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CALIBRATION OF ZMPT101B VOLTAGE SENSOR MODULE USING POLYNOMIAL REGRESSION FOR ACCURATE LOAD MONITORING

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ABSTRACT

Smart Electricity is quickly developing as the results of advancements in sensor technology. The accuracy of a sensing device is the backbone of every measurement and the fundamental of every electrical quantity measurement is the voltage and current sensing. The sensor calibration in the context of this research means the marking or scaling of the voltage sensor so that it can present accurate sampled voltage from the ADC output using appropriate algorithm. The peak-peak input voltage (measured with a standard FLUKE 115 meter) to the sensor is correlated with the peak-peak ADC output of the sensor using 1 to 5th order polynomial regression, in order to determine the best fitting relationship between them. The arduino microcontroller is used to receive the ADC conversion and is also programmed to calculate the root mean square value of the supply voltage. The analysis of the polynomials shows that the third order polynomial gives the best relationship between the analog input and ADC output. The accuracy of the algorithm is tested in measuring the root mean square values of the supply voltage using instantaneous voltage calculation and peak-peak voltage methods. The error in the measurement is less than 1% in the peak-peak method and less than 2.5% in the instantaneous method for voltage measurements above 50V AC, which is very good for measurements in utility. Therefore, the proposed calibration method will facilitate more accurate voltage and power computing for researchers and designers especially in load monitoring where the applied voltage is 240V or 120V ranges.

Keywords: voltage sensor, sensor calibration, loads monitoring, power measurement, polynomial regression.

1. INTRODUCTION

Voltage and current are the fundamental quantities of electrical system; therefore their accurate measurements are very vital in electrical load monitoring. Accurate load monitoring is necessary to facilitate energy management which is one of the most important factors that ensure sustainability in the electrical power system, of course by eliminating energy waste and unwanted activities [1-3]. On the other hand the world is becoming more automated and smarter in terms of energy utilization, therefore the importance of having accurate measurements of the electrical quantities cannot be overemphasized. Energy efficiency in electricity utilization through accurate measurement and monitoring is necessary in procuring the future of the power system [4, 5].

Sensor calibration is one of the most important aspects of energy monitoring. The measurement, control and management of electrical equipment are all dependents upon an accurate and reliable sensing. Moreover the voltage and current are the fundamental quantities from which all other electrical quantities are determined. The current and voltage are detected using current and voltage sensors which are available in numerous forms. The current sensors like ACS712, ACS716 and ACS 756 come with their factory settings or trimming, in such a way that you can convert the ADC value of the sensor into the corresponding analog input using a sensitivity given by the manufacturers. But for the ZMPT101B voltage sensor, the setting has to be provided by the user through the trim potentiometer. The easiest way of implementing sensor calibration is to apply a correction polynomial to the output of the sensor to cater for the distortion in the system [6]. Though the method used in [6] determines the calibration of a hall effect sensor with 9th order polynomial as the correction function, the method used in this paper calibrated the ZMPT101B sensor which works based on electric field detection. Moreover the analysis in this research is limited to 5th order polynomial.

In this paper a polynomial regression analysis is carried out between the analog input to the sensor and its ADC output. The best polynomial obtained according to the analysis will serve as a transfer function between the analog input and ADC output. This will eliminate the need for minimizing the output distortion in [6] especially for power consumption measurement in power system. Also the computational requirement of the algorithm is reduced with reduced order of the polynomial; hence there will be faster response by the system.

The remaining parts of the paper is organized as follows: Section 2 presents the related literatures in voltage sensing and measurement, section 3 gives the problem statement of the work, section 4 provides the methodology, results and analysis are provided in section 5 and section 6 provides the conclusion.

