Design Report – Team 02

ELETENG209: Analogue & Digital Design

Design of a Smart Energy Monitor

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Abstract

This report describes the design, validation, and operation of a smart energy monitor with the use of an ATMega328PB capable of measuring the power utilised by an appliance using electrical hardware and firmware implementations. Some key specifications provided with this Energy Monitor were accuracy, exporting data to a remote website, and outputting measurements with Bluetooth and wired capability. The maximum absolute error 5% with a typical error of 0.75%.

Introduction

The main objective of this project was to gain valuable expertise and experience and to fulfil the course requirements of ELECTENG 209.

This Smart Energy Monitor can measure the power, peak current, RMS voltage, and total energy supplied to a load within specifications. The analogue circuitry measures, filters, and amplifies signals so they are appropriate digital processing. The microcontroller's firmware samples these signals and interpolates the resulting data to provide an accurate digital representation of the analogue input signals. Results of the completed processing can be sent to a display, smartphones via Bluetooth, and computers using a USB to Serial cable. This overall architecture is summarised in Fig. 1.

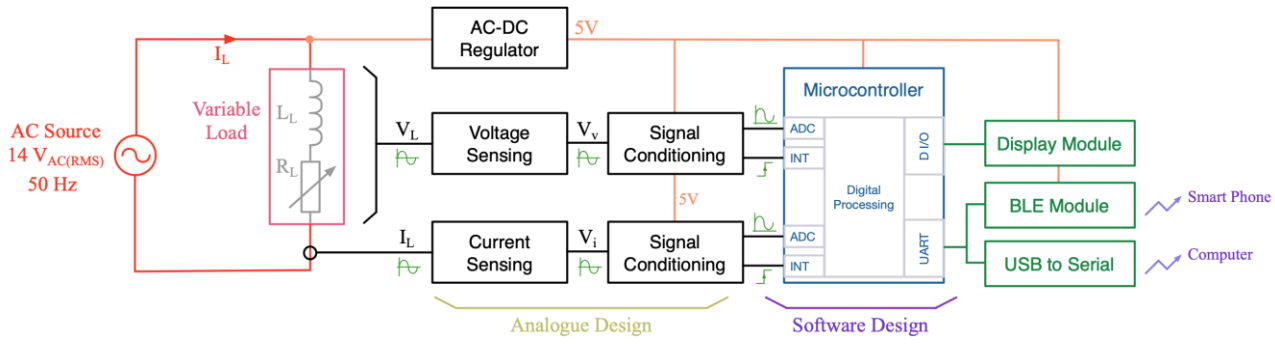


Fig. 1: A conceptual system diagram [1]

Literature Research

Table I: A Comparison of existing energy meters

Parameter	Neurio Smart Monitor [2]	Efergy Pro [3]
Operating voltage range	90 – 130V	110-300V AC
Accuracy	±1% of reading	98%
Power Consumption	< 2 W	0.2 W
Communication/Display Method	Wi-Fi, Bluetooth, wired	Wi-Fi
Peak Current	---	95 mA
Operating Temperature	0 - 65°C	0 - 35°C
Measurements	Irms, Vrms, W, X, Wh	W, Irms, Vrms, Energy (Wh)

Design Specifications

The key differences are in the communication type, operating voltage, and types of measurements. The Neurio monitor measures all the quantities this monitor can, but in addition measures reactive power (X). Efergy Pro only measures Energy. [2] The Nuerio monitor provides Wi-Fi capability in addition to the methods used by the monitor described in this report. [3]

Table II: Design Specifications

Parameter	Configuration
Source Voltage	$14V_{RMS}$ ± 10%
Source Frequency	50Hz ± 2%
Load Range	2.5VA to 7.5VA
Load Power Factor	0.75 to 0.99
Measurement Accuracy	5% of full-scale reading
ADC Conversion Rate	1kHz or slower
LCD Display Information	Voltage, current, power and energy
LCD Display Units	V_{RMS}, A_{pk}, W and W_{min}
LCD Scroll Rate	1s
UART Baud Rate	9600 Baud
Information Transferred Via UART	Voltage, Current, Power and Energy
PCB Size	200 mm^2
PCB Technology	Double layer with PTH
Device Technology	TH or SMT

The Analogue Design

The Schematic

Utilizing the most of the usable range of the ADC, the gain of the signal conditioning circuitry was increased as much as possible. This allowed the greatest input resolution to the ADC, and therefore increasing the accuracy of the sample of the input signals.

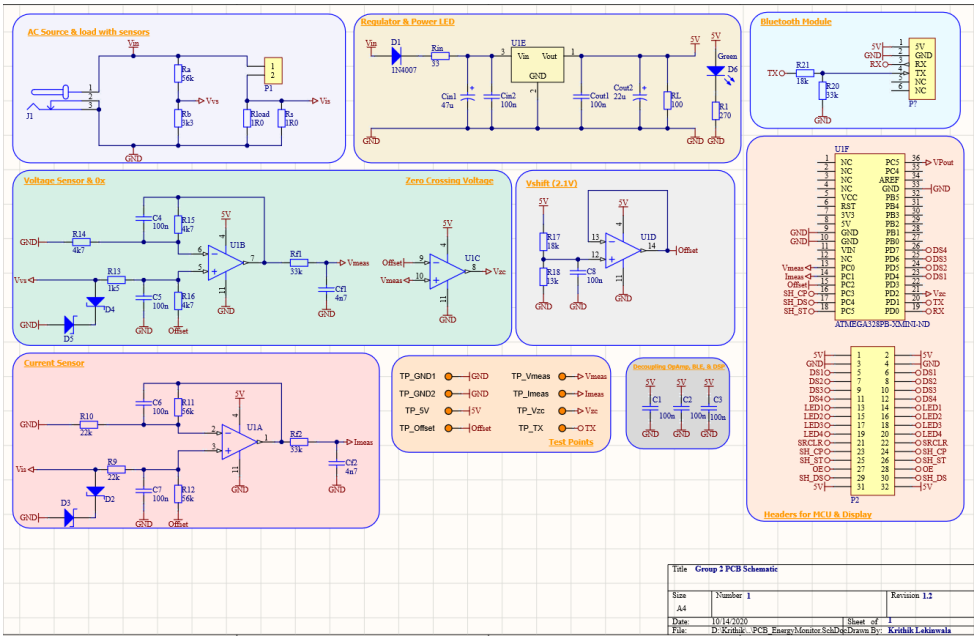


Fig. 2, Schematic of analogue circuitry

The PCB

An additional current limiting resistor has been added to the output of the linear regulator to ensure correct operation of the regulator package.

