Journal of Mechatronics, Electrical Power, and Vehicular Technology 8 (2017) 1–10

Journal of Mechatronics, Electrical Power, and Vehicular Technology

CrossMark

e-ISSN: 2088-6985
p-ISSN: 2087-3379

www.mevjournal.com

A compact design of multi-feeder data logging system for power quality measurement with a multiplexer and a single PQ transducer

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Received 10 February 2016; received in revised form 23 December 2016; accepted 26 December 2016
Published online 31 July 2017

Abstract

This paper presents a simple and costs effective equipment design multi-feeder data logger for recording and monitoring power quality. The system design uses remote supervising and multi-feeder data logging system (RESMOS). The data collected through resmos portable unit (RMPU) will automatically be saved with the format as binary and comma separated value (CSV). The time setting on the RMPU can be configured with minimum one minute per logging. This data logger uses a single transducer with a multiplexer for recording and monitoring ten channels of power quality at busbar. The system design has been validated with national metrology laboratory scientific and industrial research institute of Malaysia (SIRIM). This tool has the advantage that it can be used to measure harmonic data more than 21st at the same time for ten channels and equipped with software making it easier for analysis data with low operational costs versus another power quality equipment. The experimental results indicate that the proposed technique can accelerate data reading with conversion rate one sample per second for each channel. The device can be used to measure harmonic level and power quality with a confidence level above 95% and percentage error under 2.43% for total harmonics distortion (THD) and 1.72% for voltage harmonics.

Keywords: harmonic; power quality; measurement; data logging; multi-feeder

I. Introduction

Traditionally, measurements are taken using a variety of measuring instruments, each of which requires a particular skill for obtaining readings. If the detailed data are needed by a certain time interval, the measurement should be repeated in the interval of time and for a very short time interval, for example, a few seconds, measurement cannot be done manually.

In the 1970's and 80's first personal computer was developed, and with the development of the personal computer, people began to use computers for data analysis, data storage, and report generation. The need to bring data into the PC is a new special-purpose device for data logging. This data must be transferred to the PC for analysis, permanent storage, and report generation. Data is typically transferred either by manually moving a storage device of the data logger to the computer or by connecting the data logger to the PC through some communications link such as serial port, USB, wireless or ethernet.

Data logging is the measurement and recording of physical or electrical parameters over a period and used to collect readings, or output, from sensors a data logger is an electronic instrument that records environmental parameters or industrial parameters such as pressure, temperature, relative humidity, solar radiation, wind speed and direction, light intensity, water level, and water quality over time. This instrument is stand-alone, box instruments that measure signals, convert to digital data, and store the data internally. Although data loggers are used in many industries from space exploration to oil refining, to drag racing, this research will be focusing on their application for power quality monitoring, especially harmonic. Typically, data loggers are compact, battery-powered devices that are equipped with microprocessor input channels and data storage. Most data loggers utilize turnkey software on a personal computer to initiate the logger and view the collected

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doi: https://dx.doi.org/10.14203/j.mev.2017.v8.1-10
2088-6985 / 2087-3379
Accreditation Number: (LIPI) 633/AU/P2MI-LIPI/03/2015 and (RISTEKDIKTI) 1/E/KPT/2015.

data. Data logger is a good option, to gather some data for the future analysis on PC.

This study developed the equipment as research product output for recording and monitoring power quality problem using remote supervising techniques and multi-feeder data logging system [1, 2]. The equipment can measure and analyze the power quality problem, particularly harmonic problem measurement and the data can be saved over long test periods and analyzed with appropriate software. We had also developed the software to support practitioners to be easy and understand the analyzing power quality problem measurement.

II. Power quality problem and harmonic measurement

Harmonic problem issue is critical and heavy impacted by power quality problem [3, 4]. It is caused by interferences that have two causes such as loads with non-linear current-voltage-characteristics and non-steady operation. Equipment to monitor or record the harmonic is necessary for practitioners in electrical products to know the harmonic problem when they are testing the prototype of electrical products.

