IMPLEMENTATION OF A DIGITAL POWER METER USING TMS320C5X

Bon-Hyouk Ku
ASIC & AI Lab, Department of Control & Instrumentation Engineering, Hanyang University, Sa 1 Dong, Ansan, KyungGi-Do, Korea. 425-791*
Phone: 825-2-0345-400-4036, FAX: 82-2-0345-501-8114*

Myung-Ryul Choi
ASIC & AI Lab, Department of Control & Instrumentation Engineering, Hanyang University, Sa 1 Dong. Ansan, KyungGi-Do, Korea, 425-791*
Phone: 825-2-0345-400-4036, FAX: 82-2-0345-501-8114*

ABSTRACT - A power meter is an instrument for measuring in watts the power flowing in a electric equipment. Since the value which a conventional power meter measures is analog, the power meter is hard to determine a phase difference between the voltage and current for a inductive load. The phase difference causes a loss of electric power and a increase of power-line load. In this paper, we propose a digital power meter using TI's DSP(Digital Signal Processor) TMS320C5x, which is employed to calculate the phase difference and more accurate power consumption.

1. BACKGROUND

Up to now, a conventional analog power meter measures only active power in an electric equipment. Since the exact nature of the load is composed of a resistive load as well as a reactive load, the power measurement should be considered as a complex quantity i.e., the real part of the complex power is active power and the imaginary part of the complex power is reactive power.

The reactive power is not actually used electricity, but a loss of electric power. This power term raise some problems such as an increase of a power line load, a loss of electric power, and so on.

A analog power meter can't supply a useful solution of the reactive power. We propose the digital power meter to solve this problem with additional benefits. The proposed power meter is digitized in order to detect accurate power consumption and phase difference and to interface with host computer in an electric power company and to realize home automation. For a digital power meter. we have to get many samples of the power flowing in a electric equipment and require high speed digital signal processing for real-time operation. Also, the FIR(Finite-duration Impulse Response) filter and correlation algorithm is employed in order to calculate active power and to find phase difference, respectively. Therefore we implemented this digital power meter using TI's DSP, TMS320C5x.

2. ALGORITHM FOR MEASURING ACTIVE POWER

A voltage and current signal being provided through an electric power line is a sinusoidal signal with the same frequency as shown in Fig. 2-1.

With any arbitrary electrical system(see Fig 2-2) whose terminal a and b are fed by an arbitrary

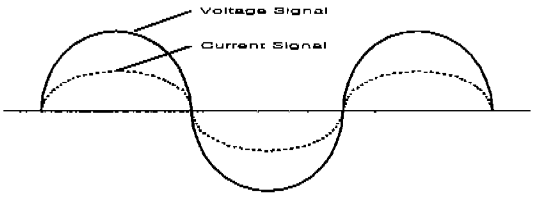


Fig. 2-1. A Voltage and Current Signal

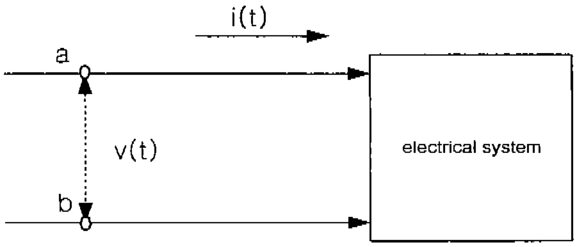


Fig 2-2. An Electrical System

voltage v(t) and its corresponding current i(t), which are assumed finite, we have two well-known RMS-values:

$$V_{RMS}=\sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} v^2(t)\ dt} \qquad (1)$$

$$I_{RMS}=\sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} i^2(t)\ dt} \qquad (2)$$

The majority of the loads in the power utilities has linear characteristics, i.e. their stationary response to a pure sinusoidal voltage $V_{peak}\sin wt$ is a pure sinusoidal current $I_{peak}\sin(\ wt+\phi\ )$. It is no problem for any electrical engineer to cope with the conventional complex analysis on linear loads, to get $V_{RMS}=\ V_{peak}\sqrt{2}$, $I_{RMS}=\ I_{peak}\sqrt{2}$, $P=V_{RMS}\cdot I_{RMS}\cdot\cos\phi$, $Q=V_{RMS}\cdot I_{RMS}\cdot\sin\phi$, $S=P+jQ$

P: active power Q: reactive power

S : apparent power ϕ : phase shift

In general terms, the active power P_{active} define as equation (3).