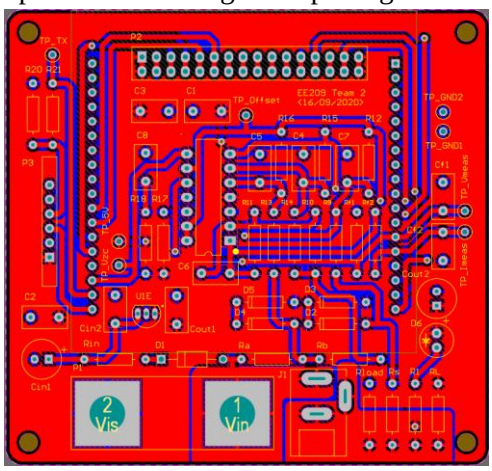


Fig. 3, 2D PCB layout

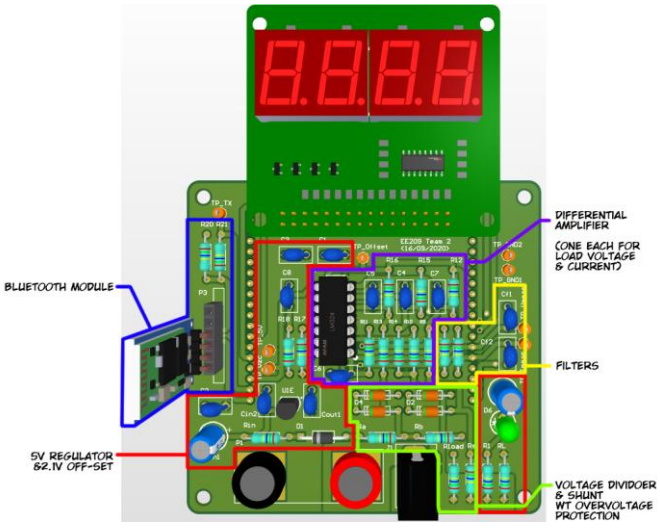


Fig. 4, 3D PCB layout

Design Validation

For naming convention refer to:
https://ee2092020class.github.io/presentations/DigitalL4/presentation.html#5.

Table III: Key design parameters

Parameter	Calculated	Simulated
G_{vs}	(3300/56000 + 3300) = 0.056	
V_{vs} when V_{AC} is 15.4 V_{rms}	0.989 V	986 mV
V_{vs} when V_{AC} is 12.6 V_{rms}	0.81 V	805 mV
G_{is}	0.56	
V_{is} when I_{AC} is 0.60 A_{rms}	0.47 V	0.446 V
V_{is} when I_{AC} is 0.16 A_{rms}	0.127 V	0.125 V
G_{vo}	(4700/4700) = 1	
V_{vo} when V_{AC} is 15.4 V_{rms}	3.09 V	3.09 V
V_{vo} when V_{AC} is 12.6 V_{rms}	2.91 V	2.91 V
G_{io}	(56000/22000) = 2.55	
V_{io} when I_{AC} is 0.60 A_{rms}	3.1 V	3.08 V
V_{io} when I_{AC} is 0.16 A_{rms}	2.37 V	2.37 V
G_{vf}	1	
V_{vf} when V_{AC} is 15.4 V_{rms}	3.32 V	3.29 V
V_{vf} when V_{AC} is 12.6 V_{rms}	3.1 V	3.08 V
G_{if}	1	
V_{if} when I_{AC} is 0.60 A_{rms}	3.31 V	3.29 V
V_{if} when I_{AC} is 0.16 A_{rms}	2.42 V	2.43 V
ΔV_{in} of 5V regulator	2.13 V	1.56 V
ΔV_{5V} of 5V regulator	0 V	0 V

The Embedded Software Design

Flowchart

The following is the flowchart representation of the program designed to run on the ATmega238PB microcontroller.

