Energy Monitoring and Management System

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Theory of Operation

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Statement of Purpose
The purpose of this document is to provide detailed information regarding the inner workings and functionality of the EMMS meter. Along with referenced documentation, the Theory of Operation should, in theory, allow the reader to understand all finalized aspects of the EMMS meter design.

To begin, an overview of the meter will be described, then this document will identify major sections of the project, each including design specifications and a top-down overview of the design.

Problem Statement
There exists a problem in developing countries involving energy conservation. In order to provide a practical way of controlling energy consumption and to create a tool for teaching energy conservation, this project was tasked to make an energy meter. The meter should be able to measure energy usage usage over a period of time and to prevent further energy usage after a specified amount has been consumed.

Design Overview
Our meter includes two devices. One device contains all of our power sensing and control circuitry (hereafter known as the power box), and the other device functions as the user interface (hereafter known as the interface box). These are shown in Figure 1.

![Figure 1: Power Box (larger box with 4 LEDs) and User Interface Box (smaller box with LCD display) making up the entire EMMS meter version 2.5](image)

The main components of the power box consist of three circuit boards and a relay. The
three circuit boards in the power box are the Command Board, the Power Sense Board, and the Power Supply Board. The current versions are shown in Figure 2.

![Image of circuit boards](image1.jpg)

*Figure 2: Power Supply Board (upper left), Power Sense Board (upper right), and Command Board (bottom)*

The Command Board contains a PIC microcontroller, loaded with our latest firmware, that runs the meter. Some examples of the PIC’s functions include its use to store values for power and allocated energy, and to calculate the energy that has been used. The PIC also controls the relay, which is used to disable power to the building, and is used to communicate with the user interface box and other modules in the meter.

For metering, the Power Sense Board uses a specialized integrated circuit to measure load current and voltage. The integrated circuit uses these values to calculate the energy used and outputs a pulse for the energy and a waveform for the current and voltage data. The PIC on the Power Sense Board captures both signals and performs the appropriate calculations to determine the energy consumption of the load and give instantaneous power feedback. The power and energy are stored as variables in the PIC microcontroller.

The Power Supply circuit provides stable 5V and 12V DC sources to our meter from an AC input of either 120V_{rms} or 240V_{rms}. 
The modular design of the meter allows for easier function expansion. This was done by adding the ability to plug in three new features or modules into the white headers on the command board and communicate through Serial Peripheral Interface (SPI). Any features added in the future will not require a redesign of the central hardware of the meter. They will simply plug into the existing circuitry and function after a code update. Hereafter, any reference to a feature that communicates with the main circuitry through SPI communication will be referred to as a module to the meter. The connections inside the meter can be seen in Figure 3 and the physical inside of the meter can be seen in Figure 4.

Figure 3: The Power Box circuit board connections
The user interface box contains a 4 by 20 LCD screen, a PIC microcontroller, and four buttons. The PIC in the UI box is used to output information to the screen, read signals from the buttons, and communicate with the power box. The screen contains menus to display usage information and statistics and allows the administrator to change the meter’s settings. All of this can be navigated using the buttons under the screen. The circuit board for the user interface box is seen in Figure 5.

There are two enclosures. One contains the power sensing circuitry, and the other...
contains display circuitry (see Figure 1 and Figure 6). Both enclosures are now off the shelf models, modified to meet our needs. The display enclosure should be located in a place where the user can access it easily. It connects via a CAT 5 cable to the power box, which is to be attached to the facilities circuit breaker box or in another location where the everyday user cannot easily gain access.

Finally, effort is being into the addition of a WiFi module, which will allow for wireless communication of the data collected by the meter to a local device. The module will most likely collect its information from the pre-existing SPI communications system already implemented into the board. This module has not yet been integrated into the design of the meter, but is detailed in the fullest extent known in this document.
EMMS Detailed Design

Command Board

Documentation for the command board is currently under development and will be added as it is completed.

