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Design and Implementation of Digital Household Energy Meter With A Flexible Billing Unit Using FPGA

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Abstract

In this paper, the idea of a prepaid energy meter with a flexible billing unit using FPGA for household as well as for industrial consumers has been introduced. It explores the design, implementation and application of billing automation system for consumer applications. The major drawback of traditional energy meter system is that the cost for the energy consumed should be calculated manually using man power. This process is time consuming. Hardware structure of the power factor and energy is designed using VHDL and simulation are done using ModelSim .The final results verifies the functionality of the proposed design. In this work energy has been calculated using two inputs namely voltage and current (both are single phase), which is then feed into energy meter and its corresponding cost are calculated as the excepted outputs. This design gives improved security, higher reliability, higher accuracy, higher performance, and takes less memory to store the power and also greatly reduces the size of a meter. Area occupied by the proposed design is 20% less than the conventional method.

Keywords: Energy Meter, Power Factor, VHDL, Field Programmable gate Arrays (FPGA).

Introduction

Power and energy shortage has become an important issue which has to be sort out with the help of advancement in the present world today. The requirement of energy in commercial, industrial and everyday uses can be at least reduced to some extent or can be solved by practicing good power management. The energy meter which is already in existence will able to calculate the energy consumed by the load in kWh, but it cannot calculate the cost. By having a alert on cost, we can control our energy consumption.

Nowadays the government is regularly revising its cost per unit consumption , this revised plan's cost per unit can be reflected in the proposed system easily by just changing the value of the cost in the cost calculation module , without affecting the entire system design . The manpower for taking up electricity reading from every house can be reduced by this proposed system. Psychologically, the electrical consumption would not be affect by the proposed energy meter. By the proposed system we can have an opportunity of controlling the cost because the pricing information will be sent or notified to the user on request [1]. The present billing system has chances of error and it is also time or labour consuming. A paper suggests a design of digital energy meter for improved metering and billing system [2]. FPGA plays a major role to optimize the memory capacity for power factor.

Top Level Design

The proposed energy meter consists of several functional modules, each of which does a specific task. The System is shown in Fig. 1. In the paper [1], the energy is calculated by sampling voltage and current which are then multiplied and added over a time period, the sampled value can cause error in calculating the energy. Paper [1] explains the fundamental equation for obtaining the power of load. In this system power will be calculated using $VI \times \cos\theta$. The Energy will be calculated by multiplying the period (t) and power [3].

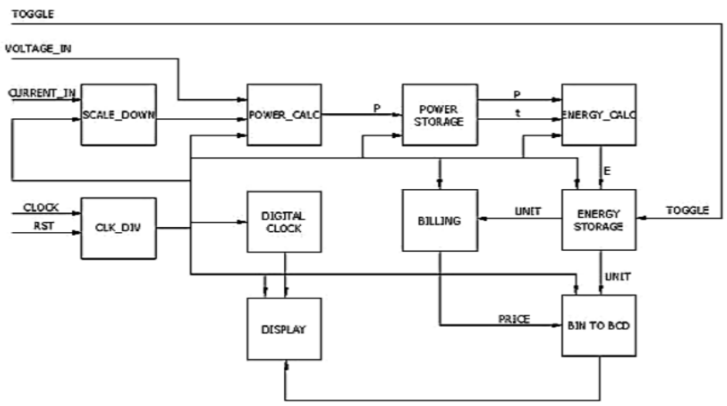

Figure 1: Proposed System (top-level design)

The cost of energy consumed is calculated according to the government norms and then communicated to the mobile. The corresponding energy will displayed in LCD. In proposed system, the power factor and the power are simulated. The simulated results are shown in the Fig.4 and Fig.5. The purpose of each module is individually described in sub-sections 2.A to 2.F.

Clock Adjustment Module

The FPGA's (Spartan 3E) operates in clock frequency is 24MHz. 12 bit ADC is used in our proposed system. For 10ms we get 240000 clock cycle counts, which cannot be represented by the ADC. So to be compatible we are using this adjustment clock module. This module is coded using VHDL.