Remote supervising technique is powerful techniques to record measurement of power quality because it can do fundamental measurement such as voltage (R, Y, B), current (R, Y, B, N), power factors (R, Y, B), and also harmonic measurement as secondary measurement such as the voltage total harmonic distortion (R, Y, B), the voltage harmonics value for odd harmonics up to 21st harmonic level (R, Y, B), and current total harmonic distortion (R, Y, B). A monitoring system for recording measurement of a power quality problem can be easy and less cost by using multi-feeder data logging system. This tool only uses a single transducer with a multiplexer to monitor from many feeders and many types of power quality measurement simultaneously. On the other hands, multi-feeder data logging system designed to operate in a harsh environment area which works like a paperless recorder, storing data in memory at a rate which is much longer than the time required for the electrical industry. It is important to understand the type of power quality problem and their measurement. Type of power quality problem can be divided into two basic categories i.e. the disturbances and steady state [5, 6]. Disturbances are measured by triggering on an abnormally in the voltage or the current. Steady state variation has normal rood mean square (RMS) voltages or the current and harmonic distortion. Measurement of power quality can be described through monitoring quality of voltage, current, power factors, and harmonic distortion [7, 8].

Harmonics are electric voltages and currents that appear on the electric power system as a result of certain kinds of electric loads [9, 10]. Harmonic frequencies in the power grid are a frequent that cause power quality problems. One of the major effects of power system harmonics is the increasing the current in the system [11]. This is particularly the case for the third harmonic, which causes a sharp increase in the zero sequence current, and therefore, increases the current in the neutral conductor. This effect can require special consideration in the design of an electric system to serve non-linear loads. In addition to the increased line current, different pieces of electrical equipment can suffer effects from harmonics on the power system.

Effect of harmonics can be divided into two categories i.e. the effect of voltage harmonics and current harmonics [5, 6, 12]. Harmonic voltages and currents in an electric power system are a result of non-linear electric loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors. The current of harmonic effect is of significance. These harmonic current components cause additional losses in the windings and other structural parts. For a transformer winding turns which consist of small strands, skin effect or the current redistribution due to internal current is usually assumed to be negligible [13, 14].

There are many measurements employed to describe the harmonic on a power system. This study used three measurements of harmonic i.e. voltage harmonic, current harmonic, and total harmonic distortion for current and voltage.

A. Voltage total harmonic distortion

A pure voltage or current sine wave has no distortion and no harmonics. Therefore, voltage total harmonic distortion (VTHD) is zero. The non-sinusoidal wave has distortion and harmonics. To quantify the distortion, the VTHD as a percentage is used to show how badly a waveform is distorted on a pure sine wave [3, 5]. Hence, VTHD is defined as below:

$$VTHD = \frac{\sqrt{\sum_{h=2}^{\infty} v_h^2}}{V_1} \tag{1}$$

$$V_{rms} = V_1\sqrt{1 + VTHD^2} \tag{2}$$

with v_h is voltage harmonic, V_1 is voltage line and V_{rms} is root mean square voltage.

B. Current total harmonic distortion

Definition of current total harmonic distortion (ITHD) is not relative similar with voltage total harmonic distortion [5, 15]. The current distorted can cause increased losses in the end-user and utility power system components. The effect is a decrease in the power factor and increases reactive power. Hence, current total harmonic distortion (ITHD) is defined as below:

$$ITHD = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \tag{3}$$

$$I_{rms} = I_1\sqrt{1 + ITHD_1^2} \tag{4}$$

with I_h is current harmonic, I_1 is current line, and I_{rms} is root mean square current.

C. The total power factor

Total power factor or true power factor can be calculated by considering the effect of harmonic in the system, as follows:

$$pf = \left(\frac{P}{V_1 I_1}\right)\left(\frac{1}{\sqrt{(1+VTHD)^2(1+ITHD)^2}}\right) \quad (5)$$

in which pf is power factor and P is power.

III. Design consideration for power quality data logger

A typical online diagram measurement of a power substation network is shown in Figure 1. The portable master unit, three phase line, and current transformer are main components in the typical online diagram measurement of power substation network. L1, L2, L3 are the three line that will be measured, and N is the neutral current. Each flow was measured using the current transformer (CT). Its compact size – the unit will fit into various types of substations or Electrical Distribution Point for both 1P/3P systems i.e. standard sub, compact and pole mounting substation, feeder-pillars, and main switchboard cabinets.