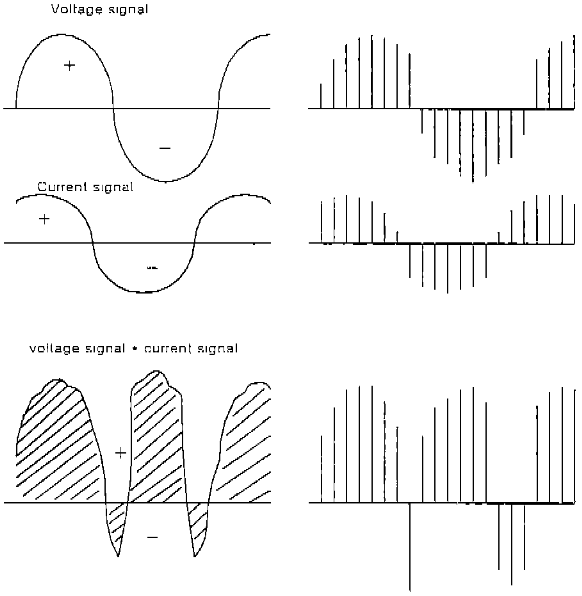
$$P_{act}=\frac{1}{T}\int_T v(t)\cdot i(t)dt \qquad (3)$$

In discrete system, equation (3) can be rewritten as

$$P_{act}=\sum_n\{\frac{1}{T}\int[\ Vn\ \sin(wnt)In\ \sin(wnt+\phi n)]dt\} \quad (4)$$

Equation (3), (4) can be represented by Fig 2-3.

To calculate active power, we must sample voltage signals and their corresponding current signal simultaneously. And then the sampled voltage data are multiplied by the sampled current data to form the product sequence and the values of product sequence are summed (this method similar to FIR calculation). And thess values are divided by the sampling number for one period.



< Continuous signal > < Discrete signal >

Fig. 2-3 The Multiplication of Voltage Signal and Current Signal

```
If sampled data is saved in
voltage [sample_NO], current[sample_NO]
in form of array
for ( i=0; i <sample_NO ; i++)
{
   temp = voltage[i] * current[i];
   PVI  += temp;
}
Active_power = PVI / sample_NO ;
```

Fig 2-4. Active Power Calculating

Let the sampling voltage signal in one period be Vn (n= 1, 2, 3, ... sample number) and sampling current signal in one period be In. Then equation (5) takes the place of equation (4).

$$P_{act}=\frac{1}{N}\sum_{n=1}^{N} Vn \cdot In \qquad (5)$$

,where N is sample number for one period.

Fig 2-4 shows a active power calculating algorithm in C-language.

3. ALGORITHM FOR PHASE SHIFT

The phase difference between the voltage signal and the current signal calculation algorithm makes use of correlation. The correlation is a method of digital signal processing, which shows the relationship between two signals. That is, as the two signals become similar, the value of correlation goes large. Finally, correlation sequences of two signal attain its maximum value at zero lag. We calculate the phase difference using this property(see Fig 3-1). Fig 3-1 (a) shows two phase shift, (b) shows one phase shift and (c) shows no phase shift. We can easily find that the correlation value of (c) is maximum. The voltage signal is supply with the same frequency of current signal. Therefore we know the phase difference makes use of cross correlation between the voltage signal and current signal. This algorithm makes use of sampling data which are sampled to calculate active power. One of the sequence (sampled voltage signal data) is rotated, then multiplied by the other sequence (sampled current signal data) to form the product sequence for that rotate, and finally, the values of product sequence are summed Then we can archive the smallest sampled difference between the first result and the maximum result in sampling counter. This sampling number represents the phase difference between the voltage signal and the current signal. We have only to transfer the sampling number to the real angle using sampling frequency(see Fig 3-2). The error rate of this algorithm is decided by sampling frequency. That is the higher frequency, the more accuracy. In addition, it has some advantages such as no additional hardware, more accurate, more robust against noise as compared with an existent digital power meter(using logic method or multiplier method). This algorithm offers a superficial power automatically.