2. LITERATURE REVIEW

2.1 An overview of voltage measurement

The sensor technology has reached an advanced level that several measurements that were not (directly) possible are now possible and easy with the availability of sensors and transducers. Sensor calibration is one of the most important aspects of all measurements. Sensor calibration research works have been carried out by several researchers [6-11]. Ramos P. M. *et al* [6] presented

ARPN Journal of Engineering and Applied Sciences

a method of calibrating current and voltage hall effect sensors specifically for power quality measurements. The sensor calibrations on DC and AC signals were combined to come out with a correction polynomial through minimization of the output distortion. Analysis on the system shows that it can improve the signal to noise and distortion ratio (SINAD) by 14.8 dB for voltage sensor and 8.7 dB for current sensor. The system produced a very good result even though the 9^{th} order correction polynomial may enforce more computational requirement than a 5^{th} or less order polynomial. Lambrecht S. *et al* [7] presented a simplified and complex calibration through the comparison between cooperative and local Kalman Filters. The simplified calibration can be replicated in most laboratories and the results indicated that the more complex the calibration the better the performance regardless of the segment and filters used. The electric power sensor designed by Pai P. *et al* [8] also involved the calibration of Hall, giant magneto-resistive (GMR) and inductive sensors. The comparison of the voltage and current measurements with that of a standard ammeter gives an error of 2 - 4% in both current and voltage. Sheng L. C. and Hong J. Z. [10] analyzed a six–axis force measuring system using hybrid neural network. The transfer matrix calibrated the sensor between the input force and the output voltage. The work by Huiskamp T. *et al* [11] presented a large-bandwidth, high-current, and high-voltage measuring system for pulse power system. The system used vector network analyzer (VNA) to calibrate the B-dot and D-dot sensors, and verify using reed-relay pulse source. Through the well calibrated system the voltage and current waveforms that pass through the sensor position are numerically reconstructed.

The digital voltage measurement has also advanced with the advancement of microcontroller and other ADC devices. Digital measurement gives more precise value of the voltage than the analog counterpart. Researchers in energy and power measurements have different contributions in voltage measurement, power measurement and energy consumption measurement [5, 12-16]. A. M. Miquel *et al* [5] implemented a smart meter monitoring system based on arduino platform, the system is capable of measuring power consumption of a house and sending it to a server or it can be monitored using mobile devices. P. Srividyadevi *et al* [12] use arduino microcontroller to measure power and energy of a single phase system. The system can measure up to 600W power with corresponding energy consumption, though there is need for higher power measurement in so many power system applications. C. Jao and X. Guo [13] used opto-isolator IC as both the voltage and current sensor to develop a power measuring meter. The device is validated using a load of 50W with a commercial measuring device giving an error of up to 5.13% in the current measurement. More effort is needed to come up with a device that can measure higher power, especially when considering the limitation of the opto-isolator IC. T. M. Chang and H. Daniyal [14] developed an arduino based single phase power meter. It uses the instantaneous calculation method to measure the voltage, current and the active power of the system. Though the system is limited to 13A current measurement but its measurement is 96.54% accurate. Christopher McNally developed an arduino based wireless power meter for home application. The data provided by the meter will help the consumer to optimize and reduce their power usage. The work developed by R. W. Fransiska *et al* [16] is an arduino microcontroller based wattmeter incorporating LABVIEW program. The system can measure voltage, current, power, energy, frequency and calculates the electricity bill of the house. It measures the voltage above 46V and the power measurement is limited to 1200W. The voltage measurement is satisfactory in power system application but there may be a need of measuring higher power consumption.

On the other hand, some researchers have made different efforts regarding energy management, monitoring and control, works that also involves measurements of the relevant electrical quantities [17-21]. A. M. F. Guimaraes *et al* [17] developed a smart energy monitoring system using ADE7758 energy measurement IC and ATmega16 micro controller. The system has error of 1.183% when compared with a professional analog meter. Babatunde S. E. [18] developed a microcontroller based power management system which is implemented using 8-bit microcontroller and simulated using Java. T. Kamal *et al* [19] developed an energy management and power control of Hybrid Renewable Energy Sources. Matlab/Simulink is used to determine the performance of the system which confirm the effectiveness of the system in terms of voltage regulation and stability. N.Tamkittikhun *et al* [20] proposed an arduino multichannel power meter. The system provides a multichannel measurement through simultaneous sampling of voltage and current. It shows a significant increase in accuracy especially with non-linear and inductive loads.