This module is given a 24MHz clock input. Dividing 24MHz by 256 over a period of 10ms will give a value around 928. As we are dealing with a real time system, the time spent on calculation should be low. This issue is taken care by taking up proper division and multiplication methods. The multiplication method used is Wallace.

The crystal oscillator uses 24MHz and it cannot be used as an external clock to the ADC. It is too fast for the ADC. This module can be used to adjust the clock to the desirable frequency for the ADC.

Power Factor Module

This module is used to calculate the power factor of the load. Power is calculated by multiplying the value of current and the voltage and the power factor $COS\theta$. By using the peak detector circuit, the value of voltage (V) and current (I) is obtained. Both sinusoidal waves are converted to square wave pulse using zero crossing detector (ZCD) and then passed to the xor gate.

The fundamental behind is to calculate the phase difference between voltage (V) and current (I). This whole function correspond to the power factor module. The power factor can be calculated by finding the number of pulses in the output of the power factor module as shown in Fig. 2 and this is divided by 928. The factor 2 is divided to the output $VI \times \cos\theta$ to obtain the power.

This module is performed using VHDL. The Fig.2 shows the design of the power factor calculation.

Billing Module

This module is used to calculate the amount (as per the government plan) for the consumed energy KWh. A KWh is taken as 1 unit. On the monthly basis the overall energy consumed will be checked over. The billing module compares the energy consumed with the data given. Then the bill is calculated by multiplying the relevant cost per unit and energy consumed. This module can be updated whenever necessary with proper authentication.

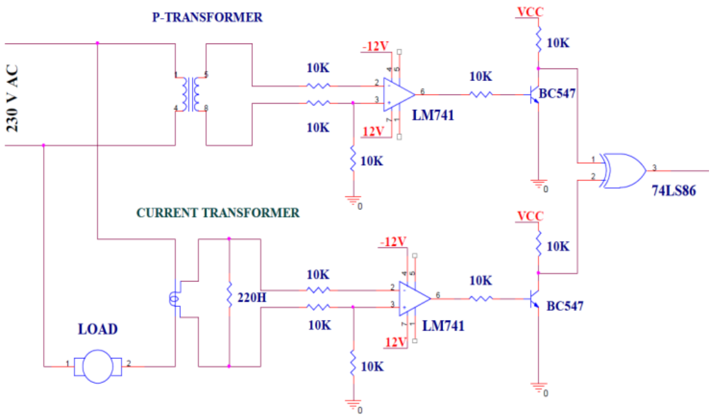

Figure 2: Design of Power Factor

This makes the whole module flexible. The design flow of the system will not be affected during update. The bill amount can be reset automatically after indicating the monthly amount. This bill is sent to the user through the GSM module.

LCD Operation

The LCDs are legible and provide more information displaying capability. To display the values in the LCD, binary values are converted to BCD values by the BCD module in the system. In 12 bit ADC, the binary values are converted into BCD values as data 4, data 3, data 2, and data 1. The LCD need ASCII package so as to display the data in the display board.

The advancement in technology has made us to produce LCD which can be used in wider temperature range. At present LCDs are being extensively used in entertainment electronics and telecommunications. The phone number to which the billing amount should be sent, can be entered in the LCD. Buttons are used to enter the phone number in LCD.

The LCD will show the following information of the system

- The amount of energy consumed
- The power factor of the load
- The voltage value and the current value
- The phone number of the person to whom you have to send the bill details.

Phone number can be edited in the system through the keypad which is included in the system.

The following Fig.3 shows the LCD interface data.

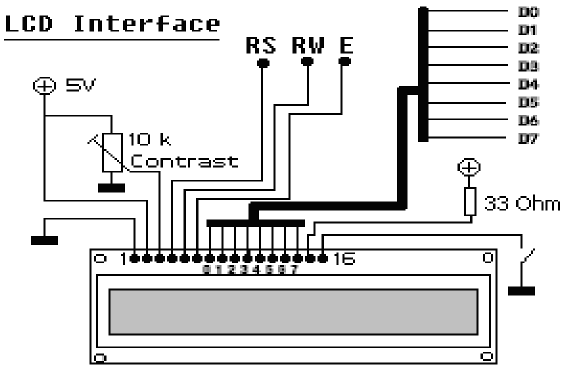

Figure 3: LCD

GSM Modem

A GSM modem is one that operates under a subscription to a mobile operator. It works based on a SIM card. It looks similar to mobile phone in terms of its function. In this paper we have utilized this module for sending energy (consumed), and cost data to the user and database server.