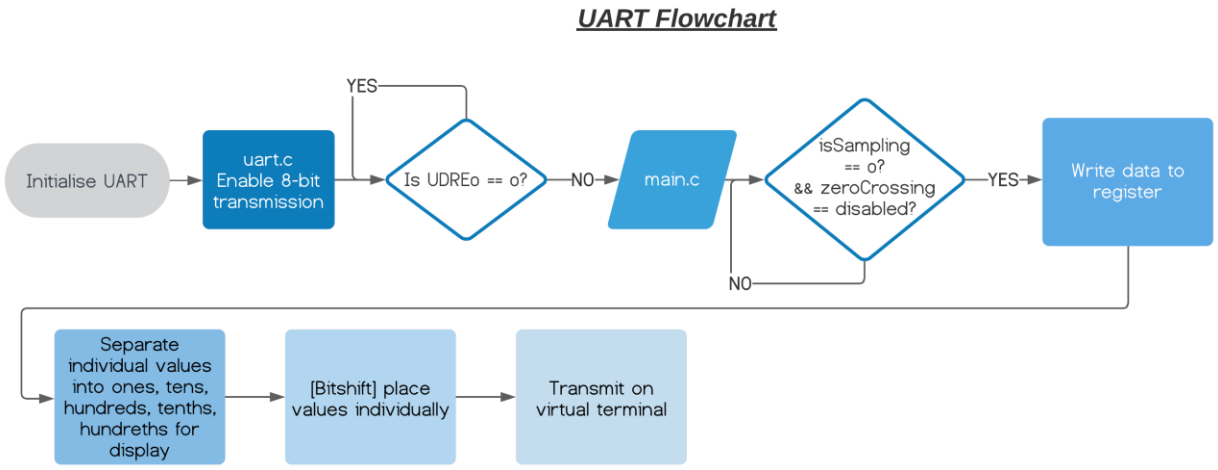


Fig. 5, Flowchart of UART firmware

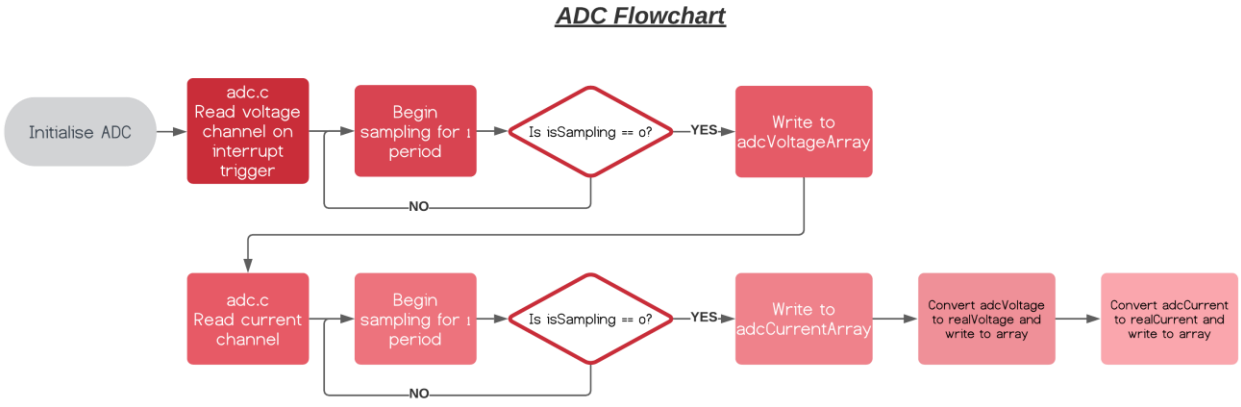


Fig. 6, Flowchart of ADC firmware

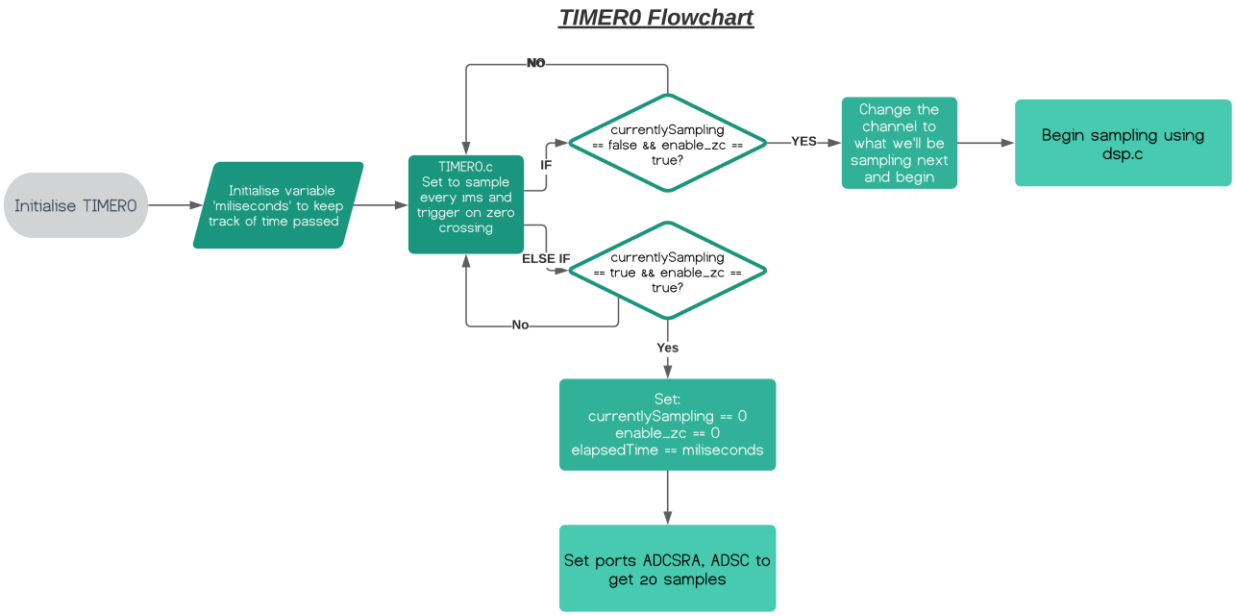


Fig. 6, Flowchart of TIMER0 firmware

In processing the samples, cubic interpolation and Simpsons rule was used to integrate points for power and RMS voltage. The cubic interpolation used was specifically chosen as the most suitable numerical integration method to accurately predict the peak values of imperfect sinusoidal waves.

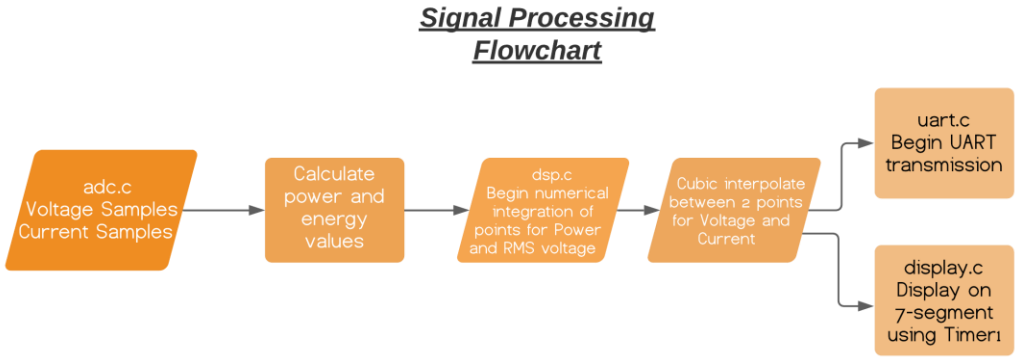


Fig. 7, Flowchart of digital signal processing firmware

Custom Print Function

A custom print function was implemented for use by the UART peripheral to reduce clutter, memory used, and to increase functionality. This function can transmit directly to the terminal by using:

print("xyz: %d %f", current, voltage)

Smart Energy Challenge

On top of this project as an extra, the values measured from Proteus such as RMS voltage, peak current, power, and energy are exported to remote website visualised as graphs in real time.