Please refer to the following project records for more information:

Command Board Redesign 1
Command Board Redesign 2
Command Board Capacitor Fix
Command Board Changes

Figure 7: Command Board Rev 2.4 Schematic
Power Supply Board

Physical Components
The following list consists of all of the physical Components and elements of the Power Supply Subsystem:

- Fuse Glass 500mA 250VAC 5x20mm
- AC/DC Converter: 5W 12V
- C1: 330nF
- C2: 33uF
- 4 Pin Connector
- 2 Pin Connector
- Fuse 2A 5x20
- 120V AC Output
- 12V DC Output
- GND

Breakdown of Circuit Design
The purpose of the Power Supply Subsystem is to take the 120V AC from the source and convert this into a 12V DC source that the meter can use. This 12V DC is then output to the command board to power its functionality. In addition, a 120V signal is passed through the power supply board untouched.

This circuit will be broken down by following the input voltage as it is converted from 120V AC to 12V DC as an output. The 120V AC is inputted into the subsystem through the left pin of the two pin header (X3), with the right pin on the two pin header connected to ground. The hot pin is then connected to the fuse before it is connected to the AC(L) pin of the AC-DC power supply. The AC-DC power supply then takes this AC input and transforms it into the desired 12V DC outputted on the +V₀ pin. The +V₀ pin and the GND pin are then coupled with two capacitors to filter out any unwanted AC voltage still present (C1, C2). The four pin header (X4) is the output of the board. The first pin of the header outputs GND from the power supply. The second pin on the header outputs the +V₀ from the power supply which is +12V DC. The third pin on the header receives and outputs the AC(N) after N is inputted to the power supply. The fourth pin receives and outputs AC(L) after the L passes the fuse. A schematic and board layout of the Power Supply board can be found in the Reference section below.

Interaction of Power Supply Subsystem with Meter
The Power Supply Subsystem plays an integral role in relation to the rest of the meter. Its functionality is to provide the power necessary for the meter to operate and function properly through the 12V DC output it provides to the command board.
Power Supply Reference

Figure 8: Power Supply Board Layout

Figure 9: Power Supply Schematic
Power Sense Board

Documentation for the Power Sense Board is currently under development as the new version is still in the development phase. The documentation will be added as it is completed.

Please refer to the following project records for more information:

*Power Sense 3.1 Project Record*

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**Figure 10: Power Sense Schematic Box Diagram**

**Figure 11: Power Sense Schematic**
User Interface Board

Documentation for the User Interface board is currently under development and will be added as it is completed.

Please refer to the following project records for more information:

*User Interface Board and Enclosure*
Wifi Board

Physical Components
The following list consists of all of the physical Components and elements of the Wifi Module as of v1.1:

- ESP8266
- PIC24KV302 28 Pin
- LED x 4
- Voltage Regulator: 3.3v
- C1: 10uF
- C2: 10uF
- R1-R5: 10KΩ
- R6-R7: 330Ω
- Female Molex Connector: 6 Pin
- GND

Communication
This communication is a subsystem of the command board and user interface. This will be addressed as documentation develops further for the two boards. This communication is different from the SPI protocol we use between our command board and power sense.

Please refer to the following documents for more information:

[Link to the Communication Code Flowchart]
[Link to the Project Record of the Communication Code]

Physical Components
The following list consists of all of the physical Components and elements of the Communication Subsystem:

On Command Board:

- R1: 10k Resistor
- R7: 1k Resistor
- R8, R9: 100 Ω Resistors
- F1: Fuse and Miniature Fuseholder
- U4: Voltage Regulator
- U3: RJ-45 Jack
- U1: Microchip PIC 20 pin
- U2: Transceiver MAX488
- 20 pin DIP IC Socket
- 6 pin Header Male
- Connectors: Molex 2 position connector, molex 4 pos connector, molex 2 pos connector

On User Interface Board:
- C3: 0.1uF Capacitor
- C1, C2: 10uF Capacitors
- R8: 470 Ω Resistor
- R5: 120 Ω Resistor
- U2: IC Diff Bus TXRX 8-Dip
- U1: 28 pin PIC
- U4: Voltage Regulator
- U3: RJ-45 Jack
- Chip Socket

The code for the Communication Subsystem can be split into two different levels: the first is the overlying description on how the communication occurs through analysis of the physical components and sent electrical highs and lows; the second level goes more into the actual code determining what data is being sent and received and what the data means. The first level is developed in the Breakdown of Circuit Design section, while the second level is described in the Code section.

