Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Desalination 209 (2007) 328–333
DESALINATION
www.elsevier.com/locate/desal

An electronic meter for measuring the saving in electrical power

Tarik Al-Khateeb*, Martin Blundell

Institute Teknologi Brunei, Department of Electrical & Communication Engineering, Brunei Darussalam
email: tarik@itb.edu.bn

Abstract

In electrical installation and building services engineering the power factor is a major consideration in efficient building or system operation. It is the measure of how effectively your equipment is converting electric current from power generation network to useful power output. Your industry can save money and gain other benefits when your power factor is high enough to avoid power factor surcharges on your electricity bills. For this purpose, this work presents an electronic circuit for the measurement of electrical energy. The design is based on a sample and hold method, which generates two DC signals. The first signal is proportional to the peak value of the line voltage, V_m and the second signal is proportional to the instantaneous value of the line current at the instant of peak voltage, $V_{m.}$, i.e. $I_m \cos \Phi$, where Φ is the phase angle between the line voltage and line current signals. Multiplication of the two signals over a predetermined period of time will provide an output proportional to the electrical energy consumed by the load. A voltage to frequency converter, VFC, is used to digitize the electrical energy signal. This signal is then digitally displayed through suitable circuitry. Results are presented to show the effect of a changing power factor on the power available at a constant current and the annual cost savings that can be made.

Keywords: Electrical power measurement; Energy saving; Renewable energy

1. Introduction

Of particular attention to society is the efficient use of electrical energy. An electrical engineer is in a place to improve the efficiency of a system using electrical energy conservation. Power systems engineers generally use a capacitor or synchronous motor to generate a leading reactive power to cancel the lagging reactive power due to inductance [1]. This concept is very logical, for a capacitor or synchronous motor drawing negative Q in parallel with an inductive load reduces the Q which would

*Corresponding author.

The Ninth Arab International Conference on Solar Energy (AICSE-9), Kingdom of Bahrain

doi:10.1016/j.desal.2007.04.047

otherwise have to be supplied by the system to the inductive load.

In other word, the capacitance supplies the Q required by the inductive load. This is the same as considering a capacitor as a device that delivers a lagging current rather than as a device which draws a leading current. Therefore, the power factor of the power system utilities can result to: $\cos \phi_R = \cos (\tan^{-1} Q_R/P_R)$ [1].

This formula can be implemented graphically to obtain the overall P, Q and phase angle ϕ for several loads in the power system network. For several loads in parallel the total P will be the sum of the average powers of the individual loads, which should be plotted along the horizontal axis for a graphical analysis.

Fig. 1 illustrates the power triangle composed of P1, Q1 and S1 for a lagging power factor $\cos \phi_1$ combined with the power triangle composed of P2, Q2 and S2, which is for a capacitive load with a power factor $\cos \phi_{R.}$

In this paper, the results of an investigation are presented in the design of a simple instrument for the measurement of electrical energy. This is not a new idea; in fact, considerable effort has been made in this field because of its special importance to remote monitoring. Thus, there are many designs based on different techniques [1–5,10].

These designs use microprocessors, linear or non-linear analog to digital converters, A/D and binary rate multiplication, etc., and some of them are available in the electronics market. However, all the designs, including the one presented in this work have their advantages and disadvantages.

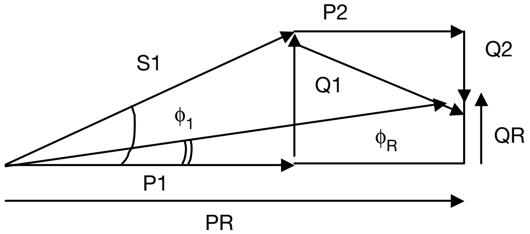

Fig. 1. Power triangle for combined loads.

The approach presented in this paper is based on sampling both the line voltage, V_L and the line current, I_L signals, holding them at the instant of peak voltage V_m, thus two DC levels proportional to V_m and $I_m \cos \Phi$ are provided [6–9].

The product of these signals, when averaged over time, will yield a DC. level proportional to the electrical energy consumed by the load. This signal is then digitized and displayed accordingly.

2. Principal of operation

Consider a normal three-wire system, where the line voltage, V_L and line current, I_L signals under steady state conditions are sinusoidal, as shown in Fig. 2.

The instantaneous voltage *V(t)* and current *I(t)* are given as:

$$V(t) = V_m \sin(\omega t) \quad (1)$$

$$I(t) = I_m \sin(\omega t + \phi) \quad (2)$$

where V_m is the peak value of line voltage, I_m is the peak value of line current, and ϕ is the phase angle between the line voltage and line current.