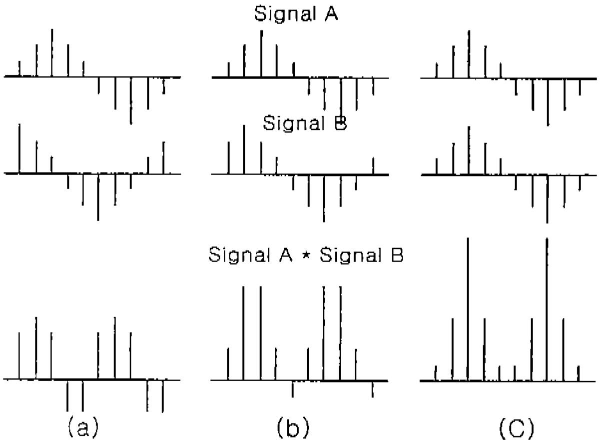
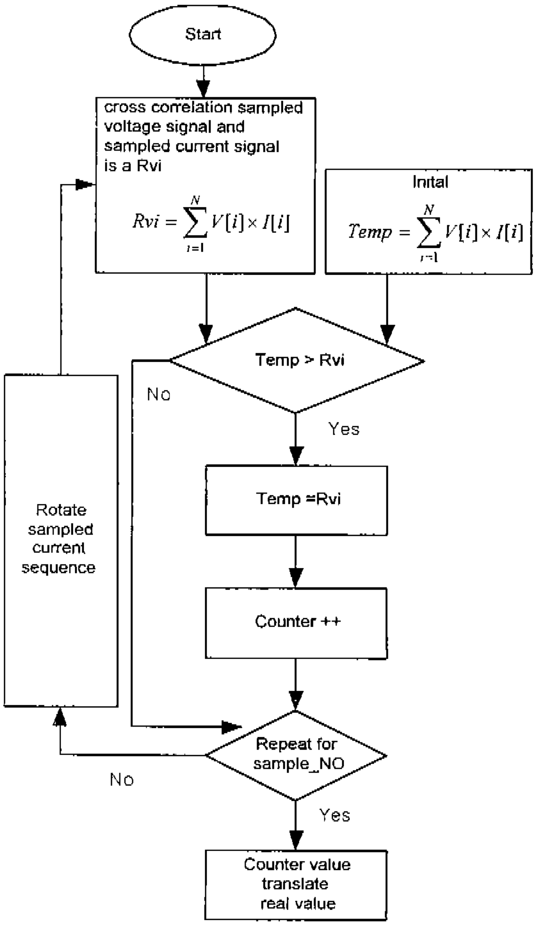


Fig. 3-1. The Multiplication Signal A and Signal B



N: sample number for one period

Fig 3-2. The Phase Shift Algorithm

The apparent power is the maximum correlation value while phase shift is calculating. Using the proposed algorithm, we could calculate element of power such as apparent power, active power and reactive power

4. SIMULATION OF ALGORITHM.

We examine whether the proposed algorithm is right or wrong. Fig 4-1, Fig 4-2, and Fig 4-3 show the simulation results for the proposed algorithm.

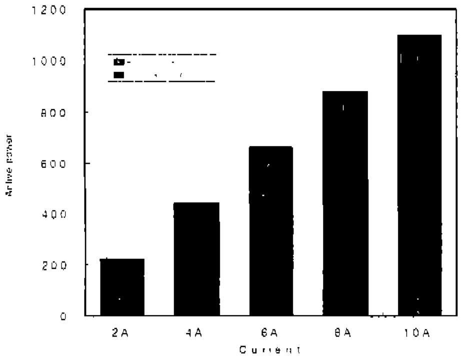


Fig. 4-1. Simulation Result #1
voltage=220[v] : fixed
current : 2→10[A]

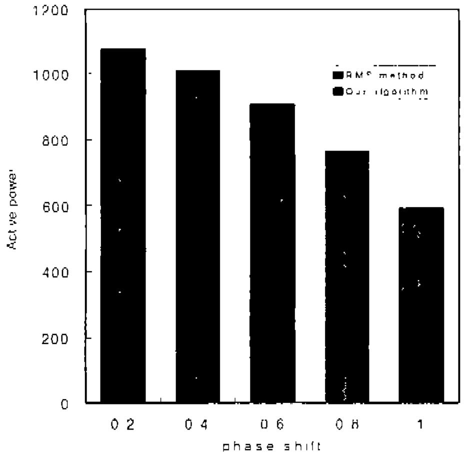


Fig. 4-2. Simulation Result #2
voltage =220[v] : fixed
current =10[A] : fixed
phase shift : 0→1 [rad]

