

Wireless Energy Consumption Tracking on Adhoc Network

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Abstract- In countries where Energy consumption is a critical issue, many rural areas have power failures very frequently and one of the biggest reasons for this problem is poor power management in urban areas. This poor power management issue occurs because of ignorance of the consumers which is more prominent as consumers do not keep a track of their energy consumption levels. Project SEM is a design proposed to help solve this problem. This system is specifically designed to tap voltage and current at the upstream of mains of a specific area, to calculate instantaneous active power values and to eventually calculate energy consumed by the systems in that area. This reading of energy, power, voltage and current is then sent to the android device for further processing and display. The sEm android app will show the user these real-time values as well as estimated bill amount till that moment of that specific month. The app will also allow the user to set bill limits in order to get a notification when energy usage has crossed the pre-defined limit.

Index Terms- Energy metering, adhoc, real-time values, android solution, tariff notification.

I. INTRODUCTION

With increase in inventions and development in technological field, we have more and more electronic and electrical systems built everyday. With increasing electronic and electrical products for the general public as well as for the industrial area, we have gigantic electricity bills on our desks. There is also a fair amount of Research and Development work going on for optimizing the power consumptions in these systems, by using advanced power management methods so as to reduce or limit the power consumed by these individual systems. But pace of this research is not even close to the pace of increase in the number of systems in each household, industry etc. Even if one (layman) knows about his/her energy consumption units, it is a very tedious job to get it converted in terms of money. This becomes a major aspect in the process of ignorance towards one's energy usage. But what if the user gets a regular energy usage reading on his android device, in terms of estimated electricity bill to be paid till date. sEm is a energy metering project with a much more transparent approach towards the user. It has two main sections in brief. First is the Main energy meter unit. Second is the sEm Android application. The main unit is to be connected at the mains upstream of the desired area, energy consumption of which is to be put under monitoring. Now you let the sEm system do the rest.

The last thing user has to do is to have the sEm android app in his/her android device and sync it with the main unit via Bluetooth. Now the app will show the user real time readings of Voltage levels, Current consumption by appliances connected in that area, Active Power reading, total energy consumption as well as the electricity bill amount to be paid till that instant of the particular month. The sEm application also allows the user to set tariff bill limit for the ongoing month and as soon as the limit is exceeded the app will pop up a notification, thus alerting the user to start optimizing his/her energy consumptions.

II. PROPOSED METHODOLOGY

This methodology is pretty straight forward. There are 4 important circuits used. The Voltage sensing circuit connected to the mains upstream in ladder topology to continuously stepdown and condition the wave form to provide equivalent peak values as well as a Zero Crossing Detector for interrupt output. The Current Sensing circuit consists of waveform conditioning circuits for equivalent peak values and Comparators for producing current interrupt. The power supply unit is designed to provide constant 5V and 3.3V DC levels for other sections. The 4th and most important circuit is the controller board. The code is completely interrupt based and not in a loop. The methodology is such that after initializations of on-chip modules the microcontroller goes into low power mode and waits for interrupt. Either of the voltage or current interrupt may occur first. But it is most unlikely that current interrupt will occur first as most of the loads connected to the mains are inductive loads causing the voltage to always lead the current. Suppose the voltage interrupt occurs, the corresponding ISR is executed which includes capturing the ADC value and calculating the Vpeak value. This ISR will also initiate a timer and wait for the current interrupt to appear. As soon as the current interrupt appears, its ISR will capture ADC value and calculate Ipeak as well as stop the initiated timer. Using this timer count reading we find out the time between the two interrupts or rather to be more precise time between voltage and current wave forms zero crossing. Using this reading we calculate phase angle. Now we calculate the RMS values of current and voltage by

$$V_{rms} = \frac{V_{(peak)}}{\sqrt{2}} \quad (1)$$

$$I_{rms} = \frac{I_{peak}}{\sqrt{2}} \quad (2)$$

Next thing in the algorithm is to calculate power $P = V_{rms} \times I_{rms} \times \cos(\text{phase angle})$. Now as the load in any area may not be constant we need to calculate the area under the curve of active power reading. With dt as sampling period. Calculate Energy using power in kW and time in hour (time since controller reset) to get the energy reading in kW-hr. Next step is to send these real time readings on an android device via Bluetooth 4.0 (BLE). This data will be further processed by sEm android application. The android app will first acquire the data from the Bluetooth adapter API and display the real time values of Voltage, current, power and energy. The app will then calculate the bill amount based on the energy consumption level and standard electricity tariff table of the particular region. The app will display the tariff till that instant on a gauge with maximum level as the limit set by the user. As soon as the limit is reached the app will notify the user.

