ARDUINO BASED POWER METER USING INSTANTANEOUS POWER CALCULATION METHOD

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ABSTRACT

This paper describes the design and development of a single phase power meter using instantaneous power calculation method. It is an electrical device that is used in power system to measure the amount of electric power consumed by electrical appliance. It is closely related to the field of monitoring electric energy consumption which it involve both current and voltage signal from power system. In this research study, an accurate power meter is to be produced by using instantaneous power calculation method from the signal obtained from voltage and current sensors. Voltage and current signal are sampled and analysed by using Arduino Due as control unit, where the instantaneous power calculation takes place. The developed power meter is suitable to be used on single phase electrical appliances with its maximum current not exceeding 13A with operating accuracy up to 96.54%.

Keywords: power measurement, instantaneous power, power factor measurement.

INTRODUCTION

Power is the rate at which electric energy is transferred by an electric circuit. It is important electrical quantity and everything in our world today depends on having the power to keep them running. Hence, it is necessary to measure and monitor the power consumption of electrical appliances so to help in estimation of monthly electrical energy usage.

This project aims to develop a power measurement meter to determine the power consumption and to display it graphically. By providing such data to user is that they will optimize and reduce their power usage. Thus, it will provide a platform in reducing the wastage of electrical energy.

INSTANTANEOUS POWER CALCULATION

Instantaneous power concept is utilized in determining the total real power consumed by the appliances/load. It is the most accurate method in calculating AC power. The result is always true in all kinds of loads; resistive, inductive, capacitive and even the modern harmonics-rich nonlinear DC loads. It is the product of instantaneous voltage and instantaneous current across an element[1]. It is the power at any instant of time at which an element absorbs energy. Instantaneous power consist of two parts which the first part is a constant or time dependent and the other part is a sinusoidal function which has twice the angular frequency of the voltage and current. The value of the time dependent part depends on the phase difference between voltage and current, which it is affected by the types of load connected to the system. The instantaneous power is given by

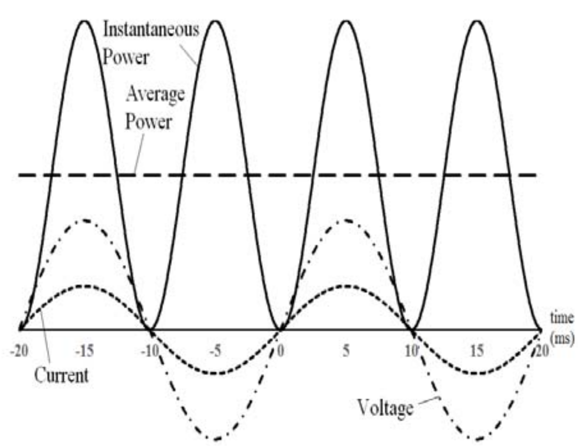
$$P_{inst}=VI \quad (1)$$

Where

$$V=V_m \sin \omega t \quad (2)$$

$$I=I_m \sin(\omega t-\varphi) \quad (3)$$

From the graph in Figure-1(a), the three waves are current, voltage and instantaneous power. The instantaneous power can be obtained by multiplying the value of current and voltage at the particular time instant. By taking the average of all the instantaneous power, the value obtained will be average power and it is represented by the horizontal line in the graph in Figure-1(a). For the graph in Figure-1(b), there is a phase angle between the current and voltage. Hence, the instantaneous power and average power obtained are lower compared to which the voltage and current are in phase. The different in the phase angle of the current is due to reactive load in the circuit.



(a)

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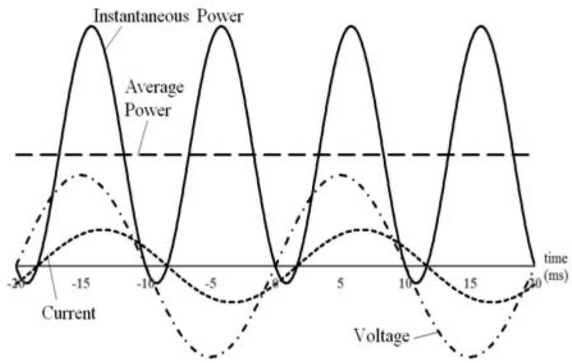

(b)

Figure-1. Waveform of current, voltage, instantaneous power and average power in two situations:
(a) current and voltage are in phase, and
(b) current and voltage are not in phase.

DEVELOPMENT OF HARDWARE

The operation flow of the power meter is shown in Figure-2. The meter was powered on, and the voltage of the measurement circuit and current drawn by the load in the circuit was detected by both voltage and current sensor. The signals produced from the sensors were computed by Arduino which follows the algorithm programmed onto it. The result of the data processed was being display on the LCD on the power meter constructed.