2.2 The ZMPT101B voltage sensor

ZMPT101B voltage sensor module is a voltage sensor made from the ZMPT101B voltage transformer. It has high accuracy, good consistency for voltage and power measurement and it can measure up to 250V AC. It is simple to use and comes with a multi turn trim potentiometer for adjusting the ADC output. The analysis in this paper tends to find more accurate relationship between the input voltage and the ADC output by regression analysis. The ADC output is adjusted using the trimpot to an appropriate value against a reference input. Figure-1 is the ZMPT101B voltage sensor module.

Figure-1. ZMPT101B voltage sensor module.

2.3 Arduino microprocessor

The Arduino microprocessor board is a single board microprocessor used in intelligent projects and

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prototyping. The functions performed by the microprocessor include; sensing, controlling, logical and computing applications. The software used in the arduino programming is a simplified version of C/C++ language which makes it easy to use in designing and prototyping. The board comes in many forms such as Arduino UNO, Arduino MEGA 2560, Arduiono Leonardo etc. It has extensible hardware and software; it is also inexpensive and can work across so many platforms.

2.4 Polynomial regression

The polynomial regression is a fitting relationship that fits two or more variables with a polynomial of a certain order (n). In a typical application the polynomial regression can be used to determine the relationship between a dependent variable (y) and an independent variable (x). the accuracy of the relationship between the two variables can be influenced by the nature of the data and its quantity, that is the more the data the more accurate the polynomial [22]. To find the coefficients of the polynomial fitting we need to find the solution to Equation 1. A more accurate relationship between the input voltage to the sensor and the ADC output is expected using this method.

$$\begin{bmatrix} n & \sum x_i & \sum x_i^2 & \sum x_i^3 & \ldots\ldots & \sum x_i^j \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \ldots\ldots & \sum x_i^{j+1} \\ \sum x_i^2 & : & : & : & : & : \\ \sum x_i^3 & : & : & : & : & : \\ : & : & : & : & : & : \\ \sum x_i^j & \sum x_i^{j+1} & \sum x_i^{j+2} & \ldots\ldots & \ldots\ldots & \sum x_i^{j+j} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ :_2 \\ : \\ : \\ a_j \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum y_i x_i \\ : \\ : \\ : \\ \sum y_i x_i^j \end{bmatrix} \quad (1)$$

Where a_js are the coefficients of the polynomial of order j which is in the form of Equation 2

$$y = a_0 + a_1 x + a_2 x^2 + \ldots\ldots\ldots\ldots\ldots + a_j x^j \quad (2)$$

2.5 The Instantaneous voltage calculation method

The nature of the voltage and current in DC power system is characterized by having a constant value unless the voltage level or loads current are changed. But when it comes to an AC supply the voltage and currents are sinusoidal in nature, hence a sinusoidally varying voltage is connected to the sensor which means it can only read the value of the voltage at a particular time. The instantaneous calculation is used in the case of AC supply in which an algorithm uses the samples of the voltage to calculate the rms value of the voltage. It is also useful in the calculation of the rms current and real power consumption of the system. As the voltage is sampled at regular intervals the Arduino programming calculates the rms voltage as illustrated in Equation 3.

$$V_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} V_i^2} \quad (3)$$

2.6 The peak to peak voltage method

Another way of calculating the rms voltage of the AC supply is by using the peak voltage of the supply, this is for the fact that the AC supply is assumed to be perfectly sinusoidal so that the rms value can be obtained from the peak value using Equation 4. The peak voltage is half the value of the peak to peak voltage which is obtained by taking the difference between the maximum and minimum sampled values. Normally the AC voltage is sampled appropriately (1000 times at an interval of 0.1ms in this analysis) and the difference between maximum value and minimum value will give the peak to peak value.