**Breakdown of Circuit Design**

We will analyze the circuit design by starting to describe the parts of the Communication Subsystem on the Command Board and their functionality. Please find the schematic of the command board attached in the Appendix. For our meter command board, we have the capability for two module attachments that the PIC can communicate with using full duplex serial port communication. An example of a module would be the User Interface. Since the communication circuitry for both modules are identical, we will look in depth upon one module and explain the few differences in the other module circuitry (note: follow along on the schematic attached). By starting at one of the two MAX488 transceivers, we can follow along and determine how the communication for one of the modules work on the circuit level. The MAX488 acts as the component that interprets what to send to the RJ-45. For the MAX488 labeled XCVR1, we have pin 1 connected to V_CC and pin 4 connected to GND. Since our PIC utilizes full-duplex communication, we have a line for transmitting data and a line for receiving data. Data is transmitted from the PIC’s pin 16, named J1_TX, by sends data to pin 3 of the transceiver. This is then sent to the RJ-45 and in turn to the module it is connected to. When coming data is received from the module, it will enter the RJ-45, be interpreted by the MAX488, and sent via pin 2 of the MAX488 to pin 6 of the PIC, named U1_RX. For a second module, the same process occurs through the MAX488 named XCVR2, this time taking transmitted data from pin 4 of the PIC (pin named U2_TX) through pin 3 of the MAX488 and sending received data from the module to pin 5 of the PIC (pin named U2_RX) through pin 2 of the MAX488.

![Figure 16: The Communication Subsystem on the Command Board. Whole schematic can be found in Reference.](image-url)
In addition to communicating with two module attachments, pins 4 and 5 of the PIC are connected to the programmable header that a PICKIT can connect to. It is through this header that one can reprogram the PIC and make modifications to the code.

**Code**

The code of the Communication Subsystem is the most elaborate of all of the subsystems. A flowchart of the code can be found in the Reference section below, as well as a project record that describes the development of the communication code, and the code itself. The code can be broken down into three main functions: splitReceivedCommand, processReceivedCommand, and sendCommands. These three functions are necessary for communication to exist between the command board’s PIC and any module that is attached to it.

The first function to be analyzed is splitReceivedCommand. The main purpose of this function is to take the received data characters and process it in a way that it can be used by the rest of the code on the PIC. Going through the code, it can be seen that the first step is to check and see if there is code in any of the five buffers ready to be processed. If there is, then the code will begin splitting the received command. This is done by first identifying if we have a start character, a specified character that allows the code know valid data is now being received. The start character is the symbol, ‘%’. After the start character is found, the code begins to split the received data and sending the pieces to the receivedAttribute array. The received data is split into pieces through a delimiter, a character that helps the code identify when to split the code. In our case the delimiter is space, ‘ ’. This continues until either invalid characters or the end of the command is reached. The end of command character lets the code know that the end of the received data is reached. In our case the end of command character is a period, ‘.’. At this point, all of the received data has been processed.

The second function to be analyzed is processReceivedCommand. The purpose of this function is to process the received command and take the proper action based upon the command. This function first checks if there is a command ready to be processed that is stored in receivedCommand, receivedAttribute, and receivedValue. If not, then the function is terminated. If yes, the value of receivedCommand is compared to a list of valid options. If a match is found, then the value of receivedAttribute is compared to another list of valid options. If a match is found again, then a specified action is taken based upon finding matches in the values of receivedCommand and receivedAttribute.

The last function to be analyzed is sendCommands. The purpose of this function is to determine if there is data ready to be sent, and if there is to send it. The first step in this function is to determine if the program is currently sending a command. If it is not, then the send buffers 1 through 5 are checked, starting at buffer 1. If a command is found in a buffer, the command is moved to the next lower number buffer until buffer 1 is reached then the program begins sending. Once the program begins sending, it determines whether or not it is currently sending on its interface. If not, it checks if any sending is occurring on any interface. If yes, the characters on stringToSend is copied into the hardware transmit register until it is either full or the end of command character is reached. The program then checks if an end of command occurred. If it did occur, then it determines that it is no longer sending on its interface. It this checks if any sending is occurring on any interface. If no, then no sending is in progress, and the function is terminated.

To obtain a more thorough understanding of the code, please find the flowchart of the code in the reference, the project record that accompanied the code, and the code itself all in the Reference section.
Interaction of Communication Subsystem with Meter

The Communication subsystem is what allows the meter to communicate with the outside world, specifically the modules. This means that the user interface can display to the user the operations of the meter, and see the details of what is occurring. In addition, the code can be reprogrammed through the 6 pin header on the command board. Without the Communication subsystem, the user would not be able to make modification to a meter’s settings nor be able to see the details of power usage, time, etc.