III. ALGORITHM

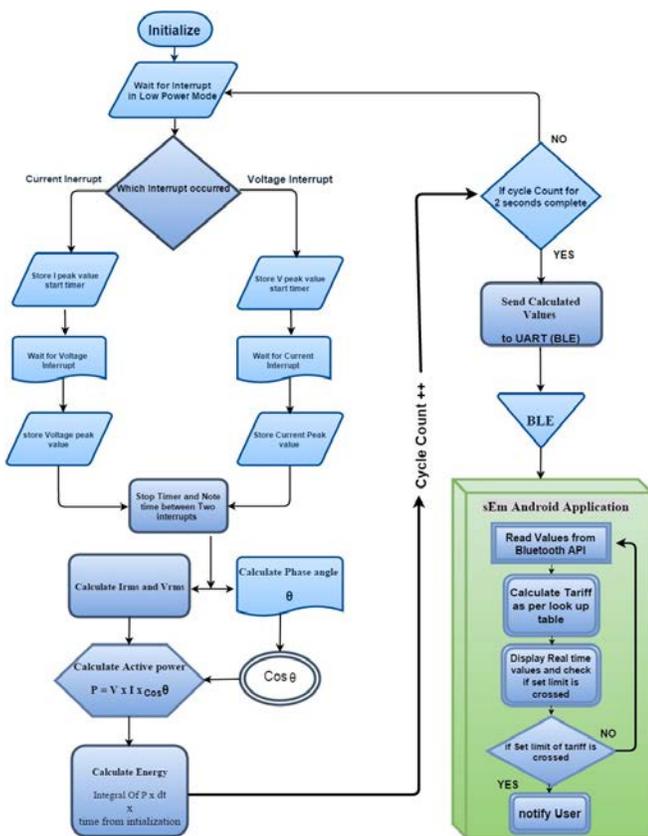


Fig. 1: sEm System Flow Chart

IV. DESIGN AND IMPLEMENTATION

The controller used is based on MSP430 architecture designed by Texas Instruments. Texas instruments provides a wide range of variants of MSP430 specially designed as low power MCUs. The specific variant used in this project is MSP430F5529LP. [2]

Current Sensing Unit: For current sensing we have used ACS712 Hall effect sensor module. This hall effect sensor module is connected in series with the Line of the mains and its output voltage corresponds to the current in Amperes flowing through the Line. Output of this module is at $V_{cc}/2$ dc offset level, which means that for 0A current flowing through it (with $V_{cc} = 5V$) its output will be 2.5V. It has a sensitivity of 0.066V/A, which means for every 1A through it its output will rise by 66mV. Therefore for conditioning this signal according to our needs we used op-amps, OPA2340 to be specific. With V_{cc} at 3.3V for the sake of protecting the on-chip ADC in undesirable cases. 2 Op-amp circuits are used: first is the peak detector since the algorithm created requires peak value in positive half cycle. Taking into consideration the 66mV/A sensitivity of Hall effect module and the 3.3V VDD of op-Amps, a maximum of 12 A can be accurately sensed in this system above which the output of Op-Amps will be saturated. Second Op-Amp circuit used is a Comparator with 2.5V as reference used such that if output of Hall effect sensor increases over 2.5V (which means Line Current through the sensor has reached its Zero crossing), the output of comparator will have a transition, Thus providing a interrupt for the controller. Fig 2 shows the schematic of Current Sensing Board [1]