Energy Calculation

Energy is measured by calculating the power over a period of time. We are using a light bulb as a load which has a 100W rating. It consumes 100 watts of power in order to create light (and heat) [2] during an hour. In the conventional system, the power consumed by the load by using the equations (1). The frequency across 100 W load obtained during this experiment is

F= 50 Hz

And P = 100*X/50

P = 2*X

Where X is the frequency of pulses that is produced by the energy meter.

1 watt sec = 1 kW sec/1000

1 watt sec = 1 kWh/ (1000*3600)

Therefore Energy = P * Sec/ (1000*3600). (1)

By this equation the typical conventional digital energy meter calculate the energy. In the paper [1], the energy is calculated (2) in the following way

$$Energy = \sum (Vn * In) * \Delta t \qquad (2)$$

Where

Vn is instantaneous value of voltage.

In is instantaneous value of current.

ΔT is the sampling time.

Here the voltage, the current are sampled and multiplied over a period to calculate energy. In our system we are going to calculate power using voltage value, current value and the power factor. Using the power obtain we can calculate the energy consumed over a period.

Simulation

The proposed system is coded in VHDL and compiled and simulated using the Modelsim and synthesized in Xilinx ISE. The Fig.4 shows the VHDL output simulation of Power factor. In the Power factor simulation, we have simulated for three different values (1, 0.80, and 0.69). The output of the power factor simulation is divided by 1000 to obtain the actual values.