Enclosures

Meter Layout and Power Box

In the past, we were able to rapidly prototype designs in house using the MakerBot 3D printer. However, because of frequent failures and the long amount of time that it takes to 3D print, we officially moved to purchase prefabricated boxes for our Power box. The current layout has been implemented in the meter as seen in Figure 4, and can be seen through a Solidworks model in Figure 17.

Please refer to the following documents for more information:

Power Box Baseplate Record

![Figure 17: Solidworks model of the meter layout](image)

Power Box Baseplate Design

We designed a laser cut baseplate that is adaptable and quickly made. It allows for the circuit boards to be constrained using standoffs and screws. This baseplate design can be seen in figure 18.
Figure 18: V3 baseplate Solidworks

Independent Board Layout

Since there is no available room for the command board and new wifi board on the surface of the baseplate, they will be mounted to the box walls. The current design for this requires the use of lock-in supports with adhesive that will secure the two boards to the box walls, independent from the baseplate.

Interface Box

We recently moved to an off the shelf User Interface Enclosure away from 3-D printing them. This makes our meter more cost efficient and commercially available. To manufacture these enclosures, a CNC machine is used to rapidly cut out sections for the buttons, LCD screen, and RJ-45 jack. See User Interface Project Record for more information.
Figure 19: User Interface Enclosure with drilled holes and cuts made
WiFi Module

Communication for the Wifi Module is still under development. Communication has been achieved wirelessly into the module but not from the module to the command board of the meter.

Please refer to the following documents for more information:

Wifi Project Record

Full Circuit Diagram:

![Current Circuit Design](image-url)

Fig. 20: Current Circuit Design
Appendix A

Change Log

- 2014-01-13
  - Add menu language requirement
- 1001-1.C.1.a
  - Visual accessibility - bar graph
- 1001-1.C.3.b

- 2013-11-03
  - Add UV resistance to enclosure materials
- 1010-02.5.J - sunlight resistance

- 2013-09-29
  - Incorporate comments from Matt Walsh
  - 1001-01.2.D.1.a - daily usage
  - 1010-02.14.C.2 - clock survival time
  - Add section for connecting cable
  - 1010-02.16

1001 General

Scope

1. This design is to be considered a “70%” Device in that it is 70% towards a finished and manufacturable product. The core of the design is to be essentially complete with only tweaks to complete it. As such the device is to be made only in small numbers.
2. The Kilowatt Hour Meter device (Device) is to provide power systems with a means to monitor and control the use of electrical power downstream of the device. It is used to educate the user to energy usage and provide a fair system to share energy amongst several users.
   A. Wiring Interface
      a. All components within the device must be able to interface with the following power system wiring.
         1. 120 VAC with 1 hot, 1 neutral, 1 ground
         2. 120 VAC with 1 hot, 1 neutral, no ground
         3. 240 VAC with 1 hot, 1 neutral, 1 ground
         4. 240 VAC with 1 hot 1 neutral, no ground
5. 240 VAC with 2 hots (120 VAC 180° phase shifted), 1 ground
6. 240 VAC with 2 hots (120 VAC 180° phase shifted), no ground
7. 240 VAC with 2 hots (120 VAC 180° phase shifted), 1 neutral, 1 ground
8. 240 VAC with 2 hots (120 VAC 180° phase shifted), 1 neutral, no ground

b. The Device shall be capable of monitoring and switching 0 to 20 amps at all wiring voltages.

B. Safety
a. The Device shall be electrically safe and shall not present a shock hazard during installation, modification, or normal use.
   1. Operations with the cover removed should have provisions to minimize exposure to high voltage components while energized.
b. There shall be a disconnecting means to de-energize the internal wiring of the Device.
c. The Device shall have an overriding capability to restore power downstream of the device in the event that the device program disconnects power during a time that is considered an emergency.