$$V_{rms} = \frac{V_{peak}}{\sqrt{2}} = \frac{V_{peak-peak}}{2\sqrt{2}} \quad (4)$$

3. PROBLEM DEFINITION

The ZMPT101B voltage sensor module is a voltage sensor board made from ZMPT101B potential transformer which is capable of measuring up to 250V AC. The sensor comes with a multi turn trim potentiometer for adjusting the ADC output. Unlike the current sensor where the scaling is provided by factory trimming, the ZMPT101B sensor has to be trimmed and calibrated by the user. P. M. Ramos *et al* [6] used correction polynomial to calibrate voltage and current sensor, whereas [23] developed a system for the calibration of non-intrusive load meters that is capable of both the calibration and identification of the loads. In this work the trimming is selected and the algorithm for determining the sampled voltage from the ADC output of the sensor is determined by using polynomial regression. The work correlates the peak-peak analog input and peak-peak ADC output as illustrated in Figure-2.

ARPN Journal of Engineering and Applied Sciences

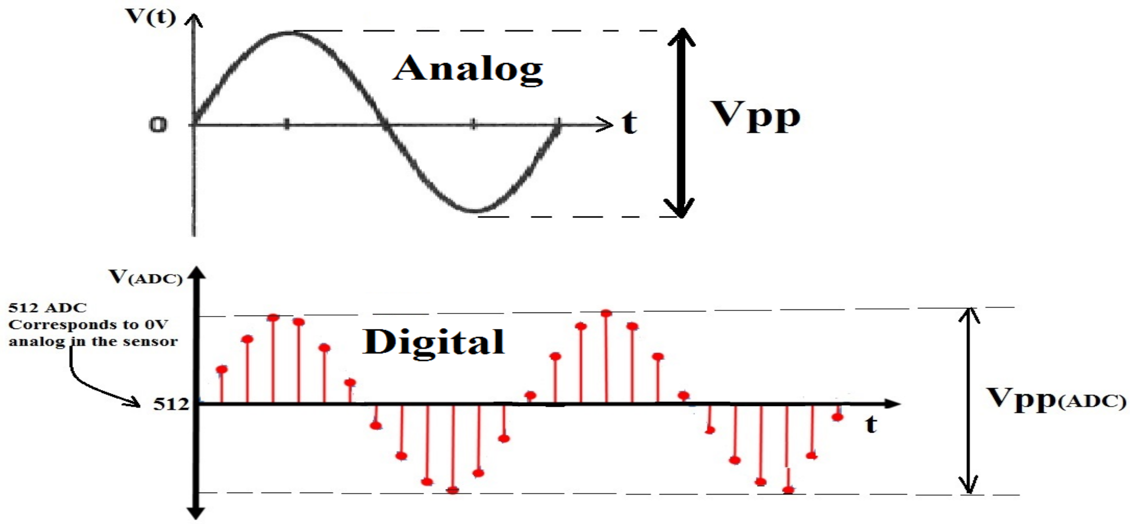

Figure-2. Analog and digital voltages.

The correlation is performed using polynomials of order 1 to 5 and among the 5 polynomials obtained the best in terms of accuracy is taken. The root mean square value of the voltage can be obtained using instantaneous or peak to peak voltage method. The determination of the Vrms will involve taking as many samples of the voltage as required for the instantaneous or peak to peak calculations. Figure-3 illustrates the flow chart of the voltage calculations.