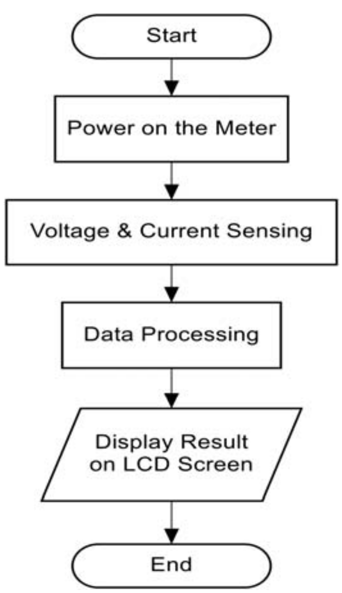

Figure-2. The operation flow of the power meter.

The block diagram of the operation of the power meter is shown in Figure-3. The single phase power meter was connected to the main supply before the load was connected onto it. The voltage was sensed by connecting both the live and neutral wire to the voltage sensor. For current measurement, only the live wire was passed through the Hall Effect current sensor to obtain the current drawn by the load. Both the analog signal from current and voltage sensors were converted to digital by analog to digital converter (ADC) in Arduino. After the data was processed, the results were displayed on the LCD display. Users can also interface the data to personal computer through the Universal Serial Bus (USB) on the power meter.

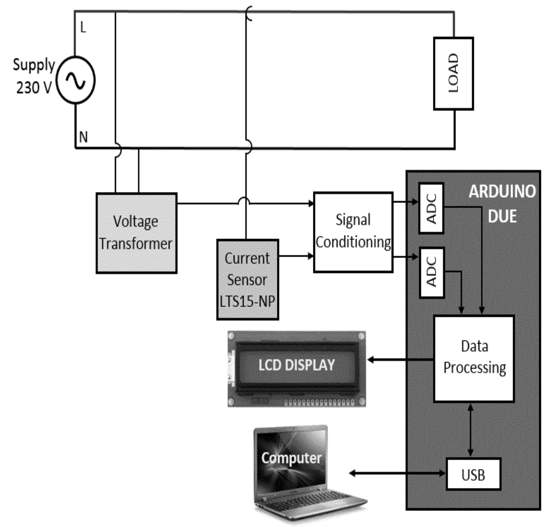

Figure-3. Block diagram of the designed single phase power meter.

There are several methods for current sensing as mention in [2]. The current sensor used in this project was current transducer LTS 15-NP as shown in Figure-4. It is a closed loop Hall Effect current transducer which only requires unipolar voltage supply in order for it to operate. It is a convenient sensor which it direct convert current into voltage signal which correspond to the magnitude of the current sensed. The output of the sensor can be directly connected to the Arduino for data processing.

Figure-4. Current transducer LTS 15-NP [3].

Closed-loop Hall effect method contains of five building blocks which includes the Hall generator, magnetic core, amplifier, driver circuit[4] and a coil wound around the magnetic core as shown in Figure-5. In closed-loop Hall Effect current sensing, the driver circuit drives the wound coil that is in series opposition with the

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magnetic core, which will later produce a magnetic field that oppose the magnetic field produced by the current carrying conductor. The output of the sensor is grounded through a sense resistor to complete the circuit. This operates the core at nearly zero flux [5], which effectively eliminates the dependence of linearity of the Hall generator and magnetic core. The output of the sensor is proportional to the number of turns of coil in the magnetic core.

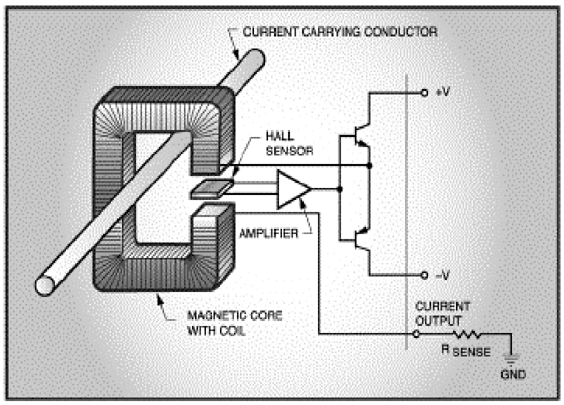

Figure-5. The closed loop hall effect sensor [5].

The advantages of using Hall Effect sensor in current measurement is that the Hall Effect sensor is able to measure DC and AC currents. Apart from that, it is very reliable and it provides electrical isolation to the measurement circuit for safety in operation [5].