C. User Interface
a. The user shall be presented with an interface that is intuitive and easy to use.
   1. User interface must be available in the following languages
      a. English
      b. French
b. A separate administrative section that is protected shall be provided to set meter parameters.
   1. The password protection can be disabled by the administrator menu so that a password is no longer required to enter the administrative menu.
c. A minimal fully functional device will be able to display the instantaneous power use, the amount of total power used, and the power remaining.
   1. A warning is to be presented to the user with the power remaining is below a predetermined level.
   2. Display of information is to be simple and intuitive - no special understanding shall be necessary to understand the information presented.
      a. A simple graph of all pertinent parameters shall be a part of the display.
      b. A 3 position indicator shall be a part of the display to show 3 levels of operation.
         i. high, normal, low power usage
         ii. much, some, little power remaining
D. Function
   a. The Device will be capable of monitoring the total power consumption over a predetermined period of time.
      1. typical use ranges from 500Wh/day to 4000Wh/day
   b. At a predetermined total power consumption level the Device shall be capable of breaking the circuit to prevent further power consumption.
   c. The device will be able to store usage information on an hourly basis for later retrieval.

E. Environment
   a. The Device is primarily designed to be used in the country of Burkina Faso, West Africa and surrounding areas.
   b. Outdoor
      1. 60°F to 120°F
      2. Rain resistant
      3. fine soil dust tolerant
   c. Indoor
      1. 60°F to 105°F
      2. Splash resistant
      3. fine soil dust tolerant

F. Future Expansion
   a. The Device is to be easily expandable with future capability. Devices installed in the field are to be easily upgraded without requiring replacement of unnecessary components.
   b. Existing devices that may have been deployed are to be easily upgradable with basic instructions and no specialized equipment or tools.
   c. Adding a hardware module should not require a replacement of any component in the system.
   d. A software upgrade should consist of either:
      1. reprogramming the on board CPU program memory.
      2. replacing the CPU memory with a new pre-programmed component.
e. Core components in the design that may be upgraded in the future are to be easily field upgradable without specialized equipment, software, or tools.

G. Submit for approval products and designs for approval prior to use in the Device. Products and Designs must be explicitly approved in the design process. Approval of a submission does not constitute approval of any products or designs that may be missing from the submission.

3. Product specifications are derived from the first named product. Proposed products shall have similar characteristics to the first named product.

4. A consolidated submittal consisting of products and designs shall be submitted for approval prior to final construction of the Device.
   A. Submit a Bill of Materials including items, source, quantity, and price information
   B. Submit a design book detailing the design of each component and the manufacturing process to be used.
   C. Submit the source code to be used.

5. All program code shall be printed and peer-reviewed in walk-through sessions
   A. Program code shall be broken down into independent code blocks
      a. Each code block will consist of functions and supporting code for one main operation of the device
   B. Walk through sessions will generate comments which will need to be addressed in a separate submittal.
      a. Submit the comments, how the comments were addressed, and the code as a submittal for approval.
   C. Program code must be approved through a submittal prior to inclusion in the Device.
   D. The final program code will be reviewed in a walk-through session and comments submitted prior to inclusion in the final Device.

6. Submit a testing plan for approval prior to the start of testing.
   A. Testing of functionality is to include a third-party that is not a member of the group
      a. third-party to be approved by the Advisor.

7. The final product is to be presented to a panel of 3 independent testers for approval prior to delivery to the Customer.
   A. Submit the presentation and testing plan for approval.

Products

1. Not Used.

Implementation
1. The device shall consist of a minimum of two separate components; a Power Component and a remote
   A. Display component.
      a. A Power Component that is fully functional and provides the minimal user interface.
         1. will provide the wiring interface
         2. will provide the power control means
         3. will provide minimal user interface
         4. will provide full operation without need for another component
         5. to be mounted at a location convenient to premise wiring
   b. The Display Component that functions when connected to the Power Component
      1. will provide full Device control
      2. will provide full Device displays
      3. will provide a portable programming interface to set Device parameters
      4. is to be mounted at a location convenient to the user

1010 Components

Scope

1. Components shall be manufactured by well-known manufacturers and readily available through mail-order in the United States.
2. Submit product information on all components for approval prior to use in the Device.
   A. product sourcing.
   B. product cut sheets.
   C. design application.
   D. product cost
   E. estimated quantity to be used

Components

1. Displays
   A. Displays shall be readable in bright daylight as well as near dark conditions.
   B. simple displays for indicating a range shall:
      a. be bar-graph style with minimum 3 segments.
      b. have progressive colors where minimum is green, middle is yellow or orange, and the maximum value is red.
   C. complex displays used for menus and displaying numerical data shall:
      1. be a minimum 2x20 character dot matrix display.
      2. be readable in bright sunlight as well as near dark conditions.
D. be one of the following components:
   1. LCD display with backlight
   2. OLED display
   3. or approved equal