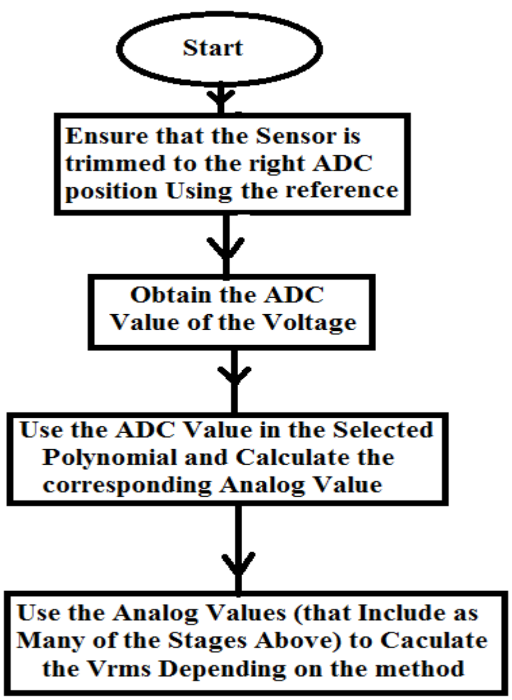

Figure-3. The flow chart of voltage calculation.

4. METHODOLOGY

The characteristics of ZMPT101B is considered to be linear in which the corresponding input voltage is having a linear relationship with the ADC value. The linearity of the sensor covers up to 1000V [24], therefore for the purpose of this research the maximum ADC output is adjusted to 640 at an input voltage of 250V AC, which serves as the trimming of the sensor and this therefore forms the reference of every measurement using the equation(s) obtained in this research. Using the polynomial regression analysis will ascertain whether higher order polynomials can improve the accuracy of the sensors when compared with the measurements of standard meters. In this work a standard FLUKE115 meter is used to measure the input voltage and the peak to peak value of the input voltage is correlated with the peak to peak ADC output to determine the polynomial relationship between them. Polynomials from order 1 to 5 are generated using the data.

4.1 Data collection

The FLUKE 115 meter is used to measure the input voltage which is varied from 0 to 250V AC. The ADC output of the sensor at 0 input voltage is 512 hence if 512 to 1024 is allowed to reflect 0 to 1000V range [24] then 512 to 640 will be suitable to scale 250V range. In this regard with 250V connected to the sensor the maximum ADC is adjusted to be 640 using the sensor trimpot (this serves as the reference). A variable voltage from variable transformer (measured using FLUKE 115 meter) is applied to the sensor and through the arduino program maximum and minimum values of the ADC are recorded against each input voltage. The peak to peak input voltage and peak to peak ADC output are tabulated for the analysis. The arduino code sampled the voltage 1000 times and obtain the minimum and maximum ADC values from the samples.

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4.2 The programming code

After the regression analysis the five polynomial equations obtained are used to analyze the sensor output voltage using instantaneous voltage calculation and peak voltage methods. The results of each measurement using each of the five equations are tabulated for both the two methods. Figures 3 and 4 shows the code for instantaneous voltage and peak voltage methods respectively.

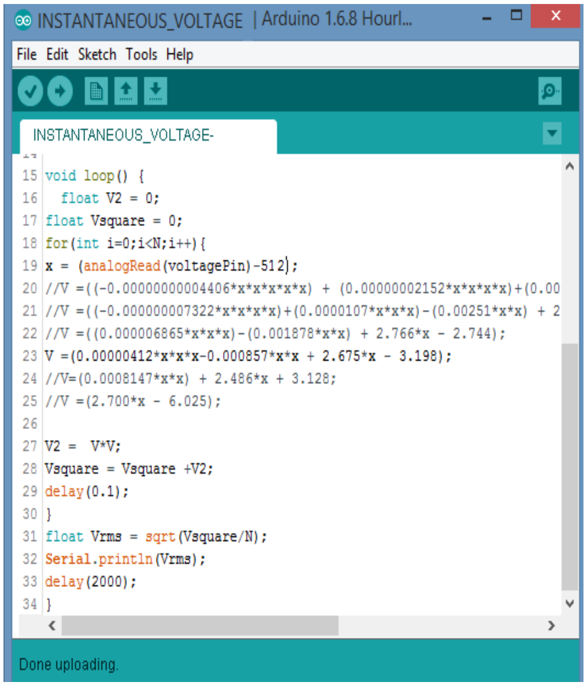

Figure-4. The code for instantaneous calculation.