From Fig. 2: at $\omega t = \pi/2$, then

$$V(t) = V_m \quad (3)$$

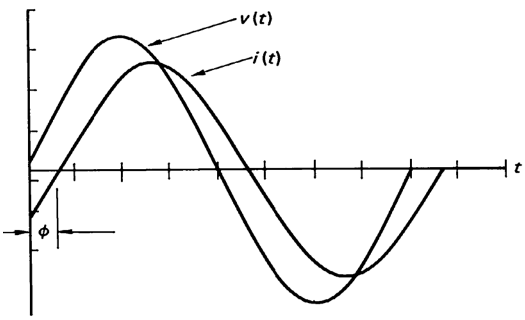

Fig. 2. Voltage and current signals.

$$I(t) = I_m \sin(\pi/2 + \phi) = I_m \cos \phi \quad (4)$$

Thus multiplication of Eqs. (3) and (4) will give:

$$P = V_m I_m \cos \phi \quad (5)$$

Which is the instantaneous value of consumed power P. Averaging this power over a number of time increments T_i, will give the total electrical energy E in kWh:

$$E = l/n \sum_{i=1}^{i=n} p_i T_i \quad (6)$$

where $i = 1,2,3 \ldots n$

3. The electronic meter

The block diagram of the hardware is shown in Fig. 3 and the timing waveforms are shown in Fig. 4.

The line voltage signal $V(t)$ is shifted by 90° and then shaped to a T.T.L compatible square wave which is then inverted, producing the signal "A" at point "a" on the schematic diagram. The "A" signal is used to control the Sample/Hold (S/H) circuits; thus, sampling of the input signals by the S/H will start at logic "*ONE*" of signal "A". The input signal will be held until

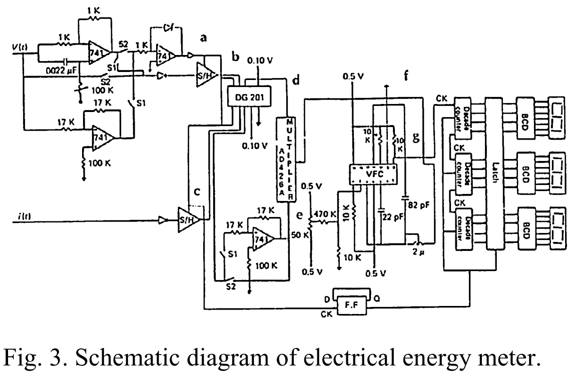

Fig. 3. Schematic diagram of electrical energy meter.

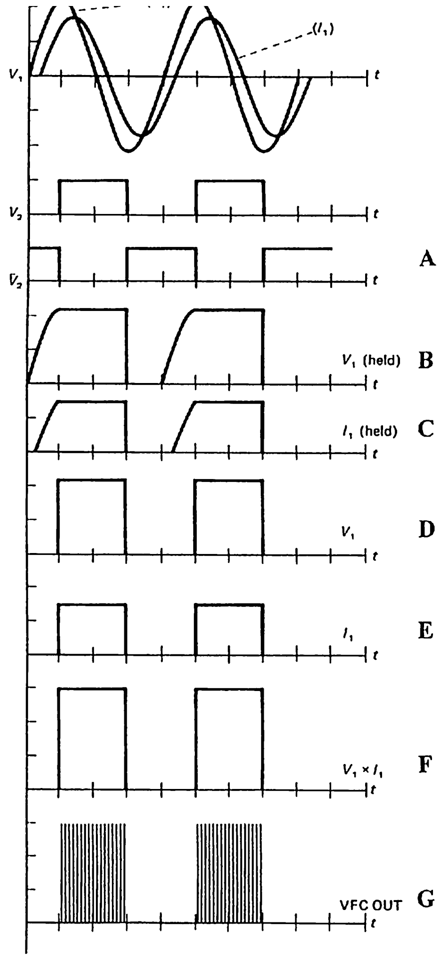

Fig. 4. Timing waveforms.

the negative edge of "A" and then the holding process will terminate at the positive edge of $\overline{A}$. This cycle will continue, producing at points "b" and "c" on the schematic diagram, the waveforms "B" and "C", "B" is proportional to V_m, and "C" proportional to $I_m \cos \phi$.

These two signals are shaped to give the signals "D" and "E" at point's "d" and "e" respectively, after passing through the analogue switch circuit of type DG201.