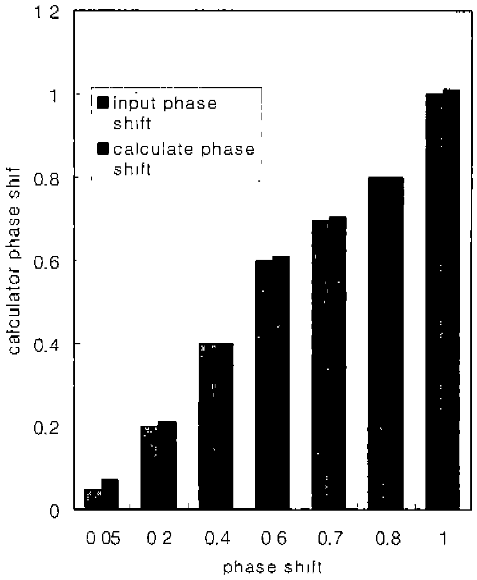


Fig. 4-3. Simulation Result #3
phase shift : 0→1[rad]

As Fig 4-3, actual phase shift is 0.05 radians, but calculated phase shift is 0.07. The error is 0.02 radians (≒ 1.146 °), but we can neglect this small error.

5. IMPLEMENTATION USING TMS320C5x DSP

Sampling : According to the sampling theory, If the signal is sampled at a Nyquist rate, the signal can be exactly recovered from its sampled values. But in the proposed algorithm, Nyquist rate is not suitable to sampling rate. We use equation (6) as sampling rate.

$$Sampling\ rate = \frac{1}{Frequency \cdot N} \qquad (6)$$

,where N : sample number for one period.

Active power : The proposed algorithm operate the FIR form to calculate the active power. We used the TMS320c5x DSP chip, it offers the instructions that the proposed algorithm calculate easily. The DSP's MAC(Multiply and Accumulate) instructions are provide these advantage.

Phase shift : The algorithm of phase shift make use of correlation function. The proposed algorithm must repeat calculation of correlation between one fixed sampled value and rotate sampled data. TMS320C5X also offers circular addressing operation for correlation calculation (see Fig. 5-3).We get the phase shift value easily using the circular addressing operation.

FIg 5-1 and Fig 5-2 are shown the top block of a digital power meter using DSP.

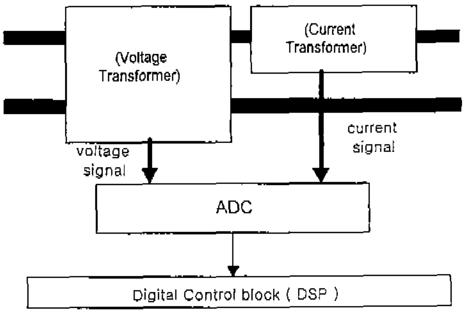


Fig 5-1 Top Block

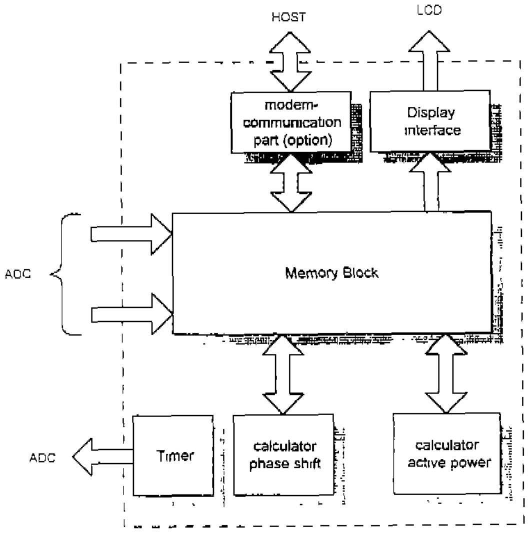


Fig 5-2 Digital Control Block

After implementing the digital power meter using the proposal algorithm, it is put to test. As results, we could get Table 1 and Table 2. These results are shown in Fig 5-4, Fig 5-5 and Fig 5-6.

In Fig 5-4, Fig 5-5 and Fig 5-6, we verified that the proposal algorithm acts properly. Because of sampling error and calculation error in fixed point, we have to add some gain to the result value of active power in practical implementation. The implemented board includes TMS320C5x DSP and MAX158 ADC chip.