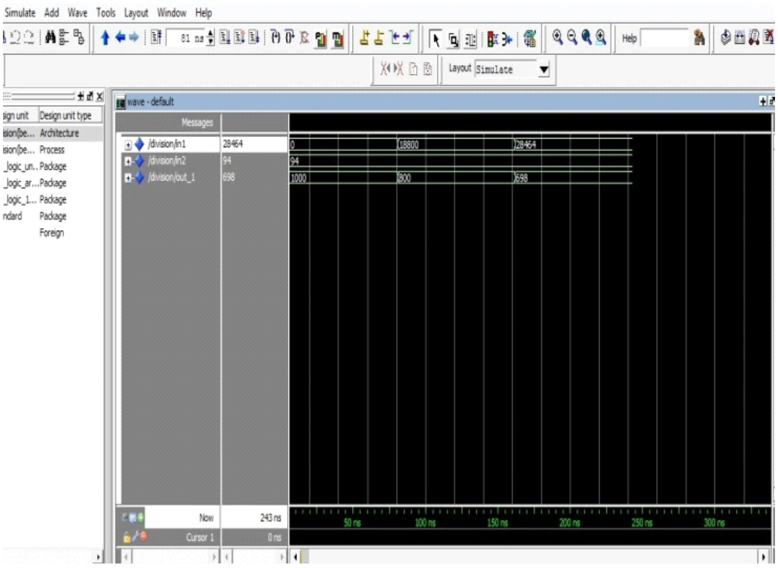

Figure 4: Power Factor-Simulation Output

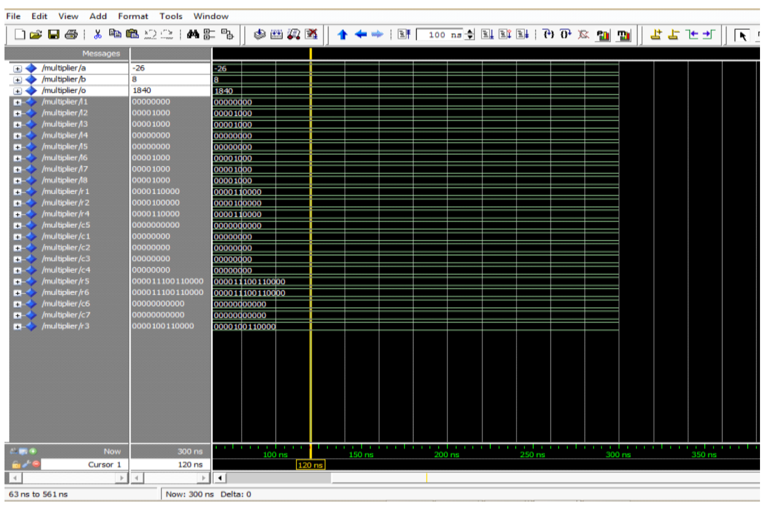

Figure 5: Simulated Output of Power

The inputs in the Fig.5 are the current value (8mA) and the multiplied values of voltage (230V), power factors (1). The Fig.6 shows the hardware utilized (Xilinx Synthesized report) by two energy meters that are used for different households, the number of LUT's, Flip-flops and slices utilized are 94%, 25% and 99% respectively. In order to reduce the slices in the proposed system we used external keypad and external memory. So now the proposed system occupied the number of LUT's, Flip-flops and slices utilized are 94%, 25% and 95% respectively.

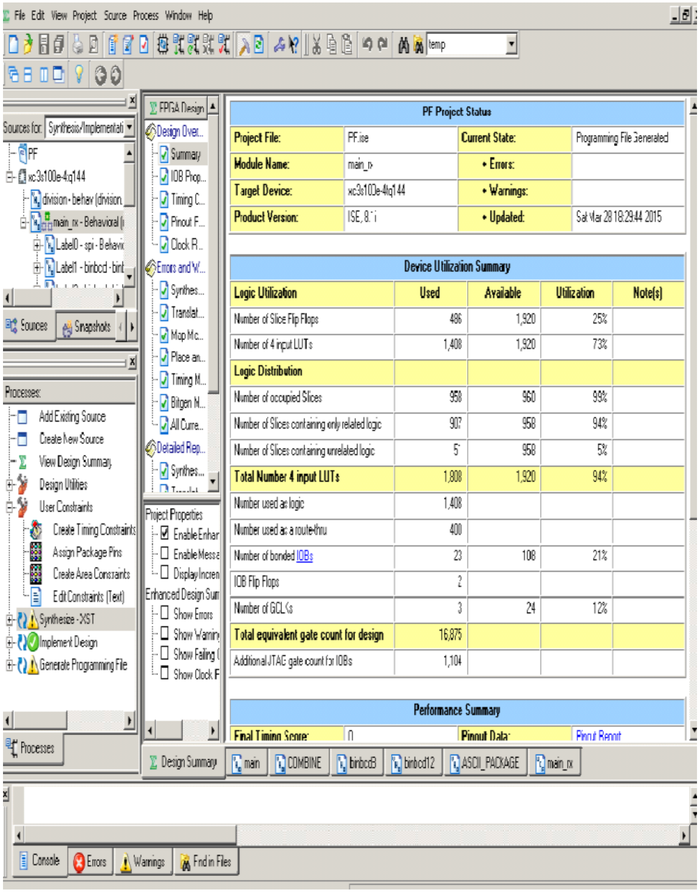

Figure 6: Xilinx report (excluding external keypad and memory)

Implementation and Result

The proposed hardware model of Power factor and Energy from energy meter is implemented and tested on Xilinx Spartan-3E (Device: XC3S250) FPGA platform. Two separate energy systems has been implemented in a single FPGA. Precision rectifier circuit is used for voltage and current. The digital input values are given to the FPGA using a 12 bit ADC. GSM module is interfaced with the FPGA. We have calculated energy for 3 minutes. By each minute end, the cost is calculated and sent to the user mobile. The hardware implementation is done and the photocopy of the hardware is shown in Fig.8. The power factor, energy, and the cost are calculated. The results are obtained in the Hardware system. The area occupied by the two energy system is 35 cm x 22 cm. The calculated cost which was sent to the mobile is shown in Fig.9.