Multiplication of the "D" signal by the "E" signal will produce at point "f" the signal "F". This is proportional to the consumed power

$P = V_m I_m \cos \phi$. The analogue multiplier circuit of type AD426A has achieved multiplication of the two signals. The "F" signal is converted to an equivalent frequency by a voltage to frequency converter VFC, giving the final signal "G", which is counted and displayed using the counters, latch, Binary Coded Decimal converters and display blocks.

The divide by "N" counter blocks are used to give the required units for measurement, i.e. in (milliwatt-second, watt-minute, kilowatt-hour, etc.), where N is the number by which "G" is divided.

4. Results and conclusion

The technique presented in this work provides a very simple means for the digital measurement of electrical energy, which may be used over a wide range of energy measurement. The results obtained exhibited linear behaviour over the range used. The apparatus gave good results under various loading conditions and with a power factor ranging from low to high values. The device was used over a range of power factors from 0.5 up to 0.9 in steps of 0.2.

Tables 1–3 show the experimental results obtained with a supply voltage of 240 V_{rms} under varying loads compared with the theoretical values. These are in good agreement with small errors. These experimental results are summarized in graphical form which exhibits a linear response as is shown in Fig. 5.

Most electrical plant exhibits inductance as well as resistance this leads to the non-unity power factor values. Electrical utilities do not like this and consequently make surcharges to their consumers based on the power factor that the consumer presents to the power supplier.

The Fig. 6 below shows a typical surcharge schedule imposed by a utility company [11].

It can be seen that even a power factor of 0.7 attracts a surcharge of 24%, an unwelcome extra cost that may be reduced by careful design of suitable compensation circuitry to connect to the inductive system.

In practice one would use capacitance in the system requiring compensation to at least partially cancel out its inductiveness.

For example even an improvement in power factor from 0.7 to 0.9 will give significant gains in power available at a given supply current. Table 4 gives details of this.

Consider the case of a load that operates with a supply of 240 V, 20 A and a power factor of

Table 1
Power at power factor = 0.5 (lagging)

Current (amps)	Calculated power (W)	Experimental power (W)	Error (%)
2	240	237.8	0.92
4	480	476.8	0.67
6	720	715.8	0.58
10	1200	1194	0.50
12	1440	1433	0.49
14	1680	1672	0.48
16	1920	1911	0.47
18	2160	2150	0.46
20	2400	2389	0.46

Table 2
Power at power factor = 0.7 (lagging)

Current (amps)	Calculated power (W)	Experimental power (W)	Error (%)
2	336	330.9	1.52
4	672	666.2	0.86
6	1008	1001	0.69
8	1344	1337	0.52
10	1680	1672	0.48
12	2016	2007	0.45
14	2352	2342	0.43
16	2688	2677	0.41
18	3024	3013	0.36
20	3360	3348	0.36

Table 3
Power at power factor = 0.9 (lagging)

Current (amps)	Calculated power (W)	Experimental power (W)	Error (%)
2	432	427.2	1.11
4	864	858.9	0.59
6	1296	1291	0.39
8	1728	1722	0.35
10	2160	2154	0.28
12	2592	2586	0.23
14	3024	3017	0.23
16	3456	3449	0.20
18	3888	3881	0.18
20	4320	4312	0.19

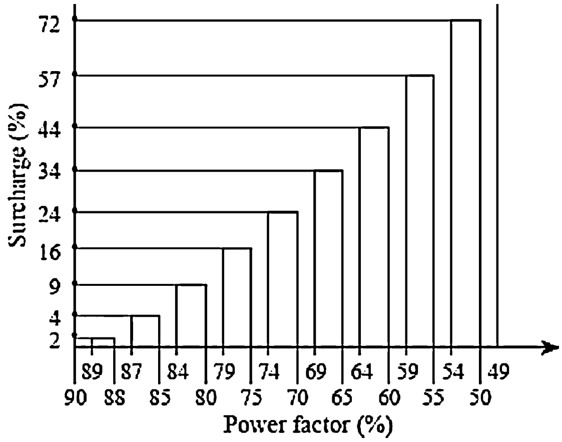

Fig. 6. Power factor–surcharges [11].

0.7, if we apply power factor correction to a power factor of 0.9 at the same power we can reduce the current to just under 16 amps. The saving is significant because under the new load conditions we save the 24% penalty. So in Brunei where the cost of electricity is 5 c per Unit, over a 16 hour per day, 300 working day year the savings are approximately $194. In comparison to this saving the cost of the required capacitor bank in fairly small both in terms of its initial cost and any maintenance costs involved.