Terminate voltage signal cables that figure the crocodile clip is used tohn measure red voltage (VR), yellow voltage (VY), blue voltage (VB) phase, neutral (N), and earth (E). Terminate of voltage crocodile figured should be clipped on the bus bar that has three voltage phases i.e. red, yellow, blue voltage phase, and also in earth (E) and neutral (N). This determination process is actually reversible of the termination process meaning that the operation must determinate neutral N followed by earth E and each phase (VR, VY, VB). After the terminating process completed, the user must switch two CPU switches such as transducer TX and auxiliary AUX switch. The rebooting system needed 10-15 seconds, and the system will run default setting of software. The user can change program setting and active channel by connection two RS-232 cables to communication board system and notebook and run the program of terminal communication. Most PC or notebook has 2 COM port which serial RS232 communication compatible.

The commonly use setting to establish a serial RS232 communication is 9600 baud rate, none parity 8 data bits, and 1 stop bit [1, 2]. As this project relates with data collection, thus the data obtained from the transducer needs to be collected and saved. This can be done by using the graphical user interface (GUI) monitoring system where it automatically saves the data received in a comma separated values (CSV) file.

A. Motherboard and daughterboard design

To reduce the footprint size of the multiplexer, a concept of motherboard and daughterboard is used as shown in Figure 2. The figure also illustrates the method of assembly of the system which is by using a stacked implementation approach.

1) Double-wide motherboard (DW motherboard)

The DW motherboard only allows phase current passing through itself, but the phase voltage is monitored directly by the voltage sensor. The phase current and phase voltage have to pass through the multiplexer before being captured by the transducer. The neutral current can only be monitored if the DW Daughterboard is stack in the DW Motherboard.

2) Double-wide daughterboard (DW daughterboard)

The DW Daughterboard is designed just to monitor the neutral current to all feeders (2 Incoming and 8 Outgoing). The Daughterboard design concept allows the inclusion of additional relays to enable the monitoring of neutral current to all feeders without having to increase the footprint size of the system unit. The DW Daughterboard size is smaller than the DW Motherboard because the number (quantity) of the DS2Y relays type on the daughterboard is 12 pieces, while DW Motherboard has 30 DS2Y relays. This board can activate only if it is stacked on the motherboard because the DW Motherboard controls the entire channel in the DW Daughterboard.