The website can be accessed through the link: https://ee209t02.herokuapp.com/

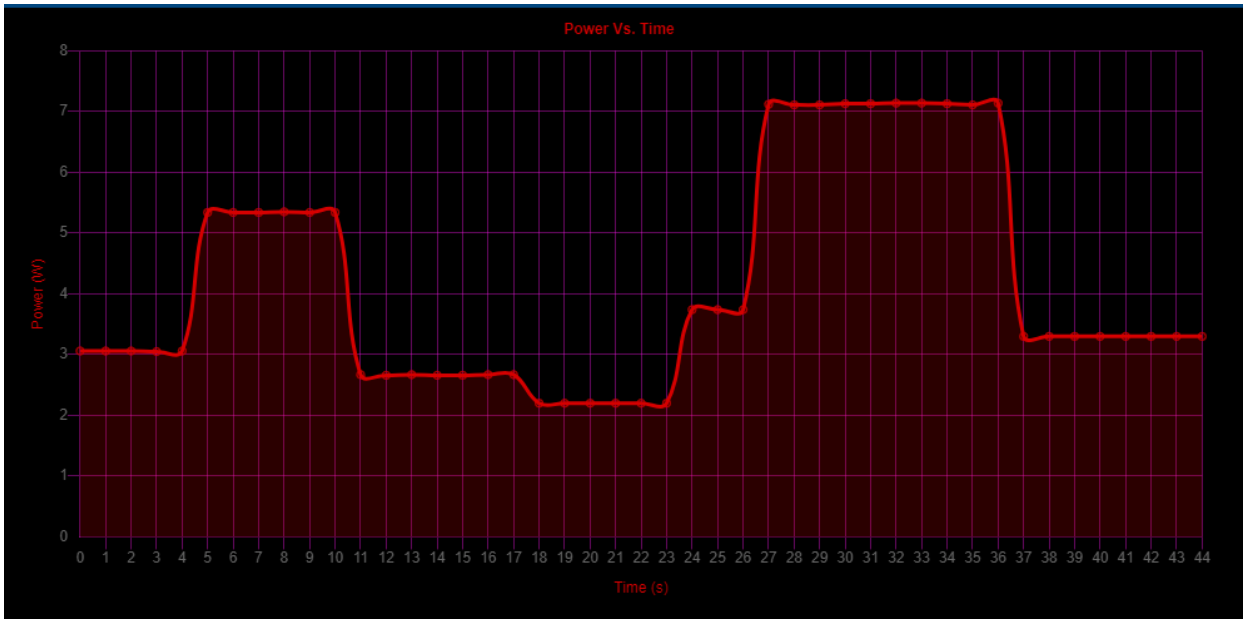


Fig. 8.1, Power vs time values exported to graph on remote website

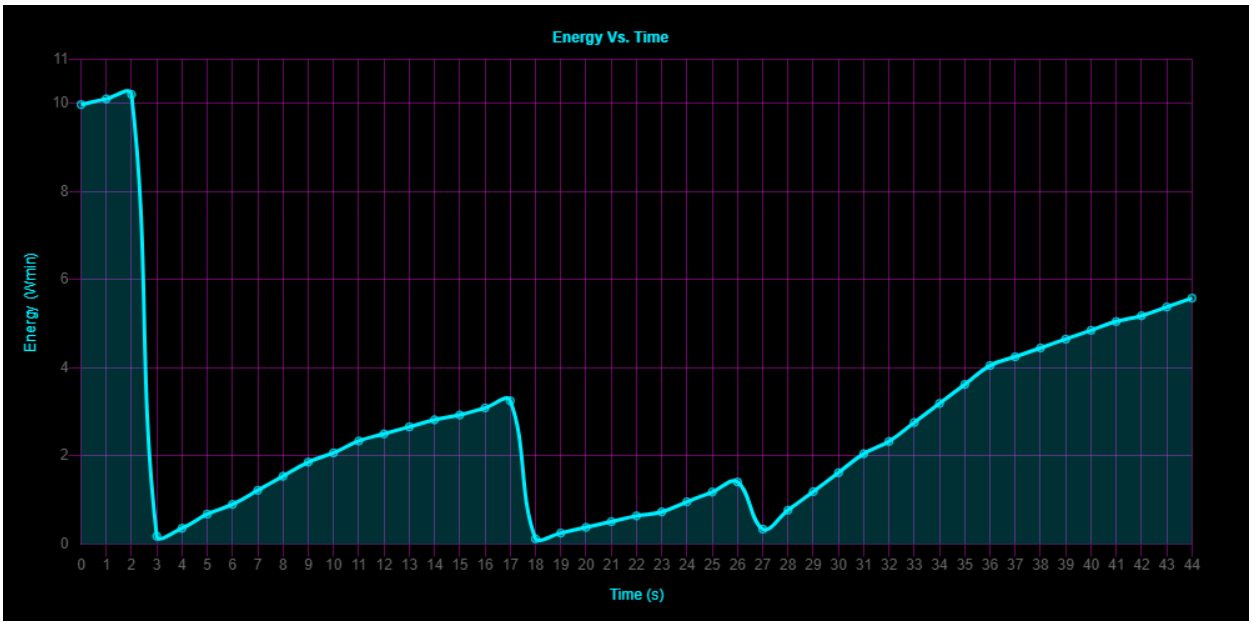


Fig. 8.2, Energy vs time values exported to graph on remote website

Peripheral Configurations

Table IV: UART configuration

Parameter	Configuration
Number of data bits	8
Number of stop bits	1
Baud rate	9600
Parity mode	None
Transmission mode	Simplex (transmit)
Transmit mode	Polling (UDRE0)
Transmit voltage	5 V

Table V: ADC configuration

Parameter	Configuration
Prescaler	4 (sim), 128 (hardware)
Timer0 ADC mode	CTC A auto trigger
ADC interrupt time	1ms
Voltage reading	ADC channel 0
Current reading	ADC channel 1
OCR0A	99 (sim), 124 (hardware)

Table VI: Display Configuration

Parameter	Configuration
7-Segment pin operation	Common Cathode
Units display	Ds4
Clock Pulse bit	SH_CP
Timer2 interrupt time	1ms
Timer2 OCR2A	99 (sim), 124 (hardware)
Timer2 display update interval	10ms
4 Display operation	Shift Register

Table VII: I/O pins

Parameter	Configuration
7 Seg Display Output	Ds1, Ds2, Ds3, Ds4 (PD4, PD5, PD6, PD7)
Reading Shift Register	SH_DS (PC4)
Toggle shift register	SH_ST (PC5)
LED toggle for testing operation	LED (PB5)

Design Validation

The zero crossing ISR (INT0) triggers every 20ms. The LED triggers as indication for when output compare match A is successful. From Fig. 8, the oscilloscope shows that the LED toggles every 20ms.