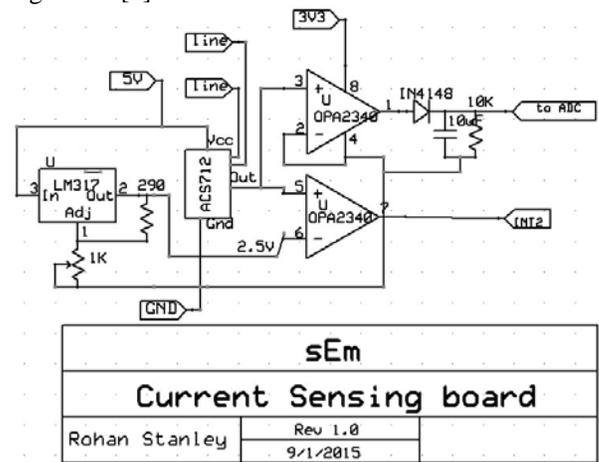


Fig. 2: Current Sensing unit Circuit

Voltage Sensing Unit: The voltage sensing circuit basically consists of a 3V, 500mA transformer with its primary winding connected parallel in ladder topology to the mains upstream of the region under energy monitoring and secondary connected to the trimmer on the voltage sensing board for voltage level adjustments. By using transformer at the beginning we can both step-down the voltage level as well as stay isolated from the grid. The output voltage of this trimmer is given to two op-amp circuits, one of them is a peak detector and the other one is a ZCD. The peak detector output is given to another ADC input channel of MSP430 and the ZCD output is given

as V - interrupt to MSP430 Fig 3 shows the schematic of voltage sensing board. [1]

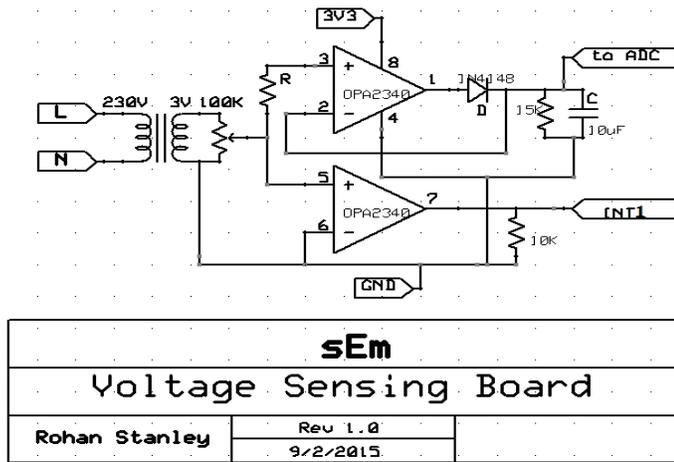


Fig. 3: Voltage Sensing Unit

Power Supply Unit (PSU): The power supply unit is specifically made to produce 5V and 3.3V for the Sensing and controller board. For generating 5V for the hall effect sensor the most commonly used regulator IC 7805 is connected with filtering capacitors. For generating 3.3V for op-Amps biasing as well as for the controller, IC LM317 variable regulator circuit is used. Due to use of low power components, the current and power requirements of the sEm circuits is very less and therefore these regulator ICs were sufficient for this project. [1]

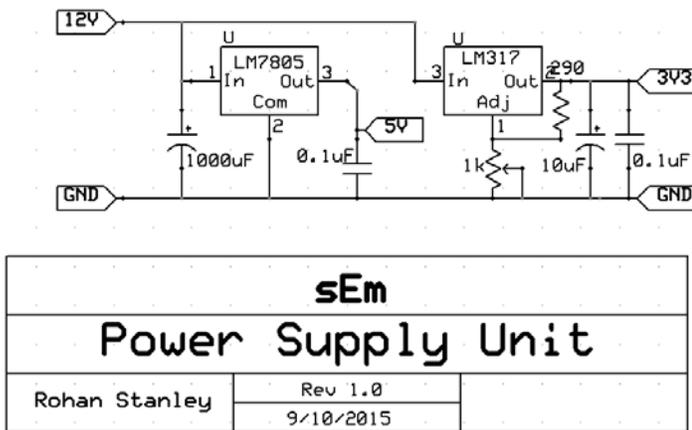


Fig. 4: Power Supply Unit

Bluetooth 4.0 (BLE): The communication module used for connecting to the android device is BLE 4.0 module. The ble module is connected to the vacant UART port of MSP430. This specific variant was selected because of its low power consumption levels and few other features which makes it much better from previous versions of Bluetooth. Previous Bluetooth version had:100msec of wake time latency ,which means when its in not connected state and in sleep mode, it takes 100 msec to wake up and start functioning. Minimum total time to send data is 100msec, which also increases its power consumption slightly. Power consumption: 1W as per reference .Current consumption: less than 30 mA.[10] While

