Energy Profiler Software - Architecture and Implementation

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Abstract
In the present paper, an architecture and implementation of modular software for measuring system are discussed. The target of the tested system is the Public Power Network. Some basic problems having been met are presented alongside with their fixes. The software has been developed for MC68HC16 family microcontrollers, produced by Motorola. Mathematical analysis for the sampling error of the aquisition system is introduced.

The present paper discuses an electronic watthour meter that is digitally configurable to operate as several different types of watthour meters for metering electrical energy from a variety of different electrical utility services. Automatic of line input currents is provided to scale the voltage input to an analog to digital converter over selected ranges such that low level and high level input signals are measured in an optimum range. MC68HC16Z1 is employed to calculate values for metered electrical energy flowing in the circuit being metered. The processor calculates the value of DC offset errors and uses that value in the calculation of metered electrical energy to compensate for such errors.
The meter employs automatic and manually initiated test-functions for testing the operation of the processor and other critical circuits in the meter.

At the beginning we setup a few new goals, the most important of which were:

Developing an electronic three phase watthour meter according to the IEC standards;

Achieving an accuracy of the measured units less than 0.1%

Implementing remote data exchange, tariff and load control according to the IEC 1107

The mainframe we produced and further used in our experiments was conceptually based on a previously existing version of an electronic watthour meter. However, our goals pushed us to add some new features most important of which were:

As far as the hardware implementation is concerned we have managed to add and test successfully the following features:
- Power supply is derived from one of the measured phases;
- New power-down-up monitoring. DS1236 is implemented to monitor the power failures;
- Flash memory is used for data storage, so the problems around power failures and data storage have been fixed;
- Implementing of optical interface according IEC 1107.

Whenever a new software has to be written, and this is the holly truth for a new complicated microprocessor systems, the question of developing tools arises. For that purpose, and to ease the whole process, an HC16 evaluation board was created. The evaluation board uses HC16 powerful feature - its Background Debug Mode. In that mode HC16 has got 16 commands like: Read/Write Registers from Mask, Read/Write MAC registers, Read/Write PC and SP, Read/Write Data/Program memory, Execute from current PK:PC, Null Operation.
Two problems arose in the process of setting up that mode:
1. The reset pull-up transistor came to be less than 800ohms. This was not documented in the Motorola's manuals;
2. The evaluation board was not galvanically isolated from the PC. That problem was caught a bit afterwards when total harmonic distortions of the metered signals were calculated. There was current flowing into the EVB introducing noise with 50-60mV amplitude and unknown spectrum.

As far as the software implementation is concerned we have managed to add and test successfully the following features:
- Manual or automatic scale for the line input current channels;
- FLASH program/erase services algorithms: DataPoll and ToggleBit;
- Subroutines for power-down-up data storage/recovery;
- Subroutines for data dumping via optical interface;

The Power Profiler software is procedure oriented with five interrupt input points. The power Profiler basic features follows:

- voltage, current and phase measurements;
- frequency measurement;
- metering of active, inductive and capacitive power;
- metering of incoming and outgoing active energy, inductive end capacitive energy;
- calculating of total harmonic distortion for all phases;
- data storage for 3 months period;
- displaying the maximum values for all measured parameters for the given period.

Interrupt input points:

- timer_1: This timer is setup according to the time interval being got from Nyquist theorem. Each time its the time interval elapses, all phase voltage and current signals are sampled by the AD7390-10
- timer_2: According this timer setup, average values for the 10 minutes interval are stored into FLASH memory;
- timer_3: This timer is used in power network frequency measurements;
- timer_4: This timer is used in keyboard scanning;
- NMI: This interrupt is generated when power fails.

Our next goal was reducing the total error of the new watthour meter to less than 0.1%. One classification of errors in digital aquisition systems says that there are four major sources of errors[1]:

- Ys - sampling error;
- Ya - aquisition error;
- Yd - dynamic error;
- Yn - noise error;

In order to achieve our goal, we need to find means of diminishing each of the above error sources in the best possible way. A mathematical analysis of the first error source is presented in this paper.