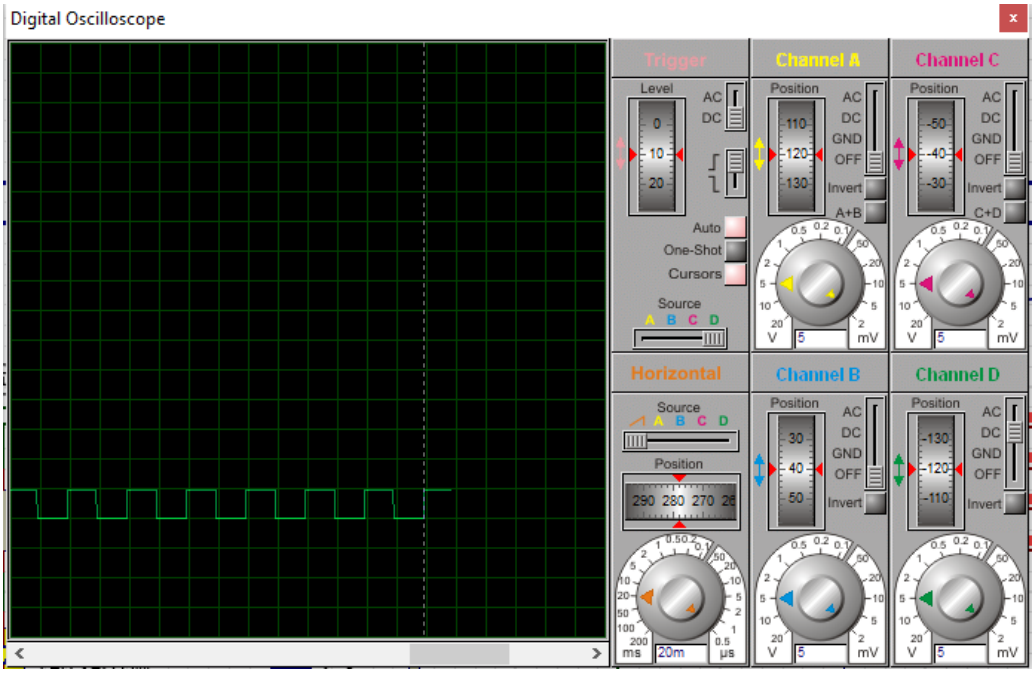


Fig. 9, Supply voltage of LED toggled by voltage zero crossing interrupt

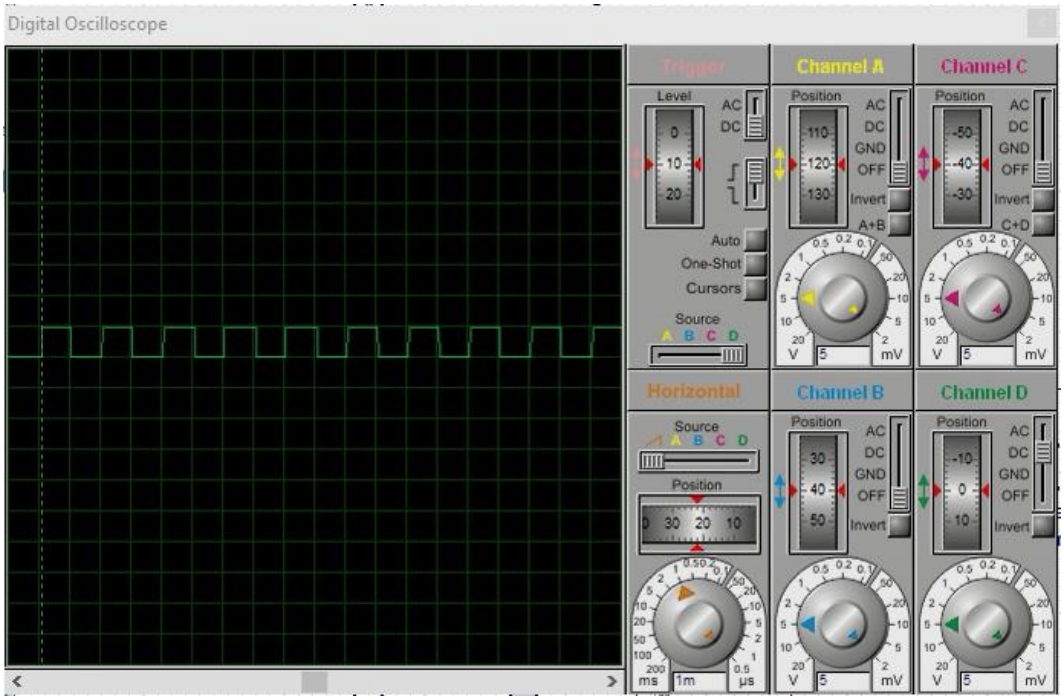


Fig. 10, Supply voltage of LED toggled by ADC complete conversion interrupt. ADC sampling ISR (ADC_vect) samples the ADC channel and toggles every 1ms.

Timer2 triggers approximately every 10.8ms. Timer2 is used to drive the refresh rate of the seven-segment display. Shown in Fig 10, the shift register clock pulse control signal (SH_CP, in yellow) is used to move data into the shift register.

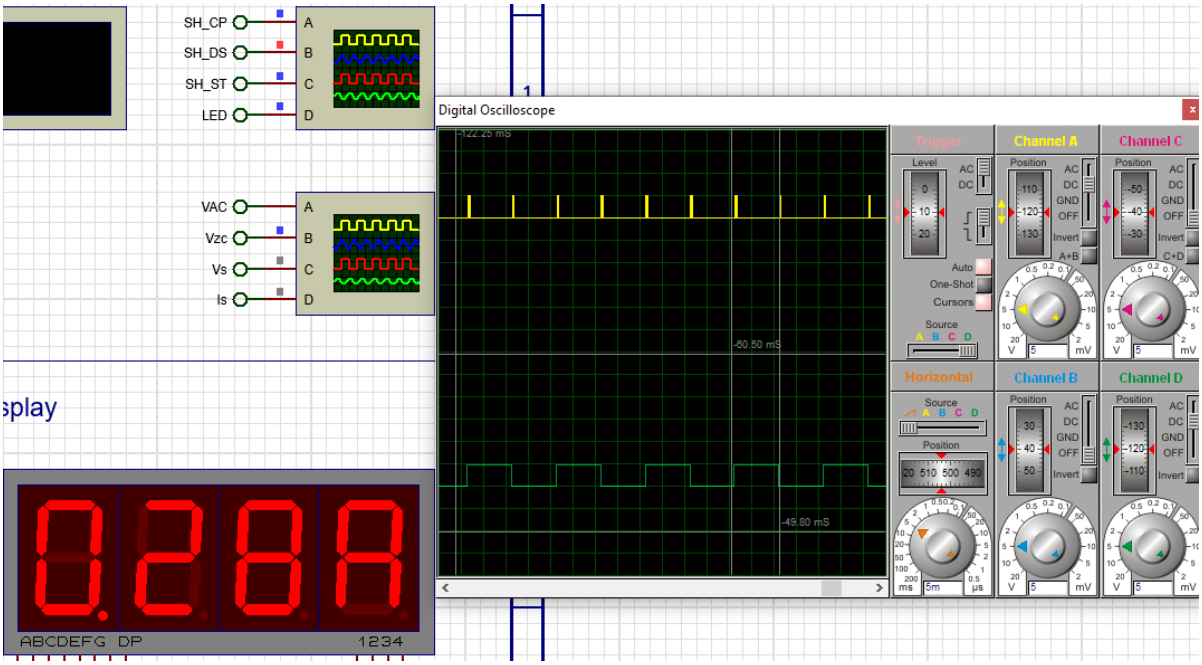
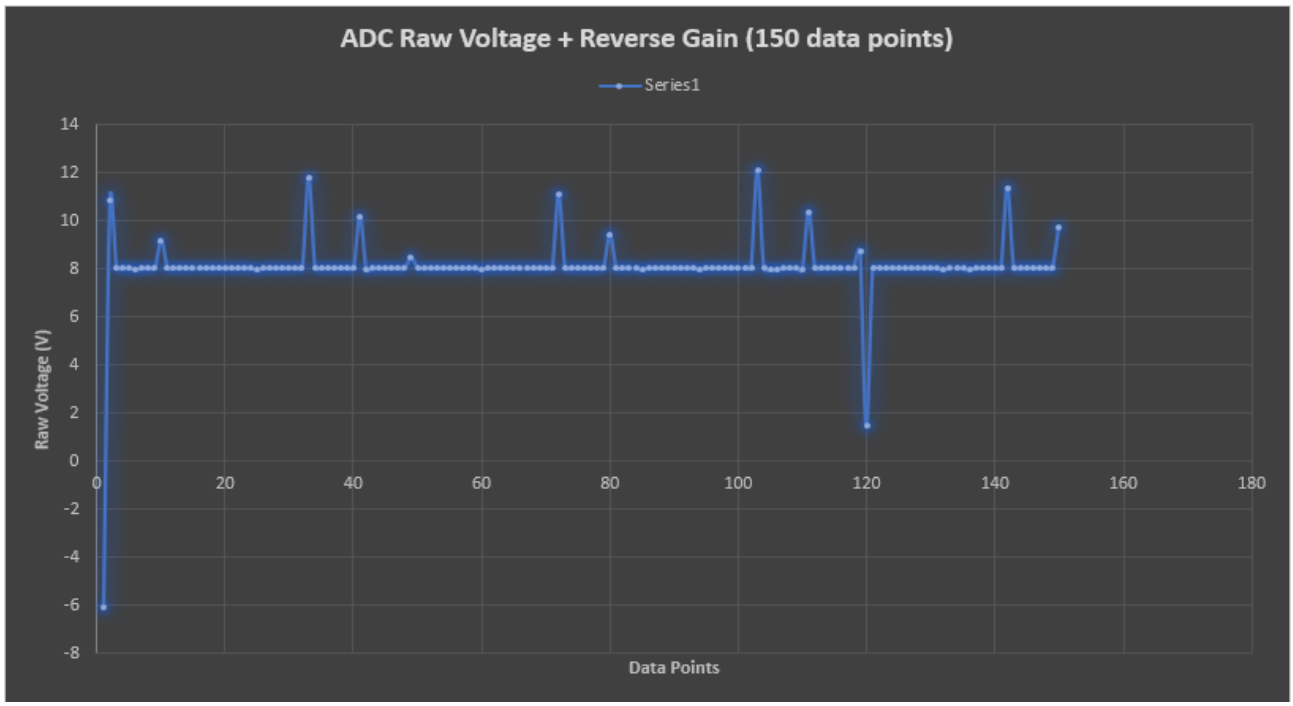