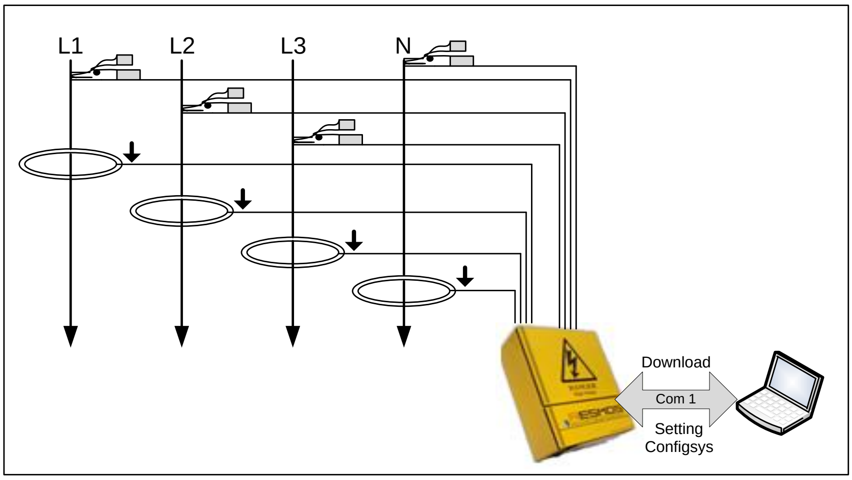

Figure 1. Typical online diagram measurement of a substation network

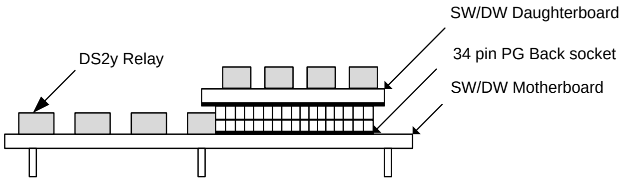

Figure 2. Stack design motherboard

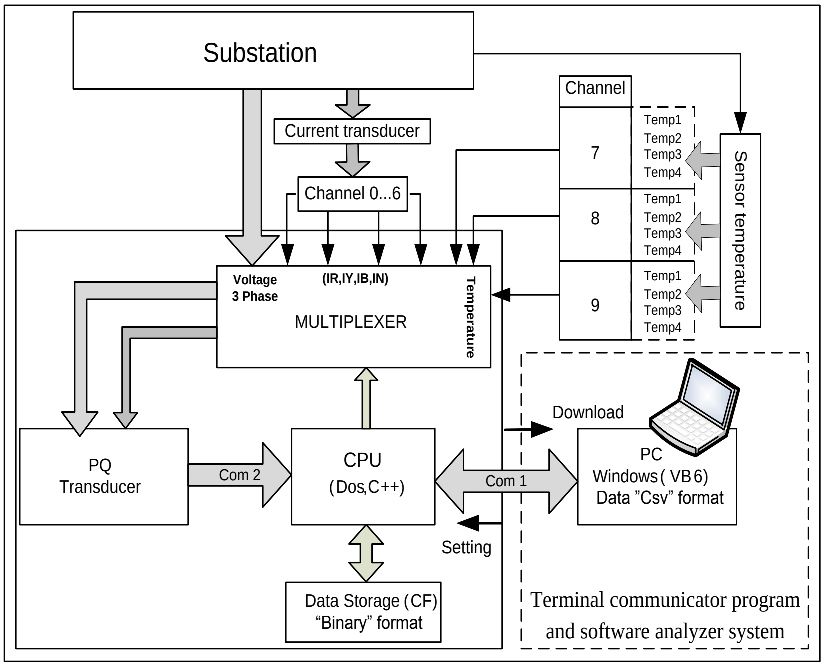

Figure 3. Remote supervising technique communicator

B. Transducer specification

The power transducer CT1700 is an instrument that measures, calculates, and displays all main electrical parameters at any electrical network (balanced or not). The measuring is true RMS value, through three AC voltage inputs 240V and three AC current inputs (from Current Transformers 100/5A). It is featured by its high measuring accuracy and easy assembly mode. It can be integrated into a communication network through its built-in-RS232 output by just using Modbus standard protocol.

C. Remote supervising techniques

The remote supervising technique is a tool to measure and monitor the power quality in distribution. Figure 3 depicted the relationship between remote sensing than the power distribution and power system.

Remote supervising has three components i.e. portable master unit (RMPU), terminal communicator program and software analyzer system. RMPU equipment is designed as a portable unit for easy handling, transportation, and installation. The function of the transducer CT 1700 is converting the electrical signal to digital signal. The communicator program enables the technician to communicate with the RMPU. It can run on a notebook or desktop PC. Analyzer software is a fundamental component that is used to record among measurement of power quality.

The analyzer program runs through Windows 95/98/Xp/win7 operating platform. It maintains the substation database containing monitored data such as line current, line voltage, neutral current, phase angle, power factor, active power, reactive power, apparent power, and substation configuration. Computerized electrical load monitoring and data acquisition system for general power industry application divided into three major modules namely display, data record, and software general specifications.

1) Display

The display form of the data logger is to view the measurement data that are being recorded. The display function can view live data and historical data. Live data display to view data as it is being acquired and many stand-alone data loggers have a live data display integrated into the box with them. Historical data display data that was previously acquired. Most stand-alone data loggers are required to move data to a PC for historical viewing. With PC-based data logging applications, both live display and historical display are combined into the same user interface. Figure 4 shows an example of data displayed the total harmonic distortion for voltage with the available software analyzer, and Figure 5 shows the harmonic spectrum for current. Figure 6 shows the view on the screen of data logger under DOS using C++ direct from RMPU at the offline condition.