BLE has following features: Wake latency : 6msec, Minimum total time to send data is 3msec, Power consumption: 0.01W to 0.5W, Current consumption : less than 15 mA.

V. SYSTEM BLOCK DIAGRAM

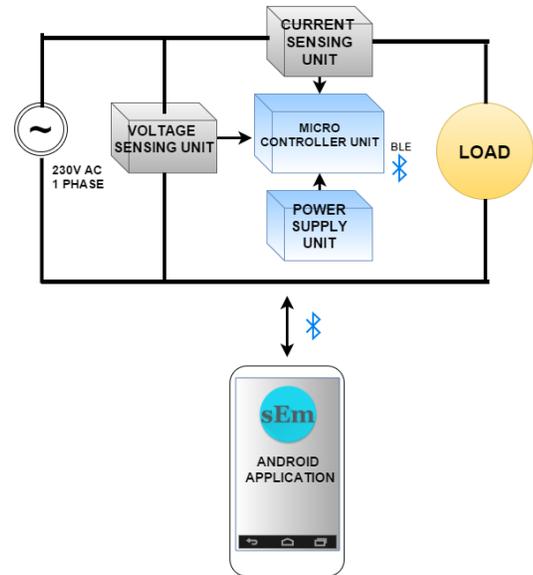


Fig. 5: System Block Diagram

VI. NORMALIZATION OF VALUES

For voltage sensing the ADC value read is passed through a simple equation

$$V_{peak} = \frac{ADCvalue}{4095.0} \times 3.3 \quad (3)$$

to get the voltage value. This voltage value is actually the peak value of the conditioned or rather attenuated version of grid voltage value. Therefore to get the actual grid voltage value we need to multiply this value with attenuation factors. After getting the peak value of Input grid voltage. We can get the RMS value by passing it in a simple equation

$$V_{RMS} = \frac{V_{peak}}{1.414} \quad (4)$$

, which is same as

$$V_{RMS} = \frac{V_{peak}}{\sqrt{2}} \quad (5)$$

For current sensing the input is from ACS712 hall effect sensor which provides an output with dc offset at $V_{cc}/2$, that means in our case the output will be shifted to 2.5V. The sensitivity of ACS712 is 66mV, which means output will change by 66mV for every 1 A alternating current flowing through the sensor. Therefore ADC value will be first converted to voltage value, same as in voltage sensing. This voltage value must first be freed from DC offset or DC shift provided by sensor. Therefore we perform

$$I = I - 2.5 \quad (6)$$

to get value having 0V reference. Now this value is divided by sensitivity of sensor ,

$$I_{peak} = \frac{I}{0.066} \quad (7)$$

to get actual current value in Ampere flowing from the grid into the monitored area. The RMS value of current will be calculated in the same way as for voltage values.

VII. CAPTURING PHASE ANGLE FOR POWER FACTOR CALCULATION

First we find out the time between current and voltage waveforms zero crossing instant by calculating time between the two interrupts rising edge. That is done by using the onchip timer module. When the Voltage Interrupt occurs we run the timer and as soon as the current interrupt arrives we halt the timer and using the count stored in timer register we can easily calculate the time between the two interrupts (timeInterval). We can then calculate phase angle by the time value using

$$PhaseAngle = timeInterval \times 50.0 \times 360.0. \quad (8)$$

VIII. POWER AND ENERGY CALCULATIONS

For calculating instantaneous power consumption we use the RMS values of voltage and current calculated before. We pass the phase angle into a trigonometric COS function to get Cos of phase Angle, which is the POWER FACTOR. Now we use the standard formula for active power [4]