For voltage sensing, this project utilised a simple voltage transformer. The voltage transformer used was a dry type voltage transformer with 230V:6V step down ratio. The reduced secondary voltage was further reduced by passing through a signal conditioning circuit which at the same time, performs a DC offset for the output waveform which later to be processed by Arduino.

DEVELOPMENT OF SOFTWARE

From the block diagram in Figure-6, two different powers were obtained from the signal output from both current and voltage transducer. For the sampling period of time interval of 20 ms, the instantaneous current and voltage were multiplied to obtain the instantaneous power. The total number of samples of instantaneous power obtained was then average by the total number of sample collected in 20 ms. The average value obtained was the average power (P) at the particular instant. During the same sampling period, the value of the current and voltage obtained were squared and averaged. The value was then square rooted to obtain the root mean square (rms) value. Both the rms value of current and voltage were multiplied to obtain the apparent power (S). In order to obtain the value of power factor (p.f) of the circuit, the average power (P) was divided by the apparent power (S).

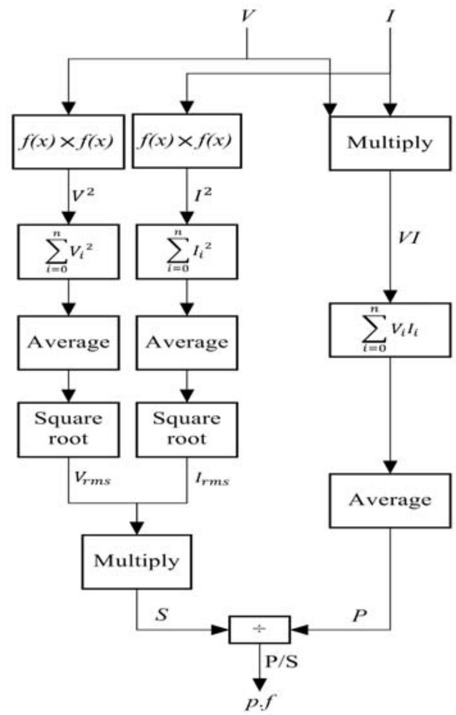

Figure-6. Block diagram of program development for power calculation.

RESULT AND DISCUSSION

In order to verify the accuracy of the prototype, testing and comparing was carried out with readily product in market. The readily product that used to carry out comparison with the prototype are Oscilloscope and Power Quality Analyzer. The oscilloscope used in this test is Tektronix TPS2024B while the power quality analyzer used is Fluke 437 Series II 400 Hz Power Quality and Energy Analyzer.

The project was tested with a variable load resistor. The resistance of the variable load resistor was adjusted to draw a specific amount of current from a supply, ranging from 1 A to 10 A. The parameters were measured and obtained by using the three equipment which are the prototype, oscilloscope and power quality analyser. Throughout the data collection, load size is determined using the calibrated oscilloscope as the reference apparatus.

In this comparison, the oscilloscope was used to set as reference for the other product, primarily on the determination of the load current. The detail of the tested result for current, voltage and power measurement are shown in Table-1, Table-2 and Table-3 respectively.

In order to ensure that the completed prototype can be used to measure power factor of electrical appliances, it is necessary to carry out testing by using reactive load. The reactive load used in this test was a fixed-step load reactor. The prototype was connected to the reactive load together with the oscilloscope and power quality analyser and measurement parameters were

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obtained by using the three equipment. The parameters measured are shown in Table-4.

Table-1. Current measured by three equipment by referring oscilloscope as reference.

Load current (A)	Power Quality Analyzer		Prototype	
	Current (A)	Error (%)	Current (A)	Error (%)
1	1.0	0.00	1.00	0.00
2	2.0	0.00	2.00	0.00
3	3.0	0.00	3.00	0.00
4	3.9	-2.56	3.92	-2.04
5	4.9	-2.04	4.87	-2.67
6	5.9	-1.69	5.87	-2.21
7	6.8	-2.94	6.83	-2.49
8	7.8	-2.56	7.84	-2.04
9	8.8	-2.27	8.87	-1.47
10	9.8	-2.04	9.80	-2.04

Table-2. Voltage input measured by three equipment by referring oscilloscope as reference. The load current is measured with oscilloscope as the reference apparatus.

