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Implementation of 3 Phase 4 Wire Energy Meter of Class 0.5 Accuracy

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Abstract— The Electrical metering instrument technology has come a long way from what it was more than 100 years ago. From the original bulky meters with heavy magnets and coils, there have been many innovations that have resulted in size & weight reduction in addition to improvement in features and specifications. Resolution and accuracy of the meter have seen substantial improvements over the years. Introduction of the digital meter in the later part of last century has completely changed the way Electrical parameters are measured. Starting with Voltmeters & Ammeters, the digital meter has conquered the entire spectrum of measuring instruments due to their advantages like ease of reading, better resolution and rugged construction. Of particular significance is the introduction of the Electronic Energy Meter in the mid-eighties. Now a days, the energy consumption and energy distribution has become a big subject for discussion because of huge difference in energy production and consumption. In this regard, energy consumers are facing so many problems due to the frequent power failures; another important reason for power cuts is due to the un-limited energy consumption of rich people. In this aspect, to minimize the power cuts and to distribute the energy equally to all areas, some restriction should have over the power consumption of each and every energy consumer, and according to that the Government should implement a policy, by introducing Autonomous Energy Meters everywhere in domestic sector. Hence, the need has come to think on this line and a solution has to be emerged out.

Keywords—Current Transformer, seven segment display, MSP430 Micro-controller, signal conditioning.

I. INTRODUCTION

Energy Meter is a Device that measures the amount of electrical energy consumed by a residence, business or an electrically powered device. The industrial energy meters are of standard sizes. Energy meter measures different parameters like voltage, current, active power, apparent power, reactive power, energy etc. Energy can be calculated from the power, it is the product of power and time. Energy is measured in Whr or Kwhr, Power is measured in Watts or Kilowatts and time is measured in hours. In industry, Energy consumption is more as compared to residential applications hence energy has to be measured accurately to avoid wastage of energy. If energy measurement is not accurate then lots of energy can be wasted. Nowadays, electricity is the main aspect of human life and energy generation is less as compared to requirement of energy hence energy has to be saved or utilization of the energy should be in a proper way and this can be achieved by Designing the meter with high accuracy so that users can get the accurate reading of the energy consumed and they can restrict their users in a specified limit.

The major objective of the project is to achieve a class 0.5 accuracy while measuring the energy. For this purpose, the main aspect is to choose a proper microcontroller with high efficiency and great accuracy and selection of components like a current transformer, analog front end circuit components of high accuracy has to be used to measure the parameters accurately. The second objective is to design the meter with pulse output circuitry so that user can measure the energy in the form of pulses.

II. THEME AND EXISTING SYSTEM

A. Theme of Project

The theme of the project is to develop a high accuracy and low-cost energy meter. As well as the size of the meter should be compact. An additional feature has to be developed like pulse output hence the user can measure energy in pulse form. It should be user programmable on the field.

B. Existing Systems

In the existing system, the accuracy of the meter is not considered as priority hence there is some error in readings. Customers have to pay the extra bill because of this ambiguity. In industry also energy reading has to be accurate. Hence by keeping this problem in mind, we have designed the system which will give more accurate readings.

output pulses from the metering IC are counted using the default timer of PIC MCU. The signal from the meter through Octocoupler is normally high and the high to low transition of this voltage wave indicates the occurrence of a pulse. The counting of low pulse is an inefficient method as improper grounding issues may even be counted as a pulse by the device. So the produced pulse is reversed before applying to the counter. A TTL compatible inverter circuit is used for this purpose.

III. Proposed System

The proposed system is as shown in fig.1 below. We have designed the energy meter by using texas microcontroller which has special features for achieving the high accuracy. We have designed the system by keeping in the mind the cost of the meter. It is a cheap product as compared to other products which are there in the market. There are other features also like pulse output circuit which will able the user to see the energy in pulse form. We have unique features like protection from PT/CT primary and secondary, on field programmable, compact size and depth, an analog load bar graph for indicating system load in percentage.