$$Active\ Power\ (P) = V_{RMS} \times I_{RMS} \times Cos(phaseAngle) \quad (9)$$

As the load in a predefined area may change any time, the power is never a constant value. It will change as and when the load changes. We need to integrate the power values to find out the area under the curve.[4]

$$\int P \times dt$$

The above equation is implemented for discrete time samples as

$$\frac{\sum P \times SamplingPeriod}{NumberOfSamples} \quad (10)$$

This integrated power value (in kilowatts) is then multiplied with time (in hours) from reset to get Energy (in kw-hr)

$$Energy_{kw-hr} = Power_{kw} \times time_{hours} \quad (11)$$

IX. SEM ANDROID APPLICATION

sEm (smart Energy Monitor) App was designed to function synchronously with the sEm meter unit. A smart meter is usually an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that

information at least daily back to the utility for monitoring and billing. Smart meters can gather data for remote reporting and displays the data on the app. Such an advanced metering infrastructure differs from traditional automatic meter reading by the fact that in this metering the unit wirelessly sends the data to the app using Bluetooth. Main Activity: The main activity is the first page that is viewed by the user when the app is launched. This activity displays the values of the various parameters calculated by the SEM energy meter unit. The values are current, voltage, power, energy. The tariff value or bill amount calculated by the app is also displayed on this activity. These values refresh in a period of 2 seconds in connected state.

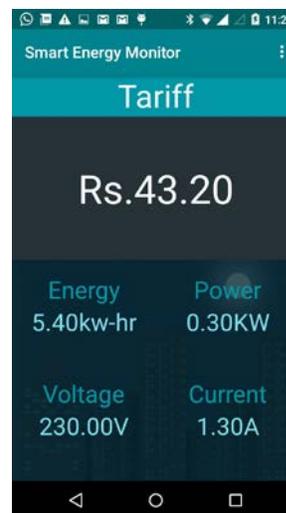


Fig. 6: Main Activity

Menu Activity: This activity creates a drop down menu which in this specific project shows the intents to Setting page, About Developer page and reset .The Reset button will reset the value of tariff from Rs. 0000. Setting Activity: This activity provides us with different options such as settings the bill limit, enabling and disabling the limit, About the app and connect button. The bill limit edit box will allow the user to set the limit for tariff, crossing which the app will notify the user .As soon as the bill limit is set the app will assign the maximum value of the gauge in main activity to the maximum bill limit and the gauge will move accordingly. The limit enable check box will allow the user to enable/disable the limit notifying feature. When the check box is enabled the limits are set on the tariff values and the limit is removed when check box is un-tick. The connect button takes the user to the Bluetooth enquiry activity, where after asking permissions for enabling Bluetooth the app will initiate device enquiry for nearby Bluetooth devices. About the app button /intent will take the user to the About App activity where the user can read the various features of app as well as important instructions.

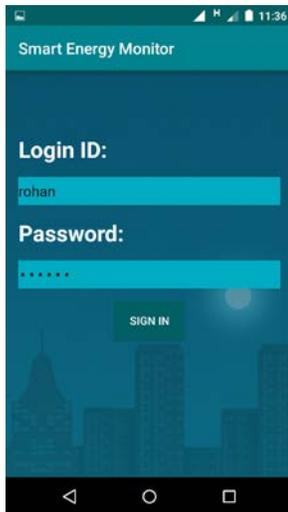


Fig. 7: Login Activity

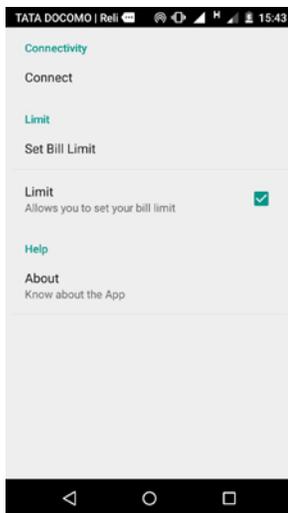


Fig. 8: Settings Activity

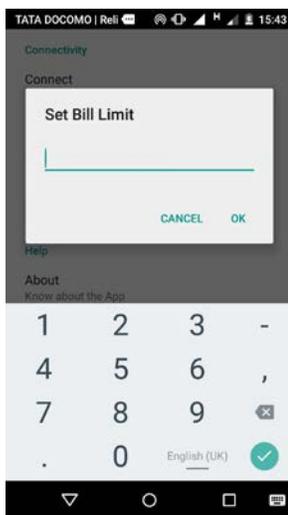


Fig. 9: Bill Limit Edit Preference

X. RESULTS

Fig 10 shows the wave form at no load condition, fig 11 shows wave forms with 300W load connected. The yellow waveform is

the V_{out} for sensing which goes to ADC and the blue wave form is the interrupt signal which appears every 20ms for a 50Hz signal.