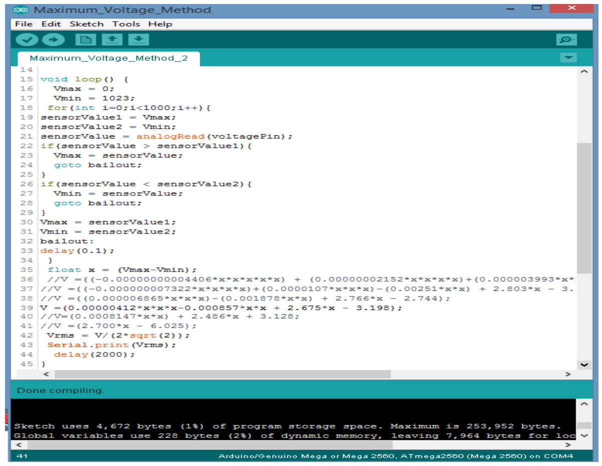

Figure-5. The code for maximum voltage method.

5 RESULTS AND ANALYSIS

The analysis begins by taking the polynomial regression of the data obtained. The peak to peak input voltage is the dependent variable (y) whereas the peak to peak ADC output of the sensor is made the independent variable (x). The analysis of the two methods using all the five regression equations is carried out followed by the comparison of the two methods using the best regression equation over full voltage range of 0 to 250V AC. Figure 5 shows the experimental setup.

5.1 The polynomial regression results

The research intended to investigate the performance of the polynomials from order 1 to 5; therefore the solution to Equation 5 is used to obtain the polynomials in Equation 6 to 10.

$$\begin{bmatrix} n & \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \sum x_i^7 \\ \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \sum x_i^7 & \sum x_i^8 \\ \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \sum x_i^7 & \sum x_i^8 & \sum x_i^9 \\ \sum x_i^5 & \sum x_i^6 & \sum x_i^7 & \sum x_i^8 & \sum x_i^9 & \sum x_i^{10} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum y_i x_i \\ \sum y_i x_i^2 \\ \sum y_i x_i^3 \\ \sum y_i x_i^4 \\ \sum y_i x_i^5 \end{bmatrix} \tag{5}$$

And the polynomial Equations obtained are:

EQUATION 1: $y = 2.709x - 8.35$ (6)

EQUATION 2: $y = 0.0007711x^2 + 2.506x + 0.2662$ (7)

EQUATION 3: $y = 0.00000412x^3 - 0.000857x^2 + 2.675x - 3.198$ (8)

EQUATION 4: $y = -0.00000004888x^4 + 0.00002986x^3 - 0.005183x^2 + 2.922x - 6.085$ (9)

EQUATIONS5: $y = -0.0000000001278x^5 + 0.00000003529x^4 + 0.00001023x^3 - 0.003271x^2 + 2.853x - 5.57$ (10)

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ARPN Journal of Engineering and Applied Sciences

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5.2 The instantaneous and peak voltage methods analysis

The Equations are run on the arduino program using instantaneous voltage calculation method (Figure-3). The input voltage is measured using a standard FLUKE 115 meter and the response of each equation including the errors are tabulated as shown in Table-1. The errors are much higher when the output voltage is computed using Equations 2, 4 and 5.

Table-1. Voltage measurement using instantaneous voltage calculation.