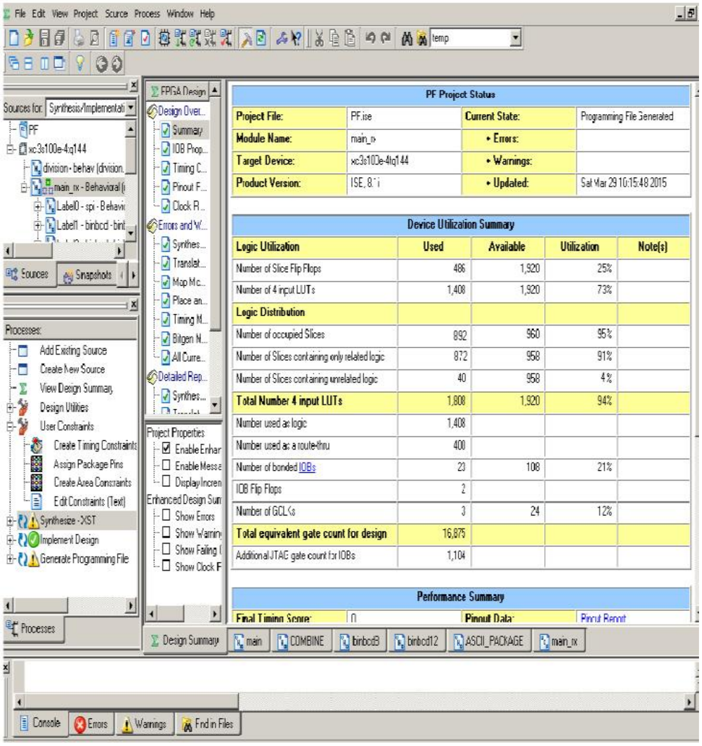

Figure 7: Xilinx report (including external keypad and memory)

Conclusion

The paper is intended to present an overview of prepaid energy meter, which can control the usage of electricity on consumer side to avoid wastage of power. It can reduce problems associated with billing consumers living in isolated areas and reduce deployment of manpower for taking meter readings. The details of the energy consumed on a monthly basis by the user are maintained in the database of the Electricity Boards. By this system the consumers will have awareness of the amount of energy consumed and the billing of the consumed energy. This helps them to save unwanted energy usage and reduce their monthly expenditure towards the EB bill. This will enable consumers for careful plans and manage their electrical consumption trends. Prepaid energy meter is more reliable and user friendly. From all these fact the prepaid system is more efficient.

Figure 8: The Hardware Photocopy

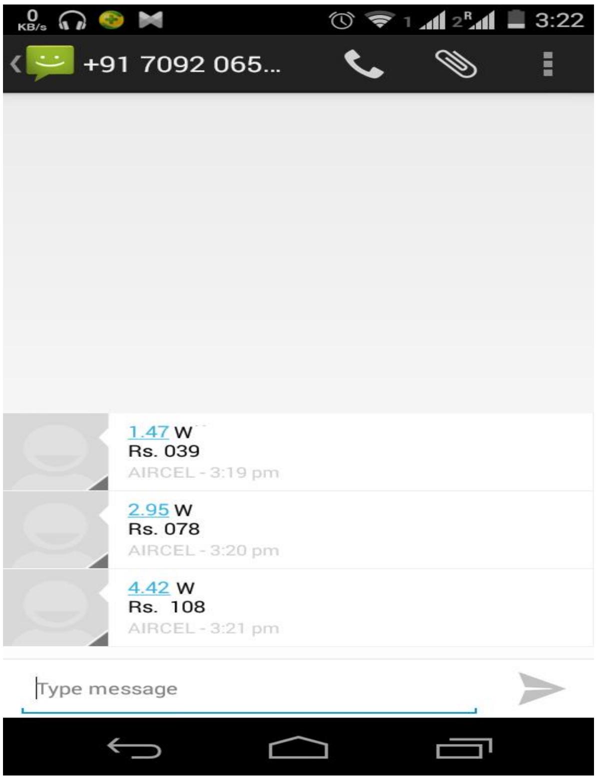

Figure 9: The SMS Photocopy

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