This example is for a small load, where larger loads are used correspondingly larger savings are obtained, possibly running into the many thousands of dollars. Hence power factor correction is an important aspect in electrical engineering.

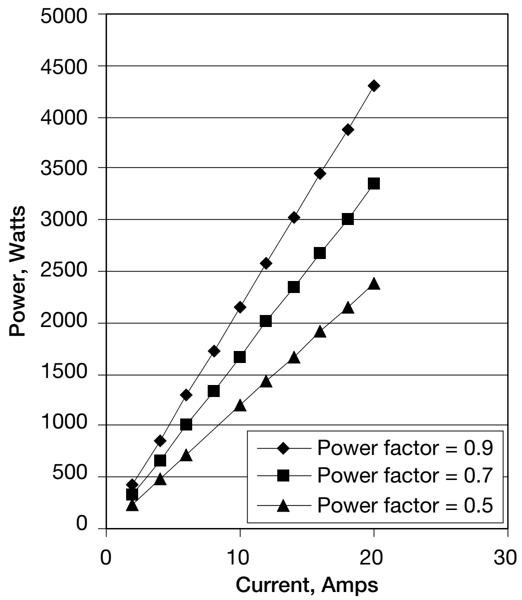

Fig. 5. Power available at various power factor values.

Table 4
Power gained at power factors of 0.7 & 0.9

Current (amps)	Power (W) pf = 0.7	Power (W) pf = 0.9	Power gain (W)
2	336	432	96
4	672	864	192
6	1008	1296	288
8	1344	1728	384
10	1680	2160	480
12	2016	2592	576
14	2352	3024	672
16	2688	3456	768
18	3024	3888	864
20	3360	4320	960

The digital circuit used permits measurements of power consumption to be quickly performed so that as the technician changes the capacitive correction applied he can monitor the power reading in real time to optimise the load.

A prototype of the proposed system has been constructed and tested under various loads and over a considerable period of time. It is believed that the design is very simple, straightforward, with a low cost, and it will have many applications in the electronics industry or education.

Furthermore, the device can be considered for replacing conventional energy meters used in switchboards and for domestic use. The device may be supplied with a standard battery back-up module, and can therefore store the consumed energy, in case of power failure during operation.

Further investigation of the method is under consideration, in particular it is proposed to redesign the circuit using a microcontroller. In this system, the microcontroller will allow many of the functions performed by hardware in the original circuit to be implemented by software and several of the components used in the original design are already implemented in some microcontrollers. The advantages of this approach are; simplified circuitry with a consequent improvement in reliability, and the possibility of storing the data and uploading data to some central controller such as a computer for further processing. A possible disadvantage of this new system is that there may be reduced sampling rates although for practical systems this is probably not a problem.

References

[1] J. John Grainger and W. Stevenson, Power System Analysis, McGraw Hill Edition, 1994.
[2] W. Banks and J.C. Mjithia, Microprocessors Design and applications in digital instrumentation and control, IEEE Trans. on Instrumentation and Measurements, IM-25, No.3., 1976.
[3] T. Saegusal, Y. Suzuki, et al., Digital phase meter using relative counting A/D conversion system, IEEE Trans. on Instrumentation and Measurements, IM-27(4) (1978).
[4] P. Filipski, A new approach to reactive current and reactive measurements in non sinusoidal systems, IEEE Trans. on Instrumentation and Measurements, IM-29, No.4., 1980.
[5] P.N. Miljanic, B. Stajanovic, et al., A novel method for the measurement of power, power factor, rms and average value of voltage and current of distorted power frequency waves, IEEE Transactions on Instrumentation and Measurements, IM-29, No.4, 1980.
[6] K.M. Ibrahim and M.A.H. Abdul-Karim, Novel phase measurement method, Int. J. Elec., 56(2) (1984) 217–221 .
[7] A.H. Karik, Y.J. Munther and Tarik Al-Khateeb, Digital active and reactive power measurement using sample and hold, Int. J. Elec., 56(2) (1988) 263–267.
[8] N. Mohan, T.M. Undeland and W.P. Robins, Power electronics: Converters, Applications, and Design, John Wiley & Sons, New York, USA 1995.
[9] D.W. Hard, Introduction to power electronics, (New Jersey, USA: Prentice-Hall International, Inc.), 1997.
[10] B.W. Williams, Power electronics devices, drivers, applications and passive components, 2nd, edn, Macmillan, London, UK, 1992.
[11] B.C. Hydro, Guides to energy management – power factor, http://www.bchydro.com., 1999.