A. Hardware Implementation

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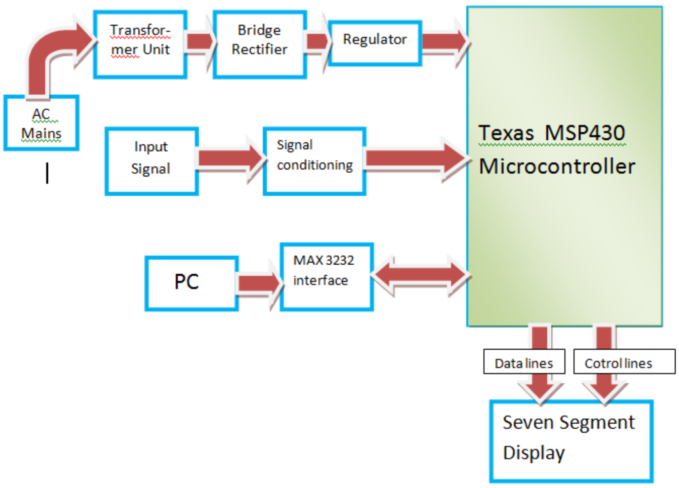

Figure 1: Block diagram of Energy meter

The MSP430™ family of devices comprises ultra low power microcontrollers from Texas Instruments. These devices support a number of low-power modes and also have low-power consumption during active mode when the CPU and other peripherals are active. The low-power feature of this device family allows the design of the power supply to be simple and inexpensive. The power supply allows the operation of the energy meter powered directly from the mains. The next sections describe the various power supply options that are available to users to support their design.

Block diagram description

1. Transformer unit

The input to the primary of the transformer is 230V AC, the step-down transformer is used for reducing the voltage to 12V AC. There are many transformers available in the market from that a suitable transformer is chosen for the power supply circuitry. The external capacitors are used to reduce the noise in secondary voltage. The voltage across the secondary of the transformer is AC voltage hence to convert ac to dc bridge rectifier is used at the output of the transformer.

2. Signal conditioning

The MSP430 analog front end, which consists of the ΣΔ ADC, is differential and requires that the input voltages at the pins do not exceed ±930 mV (gain = 1). To meet this specification, the current and voltage inputs must be divided down. In addition, the ΣΔ24 allows a maximum negative voltage of -1 V. Therefore, ac signals from mains can be directly interfaced without the need for level shifters. This section describes the analog front end used for voltage and current channels.

i) Voltage Inputs

The voltage from the mains is usually 230 V or 120 V and must be brought down to a range of 930 mV. The analog front end for voltage consists of spike protection varistors followed by a simple voltage divider and an RC low-pass filter that acts like an anti-alias filter.

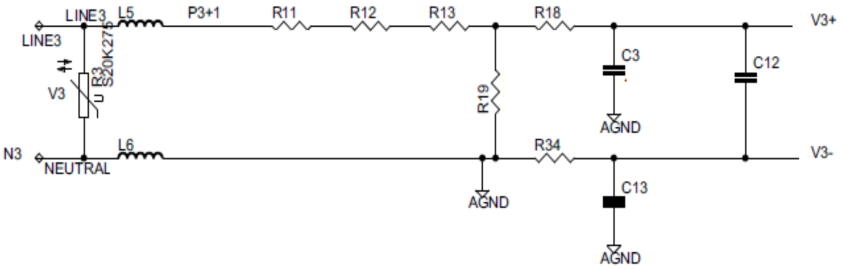

Figure 2: - Signal conditioning for voltage inputs

Figure 2 shows the Signal conditioning for the voltage inputs for a mains voltage of 230 V. The voltage is brought down to approximately 549 mV RMS, which is 779 mV peak, and fed to the positive input. This voltage is within the MSP430 ΣΔ analog limits by a safety margin greater than 15%. This margin allows accurate measurements even during voltage spike conditions.

ii) Current Inputs

The analog front-end for current inputs is slightly different from the analog front end for the voltage inputs. Figure 3 shows the Signal conditioning used for a current channel. Resistor R104 is the burden resistor that is selected based on the current range used and the turn's ratio specification of the CT.

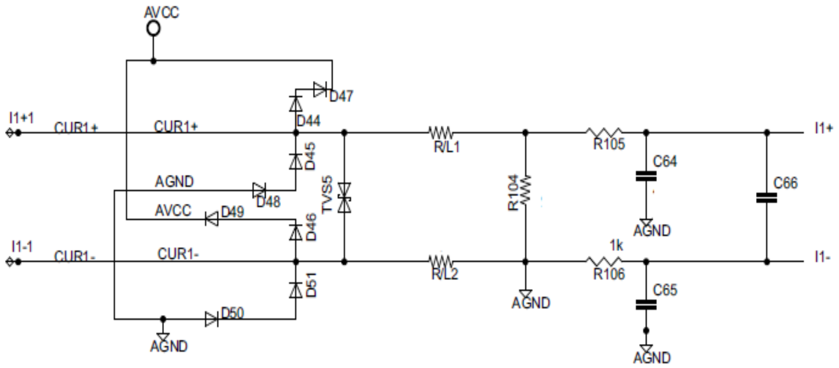

Figure 3: Signal conditioning for current inputs

The value of the burden resistor for this design is approximately 13 Ω. The anti-aliasing circuitry, which consists of resistors and capacitors, follows the burden resistor. The input signal to the converter is a fully differential input with a voltage swing of ±919 mV maximum when the gain of the converter is set to 1.