2. Power control device
   A. shall be powered by the same power source as the rest of the system.
   B. shall be a normally open connection
   C. be able to switch the various power systems as specified in the General section.
      a. must provide a completely de-energized system downstream of the Device.
      b. be of robust quality
      c. be able to withstand fine soil dust without degradation
      d. be able to withstand switching 20 amps of current repeatedly without degradation
   D. be one of the following components:
      a. Solid state relay
      b. Electrical-Mechanical relay designed for automotive use
      c. Approved equal

3. Connectors
   A. shall provide secure connection
      a. by high friction
      b. by positive ‘click’ latch
   B. shall provide polarized connection that is easily identifiable
      a. polarization shall be provided by:
         1. mechanical limitation - the connector will not fit
         b. visual identifier
         1. missing pin
         2. color coded clearly indicated and consistent across Devices
         3. other approved method
   C. shall be one of the following
      a. molex type connector
      b. pin header style connector
      c. approved equal

4. Circuit boards
   A. shall be of professional quality
   B. contain minimum 2 oz copper
   C. be of fiberglass resin type
   D. Submit calculations to show the copper traces are sized appropriately for the anticipated current.

5. Enclosures
   A. material that cannot be damaged by water
   B. material is to be durable and able to withstand normal handling for household items
C. are to house all components
D. are to be readily made and available in the United States
E. are to be either fully metallic with grounding or fully non-metallic with no showing metallic components
F. are to be mounted to a wall using hardware and techniques typically used in the locality where installed.
   a. the mounts are to be secure and able to withstand normal bumps and minor impacts without dislodging
   b. thru-wall bolts or screws have been observed
G. are to provide easy access to internal components by screw-on covers
H. are to be made of:
   a. plastic
   b. metal
   c. approved other
I. should be relatively small
J. material for outside installation must be able to withstand long periods of direct sunlight (UV radiation) without breaking down.

6. Wires
   A. are to be of same type for the same sizes used
   B. are to be stranded
   C. are to be #10 AWG for AC power conductors
   D. are to be #20 AWG for control conductors
   E. Wire color codes:
      a. Black - AC disconnectable power
      b. White - AC Neutral
      c. Red - AC second phase
      d. Blue - DC signal or power wires
      e. Green - ground wires

F. Suppliers
   a. Submit product for approval

7. Terminal Wiring Strips
   A. are to be easily accessible
   B. are to be easy to land wires on
   C. are to support #16 AWG - #10 AWG solid or stranded wire

8. Warning device
   A. shall make a sound
   B. shall have a silence function
   C. shall be of a suitable volume and tone to provide notification one room away
   D. shall not be annoying as to provide reason to disconnect
   E. shall be of the following type:
      a. speaker
      b. piezo buzzer
      c. bell
9. Buttons
   A. shall be simple and robust
   B. shall not require excessive penetrations into the enclosure
   C. shall have a professional look
   D. acceptable types:
      a. tactile circuit board mounted buttons with key cap cover
      b. panel mount push buttons
      c. or approved equal

10. Power Sensor
    A. The power sensor is the core component of the Device. The power sensor is to
        collect voltage and current measurement data to provide an instantaneous power
        level reading to the rest of the system. The accuracy and reliability of the power
        sensor directly impacts the usability of the Device.
    B. Shall have an error no greater than 1% over the entire range of operation.
    C. Submit product information for approval prior to use within the system.
    D. Submit designs along with anticipated or measured error levels for approval prior
        to use within the system.
    E. All error calculations are to be calculated against well-known sources. The
        equipment used to generate the power load must be understood and appropriate
        for the tests performed.
    F. Submit for approval evidence supporting the suitability of known sources prior to
        use.
    G. Submit for approval evidence supporting the appropriateness of the loads used for
        testing before use.
    H. Measurements must be taken from the power sensor and the known sources at the
        same time from the same circuit. Running separate tests for obtaining
        measurements from the data sources is not acceptable.
    I. Testing must be performed over the entire range of anticipated loads listed in the
        General section.
    J. Error calculations are to be calculated against well-known or calibrated sources.
       a. Values measured from the power sensor are to be compared to at least
          two known sources.
       b. Submit for approval evidence supporting suitability of the known
          sources prior to use.
    K. Measurements are to be taken from the full range of power levels specified for the
       system. Extrapolated or estimated error levels are not acceptable for final error
       calculations.
    L. The error between actual power usage and the power usage determined using the
       power sensor shall be well understood and documented.
    M. shall be able to interface with the provided wiring and provide power sensing over
       the full range of expected power usage.
    N. shall be of a modular design
a. The power sensing component must be easily interchangeable without requiring a rework of the rest of the Device
O. shall communicate with the rest of the device using a communications protocol common to other protocols used through the device.
P. shall sense voltage and current to compute an instantaneous power and make all values available to the Device.
Q. submit for approval the design and results of error testing prior to incorporation into the Device
R. shall be one of the following types
   a. Hall effect
   b. Shunt resistor
   c. other approved type

