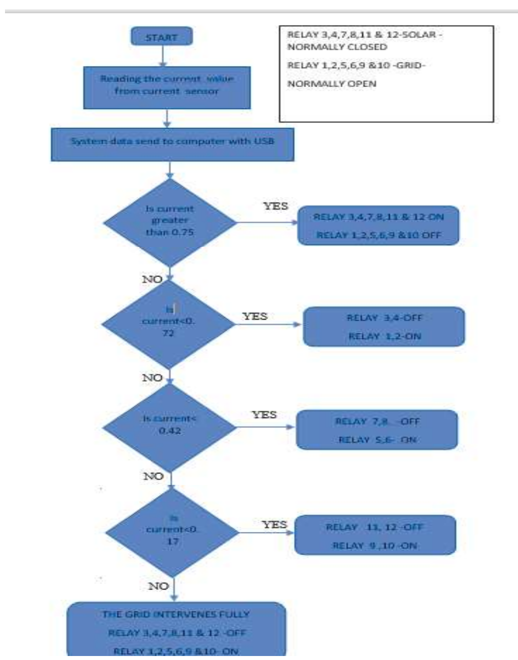

Figure 10: flow chart of the EMS current sensor

Figure 11 below shows the block diagram of the EMS.

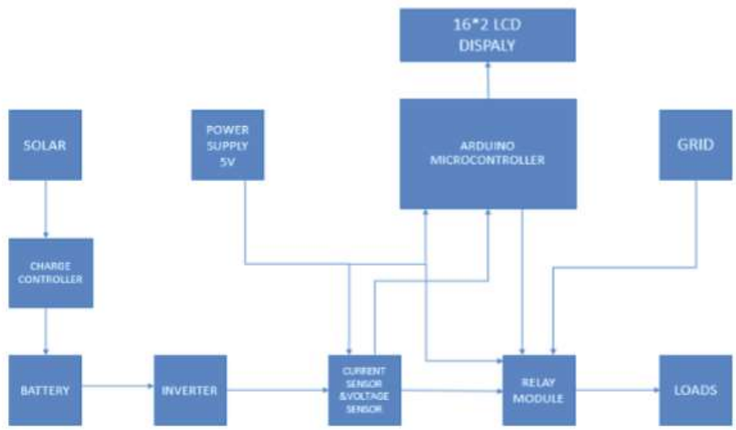

Figure 11: Block diagram of EMS

4. Results and Discussion

The energy flow between the utility grid and the micro sources are monitored to determine the specific energy source that supplies specific load at any given time. The prototype is observed to be disconnecting loads one at a time whenever the supply current from the micro sources becomes less than the specified threshold value (0.70A,0.42 and 0.17A)

```
if( current <0.70 ){
digitalWrite( solarlive1, LOW);// switch off LOAD1 from solar system.NORMALLY CLOSED
digitalWrite( solarneutra1,LOW);//switch off LOAD1 neutral from the solar system.NORMALLY CLOSED
digitalWrite( gridlive11,LOW);//switch on LOAD1 live to the grid system.NORMALLY OPEN
digitalWrite( gridneutra11,LOW);//switch on LOAD1 neutral to the grid system.NORMALLY OPEN}
```

The first load disconnected from the solar system to grid when the total supply current is less than 0.70A.the second load is disconnected when the total current supply is less than 0.42A and lastly the last load will get disconnected from solar to grid when the total supply current is less than 0. 17A.The voltage sensor is used in calculation of the power consumption in the system.

Figure 12: The EMS prototype working

The above photo is of the EMS operating from the battery charged by the solar during the day. And the total power consumption is 200W and the current displayed is approximately 0. 8333A.The relay on the right represents the grid part which is connected to the loads. The relay module on the left represents the solar system that is currently working and active while the grid part is off.

5. Conclusion And Future Work

This paper presents a complete modeled grid-connected solar system that includes solar photovoltaic array system, battery energy storage system, power inverter and grid source. The objectives for this paper (To design the electrical and electronic system to aid in energy management operation of different system connected to grid and solar, with solar given the authority hence minimizing the consumption of the grid supply hence saving on the cost) have been successfully realized through the practical implementation of the entire system. The future the project can be improvised by adding the website and database for remote monitoring of the system.

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