Input voltage fluke meter (V)	Voltage measurements of the voltage sensor from the polynomial regression equations using the instantaneous calculation.									
	Equation 1		Equation 2		Equation 3		Equation 4		Equation 5	
	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)
250	246.48	1.41	229.15	8.340	248.5	0.60	305.39	-22.16	269.55	-7.82
248	247.17	0.33	228.54	7.847	247.67	0.13	301.14	-21.43	268.96	-8.45
246	244.92	0.44	226.14	8.073	245.91	0.04	301.46	-22.54	226.17	8.06
244	244.33	-0.14	234.17	4.029	242.11	0.77	297.93	-22.10	264.68	-8.48
242	241.76	0.10	222.46	8.074	242.11	-0.05	297.93	-23.11	264.68	-9.37
240	240.53	-0.22	220.61	8.079	240.31	-0.13	295.03	-22.93	263.53	-9.80
238	237.38	0.26	217.48	8.622	238.42	-0.18	292.03	-22.70	260.74	-9.55
236	236.80	-0.34	216.69	8.182	236.61	-0.26	289.06	-22.48	257.69	-9.19
234	235.26	-0.54	215.44	7.932	234.76	-0.32	287.44	-22.84	255.41	-9.15
232	231.56	0.19	214.47	7.556	232.65	-0.28	284.41	-22.59	245.48	-5.81
230	230.97	-0.42	213.74	7.070	230.62	-0.27	282.62	-22.88	250.80	-9.04
228	229.34	-0.59	212.44	6.825	228.68	-0.30	278.48	-22.14	247.93	-8.74
226	227.25	-0.55	211.60	6.372	226.58	-0.26	276.78	-22.47	246.40	-9.03
224	225.78	-0.79	209.38	6.527	224.95	-0.42	274.27	-22.44	244.95	-9.35
222	222.91	-0.41	207.76	6.414	222.79	-0.36	270.44	-21.82	243.60	-9.73
220	222.19	-1.00	205.98	6.373	221.42	-0.65	268.41	-22.00	242.51	-10.23
218	220.39	-1.10	202.82	6.963	218.66	-0.30	265.55	-21.81	239.42	-9.83
216	217.29	-0.60	199.68	7.556	217.12	-0.52	262.33	-21.45	235.33	-8.95
214	216.22	-1.04	197.53	7.696	215.83	-0.86	260.25	-21.61	233.99	-9.34
212	213.99	-0.94	196.24	7.434	213.76	-0.83	257.19	-21.32	231.73	-9.31
210	212.10	-1.00	194.42	7.419	211.84	-0.88	255.47	-21.65	230.07	-9.56
208	210.40	-1.15	192.78	7.317	210.33	-1.12	252.35	-21.32	228.32	-9.77
206	208.71	-1.32	191.31	7.131	208.51	-1.22	249.72	-21.22	226.76	-10.08
204	206.42	-1.19	190.42	6.657	206.38	-1.17	247.53	-21.34	224.89	-10.24
202	205.18	-1.57	188.42	6.723	204.47	-1.22	244.42	-21.00	222.58	-10.19
200	204.04	-2.02	186.25	6.875	203.84	-1.92	241.26	-20.63	220.53	-10.27

This result shows that the 3rd order polynomial is the best because the percentage error is the lowest even though the first order is also comparable.

And when the peak voltage method is used (as shown in Figure-4) the result in Table-2 is obtained for the five equations. The peak to peak voltage generally gives very low errors with all the five equations. This also demonstrated that the third order polynomial equation is the best for the sensor response.

ARPN Journal of Engineering and Applied Sciences

Table-2. Voltage measurement using peak voltage method.