iii) MAX 3232 interface

The Microcontroller operates on 3.3v supply hence for designing the communication circuitry between microcontroller and PC. MAX 3232 IC is used which suitable to operate on 3.3v supply. The MAX3232 transceivers have a proprietary low-dropout transmitter output stage enabling true RS-232 performance from a 3.0V to 5.5V supply with a dual charge pump. The devices require only four small 0.1µF external charge pump capacitors. The MAX3232 is guaranteed to run at data rates of 120kbps while maintaining RS-232 output levels.

iv) Microcontroller

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. The MSP 430 Microcontroller has special features like Accuracy < 0.1% Over 2000:1 Dynamic Range for Phase Current, Support for Multiple Sensors Such as Current Transformers, Rogowski Coils, or Shunts, Flexible Power Supply Options With Automatic Switching.

The ultra-low-power nature of the MSP430 means that the system power supply can be minimized to reduce overall cost. Low standby power means that backup energy storage can be minimized, and critical data can be retained longer in the case of a mains power failure. The MSP430 features Texas Instruments' 24-bit sigma-delta converter technology, which provides better than 0.1% accuracy. Family members include up to 512KB of flash, 32KB of RAM, and an LCD controller with support for up to 320 segments.

v) Seven segment display

In this project, 3 rows of 4 digit seven segment display are used for showing the readings. While it is possible to drive each individual segment of a seven-segment (or 20-segment or dot-matrix) display with its own driver circuit, the number of driver transistors and wires becomes impractical when more than a few displays are involved. It is much more common to use a multiplexed display architecture.

Software Implementation

The software for the implementation of 3-phase metrology is described in this section. The Section a) and b) describes the setup of various peripherals of the MSP430. Next, the entire metrology software is described as two major processes: the foreground process and background process.

i) Peripherals Setup

The major peripherals are the 24-bit sigma delta (SD24_B) ADC, clock system, timer, LCD, and watchdog timer (WDT).

a) ΣΔ24 Setup

The MSP430F family has up to seven independent sigma delta data converters. For a three-phase system, at least six ΣΔs are necessary to independently measure three voltages and currents. The code that accompanies this application report is designed for the metrology of a 3-phase system with limited anti-tampering features. However, the code supports the measurement of the neutral current. The clock to the ΣΔ24 (fM) is derived from the system clock, which is configured to run at 16 MHz. The sampling frequency is defined as fs = fM/OSR, the OSR is chosen to be 256 and the modulation frequency fM, is chosen as 1.048576 MHz, resulting in a sampling frequency of 4.096 ksps. The ΣΔ24s are configured to generate regular interrupts every sampling instance. The following are the ΣΔ channels associations:

1) A0.0+ and A0.0- → Voltage V1
2)A1.0+ and A1.0- → Voltage V2
2) A2.0+ and A2.0- → Voltage V3
3) A4.0+ and A4.0- → Current I1
4) A5.0+ and A5.0- → Current I2
5) A6.0+ and A6.0- → Current I3

The optional neutral channel can be processed via channel A3.0+ and A3.0-.

b) Real-Time Clock (RTC_C)

The RTC_C is a real-time clock module that is configured to give precise 1-second interrupts. Based on these 1-second interrupts, the time and date are updated in software, as necessary.

ii) Foreground process

The foreground process includes the initial setup of the MSP430 hardware and software immediately after a device RESET. The initialization routines involve the setup of the analog to digital converter, clock system, general purpose input/output (port) pins, RTC module for clock functionality, LCD, and the USCI_A0 for UART functionality. In addition, if ZigBee™ communication is enabled, USCI_A3 is configured.