11. Power supply
   A. The power supply shall utilize the connected power source to generate all voltages at power levels that may be required by the Device.
   B. The power instability shall be understood and of a magnitude that it will not impact the output of sensors that the Device may utilize.
      a. < 10mV ripple is desired.
   C. shall be one of the following
      a. readily available industrial type
      b. in house designed and tested
      c. other approved

12. CPU
   A. shall be a readily and available component
   B. shall be inexpensive
   C. shall be easily programmable
   D. shall be one of the following
      a. PIC microchip
      b. Other approved

13. Non-volatile memory
   A. shall provide storage of all configuration parameters
   B. shall have sufficient capacity to store historical data for a one month period
   C. shall permanently store data unless changed by the Device

14. Clock
   A. shall provide date and time functions
   B. must have a precision down to at least the second
   C. shall be able to continue to operate with power removed for a period of 1 hour
      a. ideally more than 24 hours is desired
      b. client has stated 6 hours is typical
   D. shall implement daylight savings time where appropriate
E. Shall be easily settable

15. Circuit components
   A. Discrete circuit components shall be readily available

16. Interconnection Cable
   A. Shall be readily obtainable in association with solar installations in Africa.
   B. Shall provide reliable communication up to 50 feet
   C. Shall provide required power at remote location
   D. Cable shall not be easily attached to other non-compatible equipment.
      a. If cable can be attached it shall not result in damage to any component.

Methods

1. Circuit board manufacture
2. Circuit boards are to be manufactured by a ‘rapid prototyping’ method.
   A. in house milling or routing
   B. chemical etching
   C. other approved method

3. Enclosure
   A. The enclosure is to be manufactured by a ‘rapid prototyping’ method.
      a. 3D printing
      b. milling
      c. other approved method

1030 Functionality

Scope

1. The Device is to provide the following functions
   A. Voltage sensing
   B. Voltage display
   C. Current sensing
   D. Current display
   E. watt calculation
   F. watt display
   G. watt hour totalization
   H. watt hour display
   I. time and date tracking
   J. watt hour reset at specified time of day
   K. watt hour reset at specified interval
   L. watt hour reset at specified time and date criteria
M. watt hour limit set
N. watt hour limit power cut off
O. display estimated time remaining at current power consumption
P. alarm with pre-specified power remaining

2. The device is to be broken into two components
   A. Power box
      a. All core functionality is to be handled by the Power box
      b. mains wiring interface
      c. power source for the Device
      d. power control mechanism
      e. minimal information display - may be one display with user selectable option
         1. instantaneous power usage
         2. total power usage
         3. power remaining
      f. power remaining alert
      g. emergency power restore button
         1. can be disabled
      h. non-volatile storage of Device parameters
      i. clock with power outage survivability
      j. capability to add modules to expand functionality
      k. the neutral is not to be switched - it should always remain connected
   B. Display box
      a. To primarily be a display interface - all of the core functionality is to be done by the Power box.
      b. main user interface capable of displaying the following
         1. instantaneous power consumption
         2. total power used
         3. power remaining
         4. time of day
         5. user interface menus
      c. administrative interface
         1. set parameters in Power box
            a. operational parameters
            b. clock
         2. read parameters from Power box
            a. operational parameters
            b. clock
      d. non-volatile storage of parameters
         1. used to copy parameters from Device to Device
      e. Real time clock with power survivability