Mathematical Analysis of Inherent Sampling Error

When Euler-McLouren theorem is applied to Y_D

$$\Delta Y_D = \frac{1}{m}\sum_{i=1}^{m-1} f(i.\Delta t) - \frac{1}{T}\int_0^T f(t).dt$$

$$|\Delta Y_D| \le \frac{T}{12.m^2}\left[\sum_J |\Delta f_J^I| + T.|f^{II}(t)|_{max}\right]$$, where $\Delta f_J^I = f^I(t_J+0) - f^I(t_J-0)$

When the sampled signal is

$$f(t) = A_1.\cos wt + B_1.\sin wt + A_3.\cos 3wt + B_3.\sin 3wt + A_5.\cos 5wt + B_5.\sin 5wt$$

$$|\Delta Y_D| \le \frac{T}{12.m^2}\left[\sum_J |\Delta f_J^I| + T.|f^{II}(t)|_{max}\right]$$

$\Delta f_J^I = f^I(t_J+0) - f^I(t_J-0) = 0$ because $f^I(t_J+0) = f^I(t_J-0)$

Hence $|\Delta Y_D| \le \frac{T}{12.m^2}.T.|f^{II}(t)|_{max}$

The second derivative may be presented as follows

$$|f^{II}(t)| \le |A_1.w^2.\cos wt + B_1.w^2.\sin wt| + |A_3.9w^2.\sin 3wt + B_3.9w^2.\cos wt| + |A_5.25w^2.\cos 5wt + B_5.25w^2.\sin 5wt|$$

In the equation

$$A.\cos\alpha + B.\sin\alpha = \sqrt{A^2+B^2}\left[\frac{A}{\sqrt{A^2+B^2}}.\cos\alpha + \frac{B}{\sqrt{A^2+B^2}}.\sin\alpha\right]$$

We make the substitution $\sin\gamma = \frac{A}{\sqrt{A^2+B^2}}$ $\cos\gamma = \frac{A}{\sqrt{A^2+B^2}}$

$$A.\cos\alpha + B.\sin\alpha = \sqrt{A^2+B^2}.\sin(\alpha+\gamma)$$

$$|A.\cos\alpha + B.\sin\alpha| \le \sqrt{A^2+B^2}.|\sin(\alpha+\gamma)| \le \sqrt{A^2+B^2}$$

then

$$|f^{II}(t)| \le w^2.\sqrt{A_1^2+B_1^2} + 9w^2\sqrt{A_1^2+B_1^2} + 25w^2\sqrt{A_1^2+B_1^2}$$

If the member $\sqrt{A_1^2+B_1^2} = 1$, which has no effect on the final evaluation of the sampling error, we may derive from the value of the total harmonic distortion the evaluation of the sampling error

$$0.1\% = k = \frac{\sqrt{A_3^2 + B_3^2} + \sqrt{A_5^2 + B_5^2}}{\sqrt{A_1^2 + B_1^2}}$$

$$|f^{II}(t)| \leq (1+\delta).w^2$$ where δ has a negligible value

$$|\Delta Y_D| \leq \frac{T^2}{12.(n^2)}.(314)^2$$ where n is the number of samples

n=64: DY=0.08%, **n=128: DY=0.02%**

It is obvious that each time the number of samples (n) is doubled the sampling error is diminished four times.
We use 64 samples in the present aquisition system. Its total error is less than 0.2% and we need to go further in order to compensate for temperature drift and other instabilities.

Conclusions:

The following final conclusions might be derived from the above presentation:

- Architecture of the system software for Power Profiler have been discussed. The problems arose in the course of work have been presented.
- Mathematical analysis of the inherent sampling error has been presented. As a conclusion, it may be proposed that in order to diminish the total error beyond 0.1% the number of samples should have been at least 128.

References:

[1] А.А.Горлач, М.Я.Минц, В.Н.Чинков "Цифровая обработка сигналов в измерительной технике", Киев, Техника, 1985