After the hardware is setup, the foreground process waits for the background process to notify it to calculate new metering parameters. This notification is done through a status flag every time a frame of data is available for processing. The data frame consists of processed current, voltage, active energy, and reactive energy accumulated for one second. This is equivalent to the accumulation of 50 or 60 cycles of data synchronized to the incoming voltage signal. In addition, a sample counter keeps track of how many samples have been accumulated over this frame period. This count can vary as the software synchronizes with the incoming mains frequency. The set of data samples consists of processed current, voltage, active energy, and reactive energy.

iii) Computation Formulas

This section briefly describes the formulas used for the voltage, current, and energy calculations.

a) Voltage and Current

As described in the previous sections, simultaneous voltage and current samples are obtained from seven independent ΣΔ converters at a sampling rate of 4096 Hz. All of the samples that are taken in 1 second are kept and used to obtain the RMS values for voltage and current for each phase. The RMS values are obtained by the following formulas:

$$V_{RMS,ph} = K_{v,ph} * \sqrt{\frac{\sum_{n=1}^{Sample\ count} v_{ph}(n) * v_{ph}(n)}{Sample\ count}}$$

$$I_{RMS,ph} = K_{i,ph} * \sqrt{\frac{\sum_{n=1}^{Sample\ count} i_{ph}(n) * i_{ph}(n)}{Sample\ count}}$$

Where,

ph = Phase whose parameters are being calculated [that is, Phase A(=1), B(=2), or C(=3)]
vph(n) = Voltage sample at a sample instant *n*
iph(n) = Each current sample at a sample instant *n*
Sample count = Number of samples in one second
Kv,ph = Scaling factor for voltage
Ki,ph = Scaling factor for each current

b) Power and Energy

Power and energy are calculated for one frame's worth of active and reactive energy samples. These samples are phase corrected and passed on to the foreground process, which uses the number of samples (sample count) to calculate phase active and reactive powers by the formulas in Equation.

$$P_{ACT,ph} = K_{ACT,ph} \frac{\sum_{n=1}^{Sample\ count} v(n) \times i_{ph}(n)}{Sample\ count}$$

$$P_{REACT,ph} = K_{REACT,ph} \frac{\sum_{n=1}^{Sample\ count} v_{90}(n) \times i_{ph}(n)}{Sample\ count}$$

Where,
v90,ph (n) = Voltage sample at a sample instant *n* shifted by 90 degrees, and
KACT,ph = Scaling factor for active power
KREACT,ph = Scaling factor for reactive power
Active energy is calculated from the active power by Equation.

$$E_{ACT,ph} = P_{ACT,ph} \times SampleCount$$
$$E_{REACT,ph} = P_{REACT,ph} \times SampleCount$$

For reactive energy, the 90° phase shift approach is used for two reasons:
1. It allows accurate measurement of the reactive power for very small currents.
2. It conforms to the international specified measurement method.

The calculated mains frequency is used to calculate the 90 degrees-shifted voltage sample. Because the frequency of the mains varies, it is important to first measure the mains frequency accurately to phase shift the voltage samples accordingly. To get an exact 90° phase shift, interpolation is used between two samples. For these two samples, a voltage sample slightly more than 90 degrees before the current sample and a voltage sample slightly less than 90 degrees before the current sample are used. The application's phase shift implementation consists of an integer part and a fractional part. The integer part is realized by providing an N samples delay. The fractional part is realized by a one-tap FIR filter. In the software, a lookup table provides the filter coefficients that are used to create the fractional delays. After calculating the active and reactive power, each phase's apparent power is calculated by the following formula:

$$P_{APP,ph} = \sqrt{P_{ACT,ph}^{2} + P_{REACT,ph}^{2}}$$

In addition to calculating the per-phase active and reactive power and energy, the cumulative sum of these parameters are calculated by .

$$P_{ACT,\ Cumulative} = \sum_{ph=1}^{3} P_{ACT,ph}$$

$$P_{REACT,\ Cumulative} = \sum_{ph=1}^{3} P_{REACT,ph}$$

$$E_{ACT,Cumulative} = \sum_{ph=1}^{3} E_{ACT,ph}$$

$$E_{REACT,Cumulative} = \sum_{ph-1}^{3} E_{REACT,ph}$$

c) Frequency (Hz)

The background process calculates the frequency in terms of samples per mains cycle. The foreground process then converts this to Hertz by Equation.