Fig. 11, Voltage supply to LED toggled by TIMER2 interrupt in green, shift register clock pulse in yellow

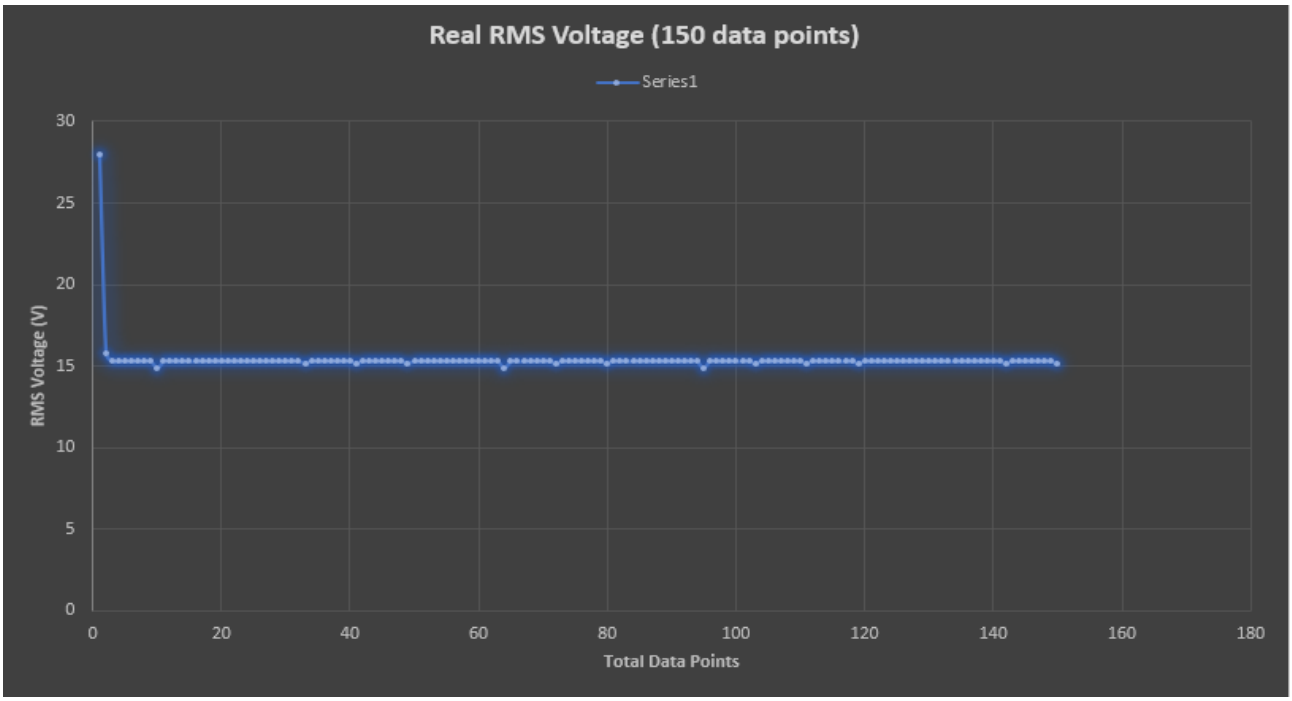
When applying a 15.4Vrms DC voltage, the ADC voltage conversion appears constant, with occational deviations.

After processing the ADC raw voltage through numerical integration and cubic interpolation, the results are more consistant. The deviation error is reduced to between 0.4-0.5mV.