Load current (A)	Oscillo-scope	Power Quality Analyzer		Prototype	
	Voltage (V)	Voltage (V)	Error (%)	Voltage (V)	Error (%)
1	249	240.81	-3.40	244.24	-1.95
2	248	240.15	-3.27	244.60	-1.39
3	247	239.34	-3.20	244.16	-1.16
4	247	238.61	-3.52	243.61	-1.39
5	245	238.03	-2.93	243.60	-0.57
6	245	236.84	-3.45	242.75	-0.93
7	244	236.24	-3.28	241.99	-0.83
8	243	235.54	-3.17	241.14	-0.77
9	242	234.75	-3.09	238.35	-1.53
10	241	233.82	-3.07	238.04	-1.24

Table-3. Power measured by three equipment by referring oscilloscope as reference.

Load current (A)	Oscillo-scope	Power Quality Analyzer		Prototype	
	Power (W)	Power (W)	Error (%)	Power (W)	Error (%)
1	249	240.81	-3.40	244.24	-1.95
2	496	480.30	-3.27	489.20	-1.39
3	741	718.02	-3.20	732.48	-1.16
4	988	930.58	-6.17	954.95	-3.46
5	1225	1166.35	-5.03	1186.33	-3.26
6	1470	1397.36	-5.20	1424.94	-3.16
7	1708	1606.43	-6.32	1652.79	-3.34
8	1944	1837.21	-5.81	1890.54	-2.83
9	2178	2065.80	-5.43	2114.16	-3.02
10	2410	2291.44	-5.17	2332.79	-3.31

Table-4. Parameters obtained by three equipment when testing with reactive load.

Parameters	Oscilloscope	Power Quality Analyzer	Prototype
Voltage (V)	248	242.91	246.62
Current (A)	2.0	2.0	2.00
Real Power (W)	287	280	236.18
Reactive Power (VAR)	393	390	-
Power factor	0.58	0.58	0.47

From the comparison of parameters obtained, it was found that the power factor obtained by the prototype is slightly lower than the power factor measured by other two equipment. By further examination on the waveform from voltage and current sensing, it was found that there are some distortion on the sensed waveform as compare to the original waveform. The point where the waveform crossed the zero axis were also different with the original waveform. This had caused the phase angle that were used to determine the power factor to be different. The comparison of both waveform for voltage and current sensing are shown in Figure-7 and Figure-8 respectively.

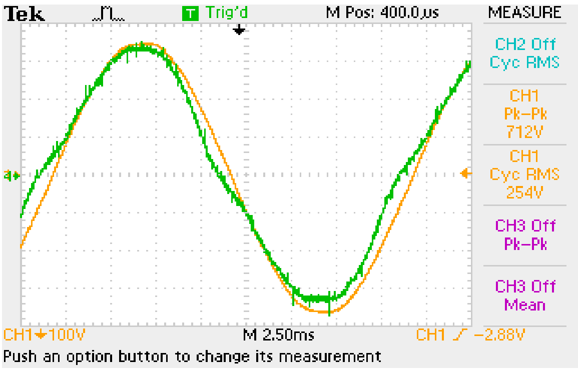

Figure-7. Comparison of original voltage (orange colour) waveform and sensed voltage (green colour) waveform.

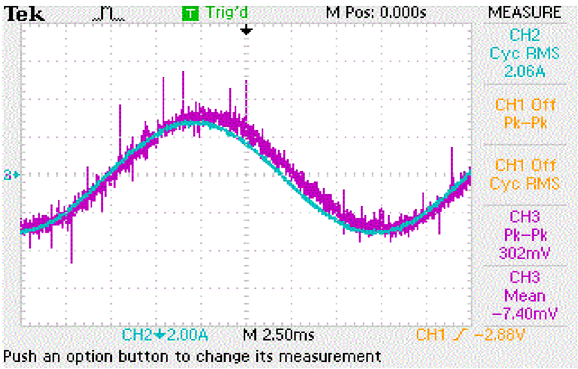

Figure-8. Comparison of original current (blue colour) waveform and sensed current (purple colour) waveform.

For further verification of result, the operation of the reactive load with the prototype remained the same. The sensed voltage signal and sensed current signal were connected to oscilloscope to obtain the phase angle of the waveform and power factor. It was observed that the power factor obtained by the oscilloscope based on the signal from the voltage and current sensing were the same as obtained by the prototype. This concludes that the calculation technique is able to compute the accurate value for the power factor measurement. However, the inaccuracy of the measurement are caused by the noise and phase different produced during the sensing of the signal.

CONCLUSIONS

The objective of this study was to develop a single phase power meter that can accurately measures true power regardless of the type of connected load by using a low cost general purpose microcontroller board. The developed prototype is able to display voltage, current, power and power factor which the data computing method is using instantaneous power calculation technique.

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