Input voltage fluke meter (V)	**Voltage measurements of the voltage sensor from the polynomial regression equations using the peak voltage calculation**									
	Equation 1		**Equation 2**		**Equation 3**		**Equation 4**		**Equation 5**	
	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)	VOLTAGE (V)	Error (%)
250	246.07	1.57	248.88	0.45	249.89	0.04	249.15	0.34	249.01	0.40
245	242.24	1.13	233.75	4.59	244.49	0.21	244.11	0.36	244.06	0.38
240	237.54	1.03	239.66	0.14	240.2	-0.08	240.05	-0.02	240.05	-0.02
235	233.62	0.59	235.57	-0.24	234.87	0.06	234.97	0.01	236.02	-0.43
230	227.87	0.93	231.49	-0.65	230.64	-0.28	230.89	-0.39	229.94	0.03
225	225.00	0.00	226.41	-0.63	225.39	-0.17	225.78	-0.35	226.88	-0.84
220	220.21	-0.10	221.33	-0.60	221.21	-0.55	221.68	-0.76	221.77	-0.80
215	215.42	-0.20	217.29	-1.07	216.02	-0.47	216.56	-0.73	217.67	-1.24
210	210.63	-0.30	211.23	-0.59	210.86	-0.41	211.44	-0.69	211.50	-0.71
205	205.84	-0.41	206.20	-0.59	204.71	0.14	206.32	-0.64	206.37	-0.67
200	201.05	-0.53	201.18	-0.59	199.63	0.19	202.21	-1.11	202.26	-1.13

Analysis

From the results obtained, both the instantaneous and peak voltage methods indicated that the 3rd order polynomial is the best among the five equations in representing the sensor response. The errors are much less in the peak voltage method even though it gives a huge error when there is spike in the supply which occur very rarely. The instantaneous voltage method has higher errors in the measurement though it is much needed in calculating the power consumption of the system.

Figure-6. The experimental setup.

5.3 Comparison between instantaneous and peak voltage methods

Finally the performance of the instantaneous and peak voltage methods are compared using the selected equation (3rd order) for the whole voltage range of 0 to 250V AC. The results shown in Table-3 indicated that the peak voltage method is more accurate with less percentage error in almost all the measurements.

6. CONCLUSIONS

This work presented a method for calibrating ZMPT101B voltage sensor module using polynomial regression. The sensor is trimmed to read a maximum output of 640 ADC at an input voltage of 250V (rms value) AC, which serves as a reference. Polynomial regression of order 1 to 5 are analyzed for the sensor peak to peak input voltage (y) against the peak to peak ADC output. The analysis shows that the third order polynomial (EQUATION 3) gives the best representation of the sensor response. The third order equation is then used to simulate the output voltage (rms value) using instantaneous and peak to peak method of calculation, when a variable voltage (0 – 250V) is applied to the sensor. The results are found to be very accurate with maximum error of 0.9% and 2.4% for peak to peak method and instantaneous method respectively, when considering measurements above 50V AC and when compared with a standard FLUKE 115 meter. This analysis can be replicated using different trimming settings of the sensor and with what is achieved here a more accurate measurement and hence monitoring, management and control of the energy consumption can be achieved.

ARPN Journal of Engineering and Applied Sciences

Table-3. Voltage sensor results using the two methods.

Fluke meter input voltage (V)	Instantaneous calculation	Error (%)	Peak voltage method	Error (%)
250	250.05	0.02	249.89	-0.04
240	240.24	0.10	240.2	0.08
230	230.93	0.40	230.64	0.28
220	221.82	0.83	221.21	0.55
210	212.36	1.12	210.86	0.41
200	202.54	1.27	200.65	0.33
190	192.44	1.28	190.56	0.29
180	183.26	1.81	181.58	0.88
170	172.67	1.57	170.72	0.42
160	163.1	1.94	160.96	0.60
150	153.48	2.32	150.32	0.21
140	143.36	2.40	140.74	0.53
130	132.83	2.18	131.23	0.95
120	122.71	2.26	120.84	0.70
110	112.14	1.95	110.51	0.46
100	101.86	1.86	100.24	0.24
90	91.48	1.64	90.01	0.01
80	80.81	1.01	79.82	-0.23
70	70.36	0.51	69.64	-0.51
60	60.65	1.08	59.46	-0.90
50	50.27	0.54	49.29	-1.42
40	40.32	0.80	40.02	0.05
30	30.28	0.93	29.8	-0.67
20	20.76	3.80	20.48	2.40
10	11.16	11.60	10.18	1.80

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