BEFORE



AFTER



Performance of the Energy Monitor

Design Validation

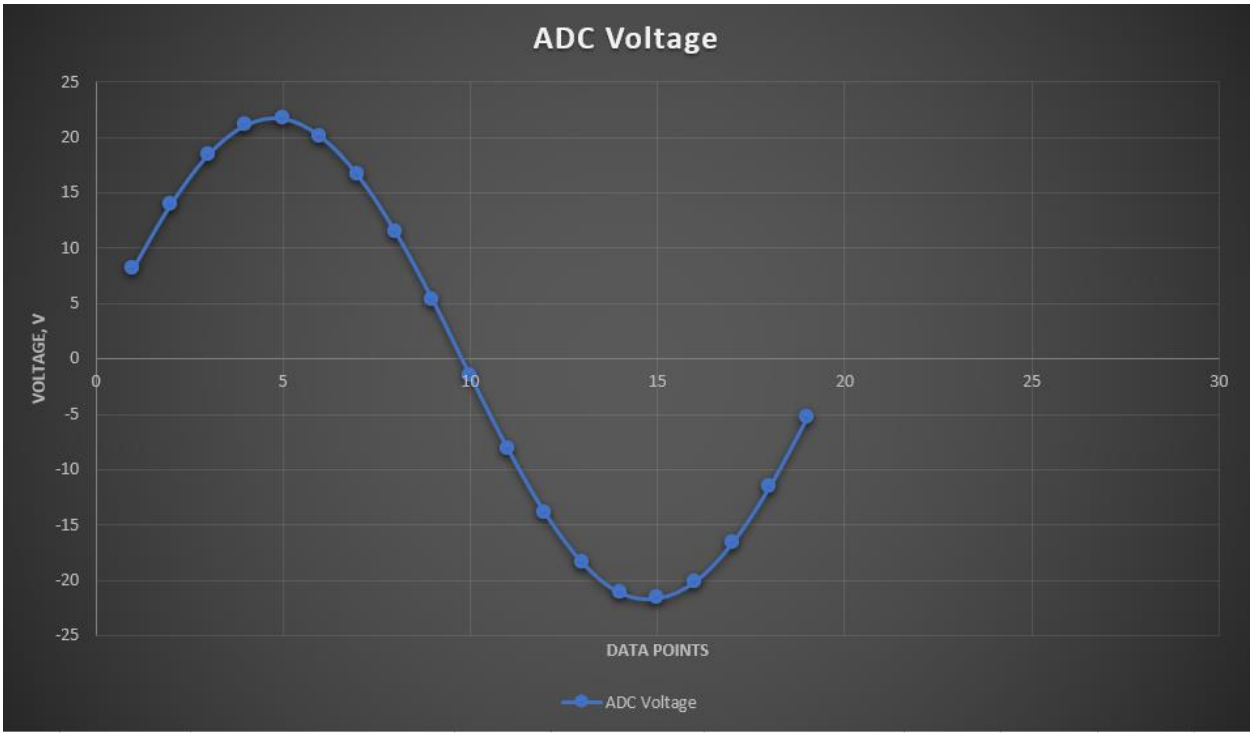


Fig. 12 One cycle of sampled and transformed voltage values

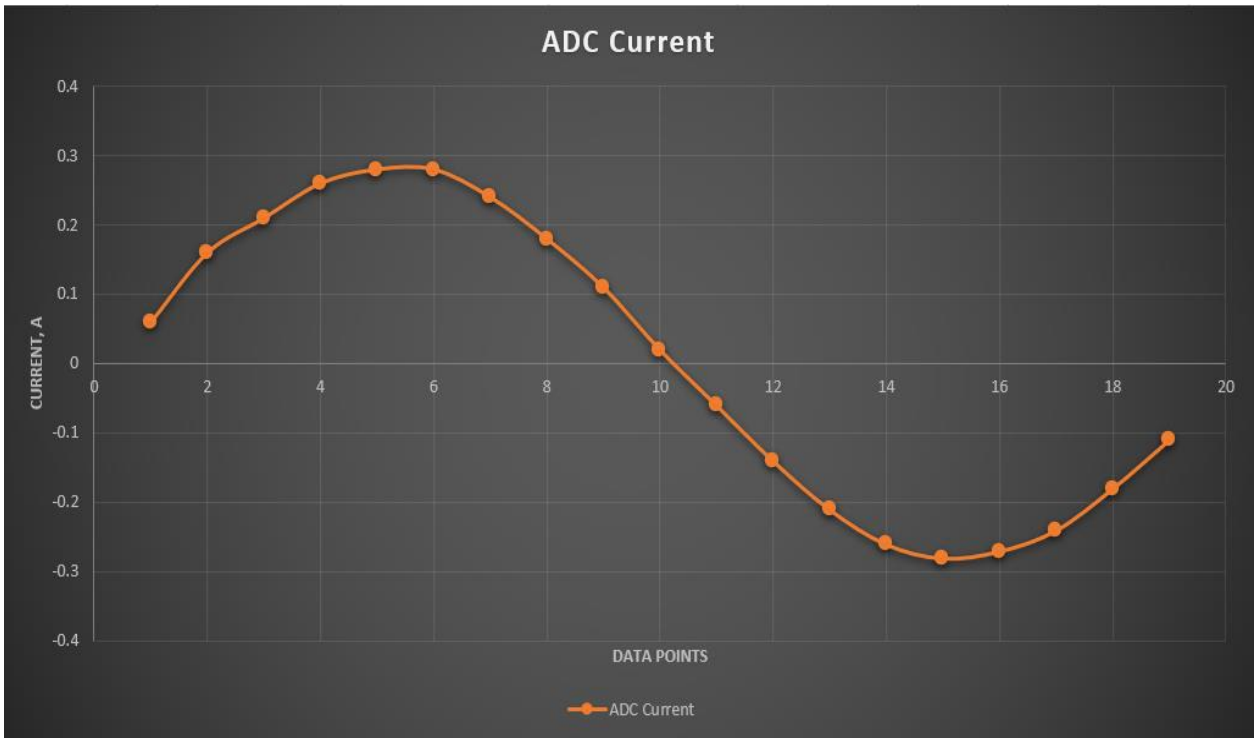


Fig. 13, One cycle of sampled and transformed current values

The Accuracy

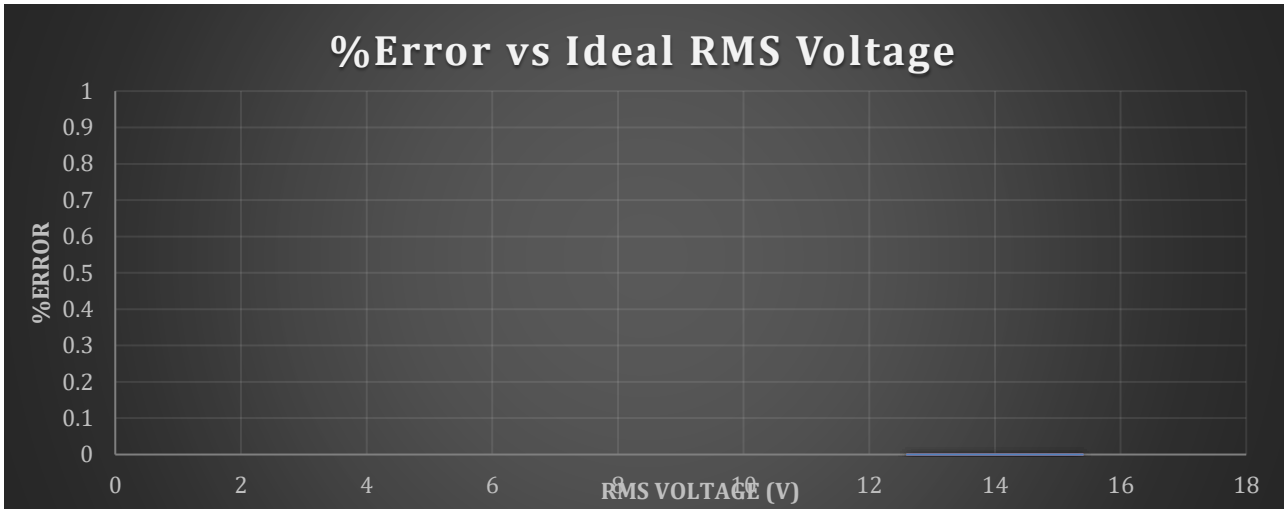


Fig. 14, Ideal Peak Current vs Error graph (most points not visible due to error being 0)

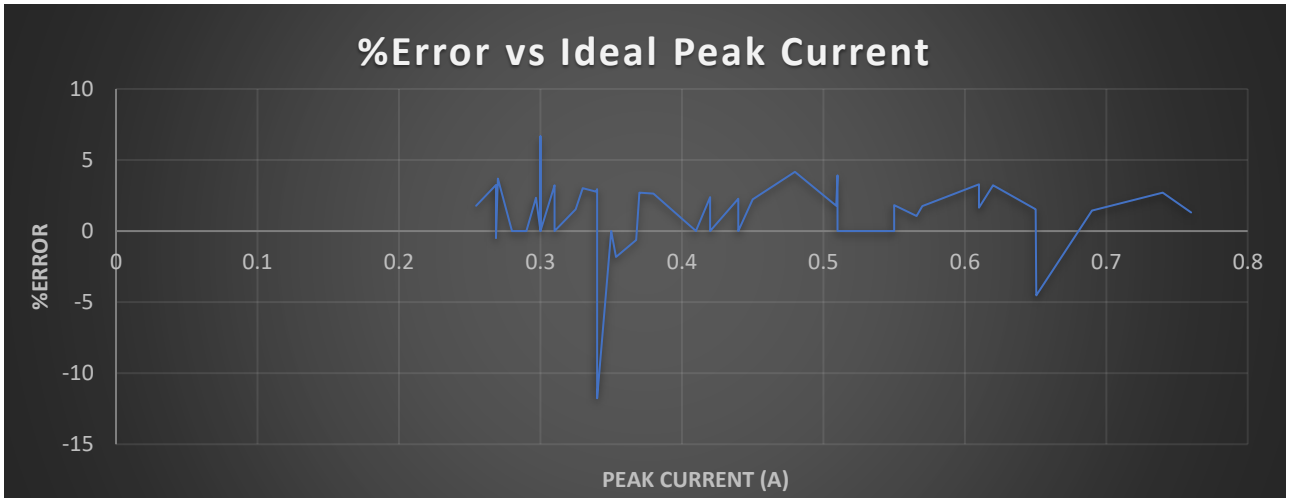


Fig. 15, Ideal RMS Voltage vs Error graph

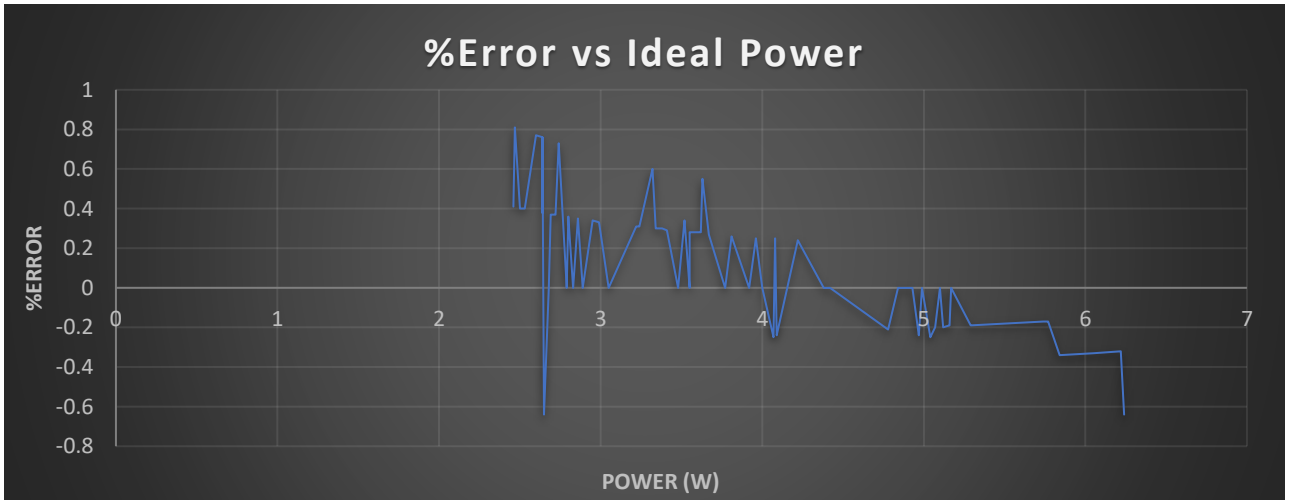


Fig. 16, Ideal Average Power vs Error graph

Conclusions

In conclusion to this Energy Monitor Project, this report discusses how the Energy Monitor operates in terms of its firmware and hardware, accuracy, workability, and comparisons to commercial grade products. The typical accuracy reached using numerical and cubic interpolation techniques was approximately 0.75%. The aim of this report was to give the reader some insight on an Energy Monitor and how it can be used in a real-world application example.

References

[1] D. J. Thrimawithana, Class Lecture, Topic: "Analogue & Embedded Software Design: An Introduction to the Course" ELECTENG 209, Department of Electrical, Computer, and Software Engineering, The University of Auckland, Auckland, October 2020.

[2] Efergy Pro Energy Monitor, https://efergy.com/efergy-pro-specs/#

[3] Neurio Home Energy Monitor Datasheet, https://www.neur.io/wp-content/uploads/Neurio_Home_Energy_Monitoring_Kit_SpecSheet.pdf

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