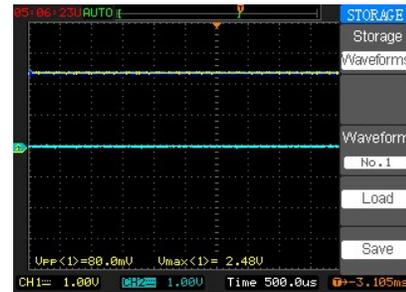


Fig. 10: No load Output waveforms

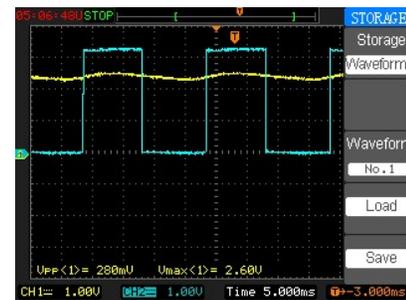


Fig. 11: With Load Current waveforms

Fig 12 shows the output wave forms of voltage sensing boards. Yellow waveform is V_{out} , peak detector output with holding time of 100msec. Blue waveform indicates the ZCD output which is used as interrupt to MSP430. Fig 13 shows both current and voltage interrupts at the same time. The yellow waveform is Voltage interrupt rising edge and blue waveform is Current interrupt rising edge. As we can see due to inductive load connected in downstream Mains , voltage is leading current by 500uSec.

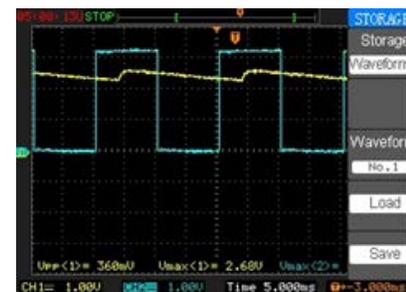


Fig. 12: Voltage Sense Unit Output Waveforms

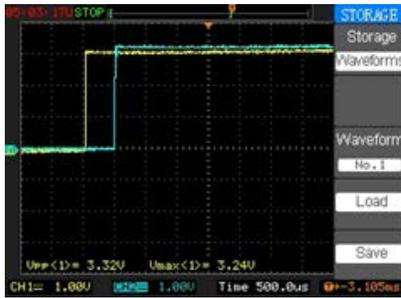


Fig. 13: Voltage ,Current Interrupt occurrence

XI. CONCLUSION

Project SEM has two functional sections, the Energy meter and android application working hand in hand to serve a larger purpose which is providing the user, information about his power consumption levels as well as bill amount till date so that he/she gets motivated as well as alerted to modify and optimize their power consumptions in order to keep the electricity bill amount in desirable limits. This will also affect various energy related problems such as requirement of load shedding, when implemented on a large scale. This concept will prove to be affective as the user begins to know the closely estimated amount to be getting out of his/her pocket in terms of electricity bills, he/she will surely start optimizing domestic energy usage due to the instinct to save money. The current system uses bluetooth for connecting to the user. The advancements which can be made in the currently proposed system are: The system can be connected to a server via Ethernet, using Ethernet LAN or Wifi module , to send the real time data to the server and the server can display it on a web app made using HTML, CSS, Jquery etc. This system can then be monitored from anywhere in the world. Some features can be added to control switching of appliances from user side. Using relays which are also controlled by sEm unit we can control and optimize power consumption from user end. Divisions can be made in SEM energy meter unit such that there will be a mother unit connected to the app and individual daughter unit connected before every appliance ,then we can monitor the individual power consumption levels of each Mains 230V outlet.

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