$$Frequency\ (Hz) = \frac{Sampling\ Rate\ \ (samples\ /\ second)}{Frequency\ (samples\ /\ cycle)}$$

d) Power Factor

After the active power and apparent power have been calculated, the absolute value of the power factor is calculated. In the meter's internal representation of power factor, a positive power factor corresponds to a capacitive load and a negative power factor corresponds to an inductive load. The sign of the internal representation of power factor is determined by whether the current leads or lags voltage, which is determined in the background process. Therefore, the internal representation of power factor is calculated by the following formula:

$$Internal\ Representation\ of\ Power\ Factor = \begin{cases} \frac{P_{Act}}{P_{Apparent}}, if\ capacitive\ load \\ -\frac{P_{Act}}{P_{Apparent}}, if\ inducitive\ load \end{cases}$$

iii) Background process

The background process uses the ΣΔ interrupt as a trigger to collect voltage and current samples (seven values in total). These samples are used to calculate intermediate results. Because 16-bit voltage samples are used, the voltage samples are further processed and accumulated in dedicated 48-bit registers. In contrast, since 24-bit current samples are used, the current samples are

processed and accumulated in dedicated 64-bit registers. Per-phase active power and reactive power are also accumulated in 64-bit registers.
The background function deals mainly with timing critical events in software. After sufficient samples (approximately one second's worth) have been accumulated, then the foreground function is triggered to calculate the final values of VRMS, IRMS, active, reactive, and apparent powers, active, reactive, and apparent energy, frequency, and power factor. The background process is also wholly responsible for the calculation of energy proportional pulses,
Frequency (in samples/cycle), and determining current lead and lag conditions.

Calibration Process

Calibration is key to any meter's performance, and it is absolutely necessary for every meter to go through this process. Initially, every meter exhibits different accuracies due to silicon-to-silicon differences, sensor accuracies, and other passive tolerances. To nullify the effects of these differences, every meter must be calibrated. For calibration to be performed accurately, an accurate a test source and a reference meter must be available. The source should be able to generate any desired voltage, current, and phase shift (between V and I). To calculate errors in measurement, the reference meter acts as an interface between the source and the meter that is being calibrated. This section describes a simple and effective method of calibration of this 3-phase circuit board.
The GUI that is used for viewing results can also be used to calibrate the circuit board. During calibration, parameters called calibration factors are modified in software to give the least error in measurement. For this meter, there are four main calibration factors for each phase: voltage scaling factor, current scaling factor, power scaling factor, and the phase compensation factor. The voltage, current, and power scaling factors translate measured quantities in metrology software to real-world values represented in volts, amps, and watts, respectively. The phase compensation factor is used to compensate any phase shifts introduced by the current sensors and other passives. When the meter software is flashed with the code, default calibration factors are loaded into these calibration factors. These values will be modified via the GUI during calibration. The calibration factors are stored in INFO_MEM, and therefore, would remain the same if the meter is restarted. However, if the code is re-flashed during debugging, the calibration factors will be replaced and the meter must be recalibrated. One way to save the calibration values is by clicking on the "Meter calibration factors" button shown in Figure 4.

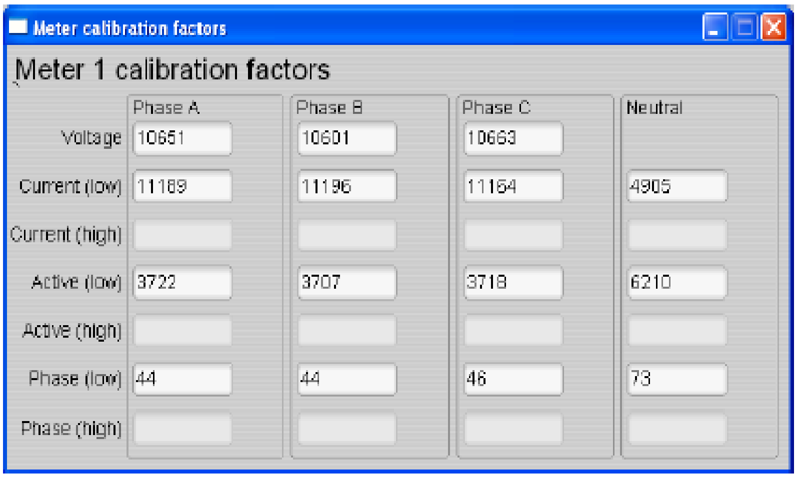

Fig 4: - Calibration factor window

Calibrating any of the scaling factors is referred to as a gain correction. Calibrating any of the phase compensation factors is referred to as phase correction. For the entire calibration process, the ac test source must be on, meter connections must be made, and the energy pulses must be connected to the reference meter.

CONCLUSIONS

The first initial goal is to get the energy reading on the meter display, for that purpose lots of R&D is done. There were many problems in hardware and software, that was successfully encountered and now the meter showing proper energy reading and pulse LED is also showing energy accurately. For the calibration purpose, MAX3232 IC is used for the communication between PC and hardware. The calibration software is now working properly

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