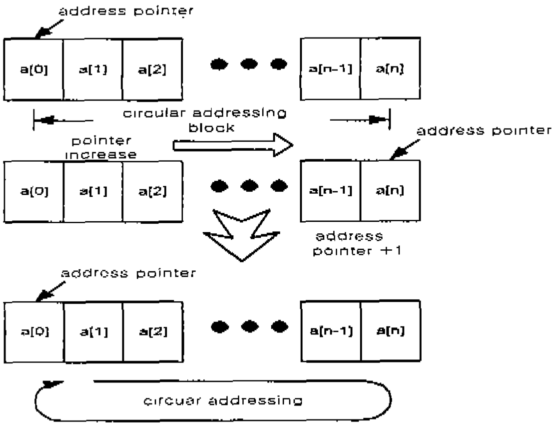


Fig. 5-3 Circular Addressing

Table 1. Test Result 1

	load resister R		
V1[V]	150	180	200
I1[A]	6.6	7.6	8.4
Cos φ	1	1	1
power meter[W]	350	490	480
A Multiple number	3	3	3
Real supplied power [W]	990	1368	1680
calculated power using voltage meter [W]	1050	1470	1740
calculated power using DSP [W]	974	1368	1661

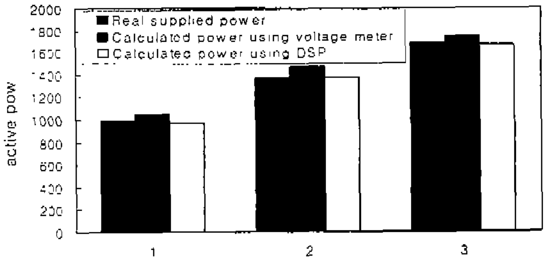


Fig. 5-4 Test : R-load

Table 2. Test Result 2

	R-L		
V1[V]	150	180	200
I1[A]	4.6	5.6	6.3
Cos φ	0.8	0.8	0.8
power meter[W]	170	250	320
A Multiple number	3	3	3
Real supplied power [W]	552	806.4	1008
calculated power using voltage meter [w]	510	750	960
calculated power using DSP [W]	551	791	1024
given phase shift	0.8	0.8	0.8
calculated phase shift	0.79	0.79	0.79

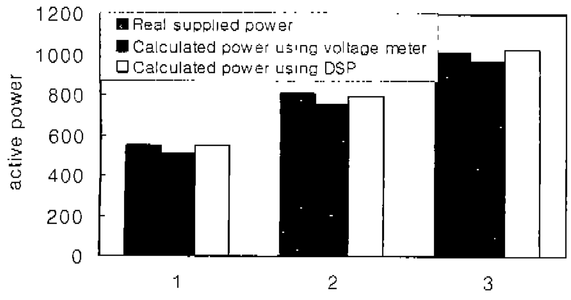


Fig 5-5 Test : R-L load

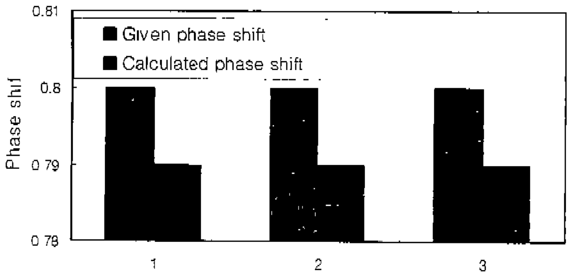


Fig. 5-6 Test : Phase shift

6. CONCLUSIONS

In this paper, we propose the active power and the phase shift the algorithm. The proposed algorithm ca calculate the active power and the phase shift properly. The proposed algorithm has been implemented using TI's DSP TMS320C5x. The performance can be improved by optimizing the software code. If the software-coded modem function is added to DSP, it is possible to include to remote control and monitoring. Owing to using 8-channel MAX158 as ADC, it is possible to execute three-phase power meter operation. After calculating the active power of a each single phase, these values are summed. The active power of three-phase system is the summing result. Implementation of a digital power meter using TMS320C5X DSP can be a good solution for exact and flexible digital power meter.

7. REFERENCES

[1] Bon-Hyouk Ku, "Implementation of a digital power meter using TMS320C3X", 3th TI Korea DSP Design contest, april 1998

[2] Texas Instrument, TMS320C5X USER'S GUIDE , 1997

[3] Texas Instrument, TMS320C1x /C2x /C2xx /C5x Assembly Language Tools USER'S GUIDE, 1995

[4] Texas Instrument, TMS320C5x C source Debugger User's Guide, 1994

[5] TMS320C2x /C2xx /C5x Optimizing C Complier User's Guide, 1995

[6] John G. Proakis and Dimitris G. Manolakis, DIGITAL SIGNAL PROCESSING -principles, Algorithms, and Application, Third Edition, Prentice Hall