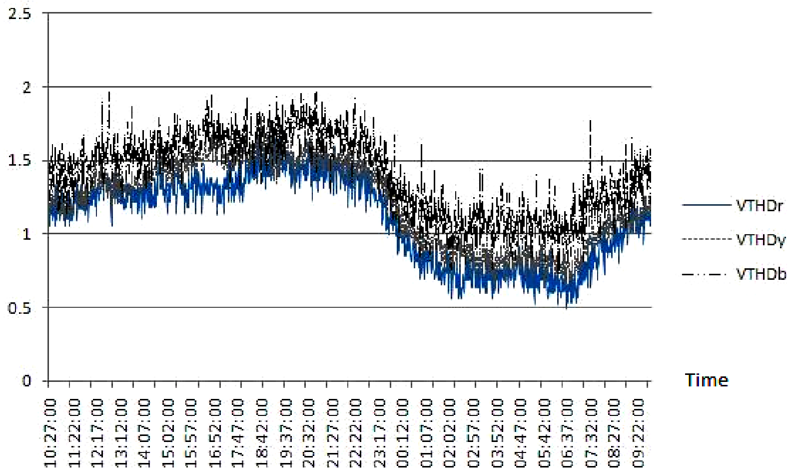

Figure 4. Graphic view on screen for voltage THD

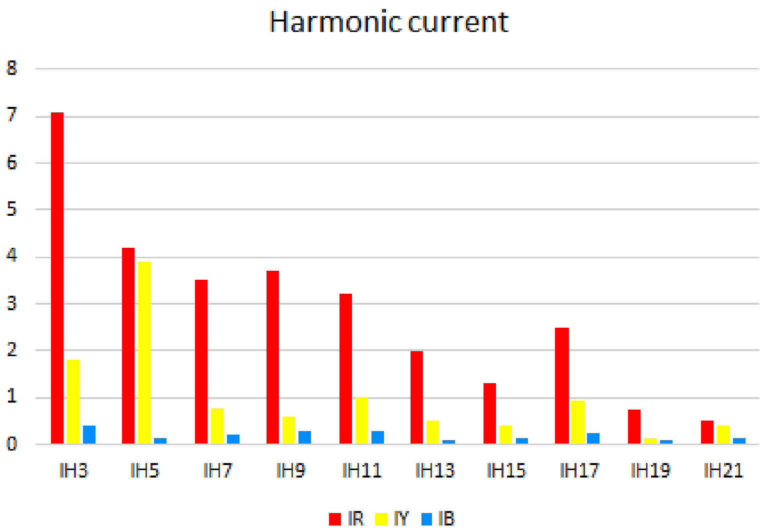

Figure 5. Graphic view on screen harmonic current

Table 1.
Software general developed

Description	Operation System	Communicator
Development Tools	Borland C++	MS Visual basic 6.0
Operating Platform	MS-DOS	MS Windows (95/98/ME/XP,win7)
Site/Location	Substation	Substation
Brief Functional Specifications	• Control data flow • Format the structure of data • Log Date & Time • Log Voltage (Red, Yellow, Blue) • Log Current (Red, Yellow, Blue, Neutral) Log Power Factor(Red, Yellow, Blue)	• Allow configuration to be made to RMPU through Windows environment • Allow data to be stored to a notebook before transferring to end user database • Download & Save data as 1. CSV (*.csv) 2. Binary (*.bin)

2) Data record

Each data collected through RMPU will automatically be formatted both as binary and comma separated value (CSV). This CSV format is purposely for viewing in Microsoft Excel. Microsoft Excel can be used to copy and paste the data operations. The time setting on the RMPU can be configured with set the minimum one minute per logging. Software analyzer can take the data from the database while communicator can download the data from RMPU to store and transfer them to the database server. Finally, software analyzer will be used to convert data into a database.

3) Software general specifications

Table 1 describes the specification of software general developed that are detailed by description, type of OS/RMPU, communication software, and analyzer software. Analyzer program supports harmonic data, for instance, VTHD, voltage

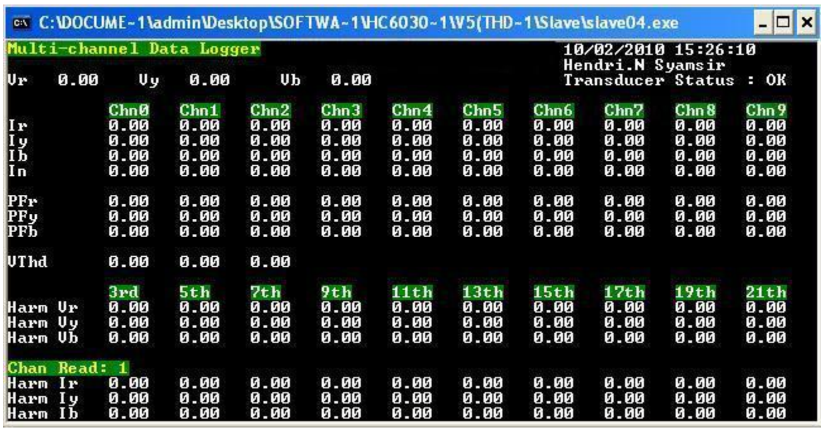

Figure 6. View on screen data logger under DOS using C++ direct from RMPU at offline condition

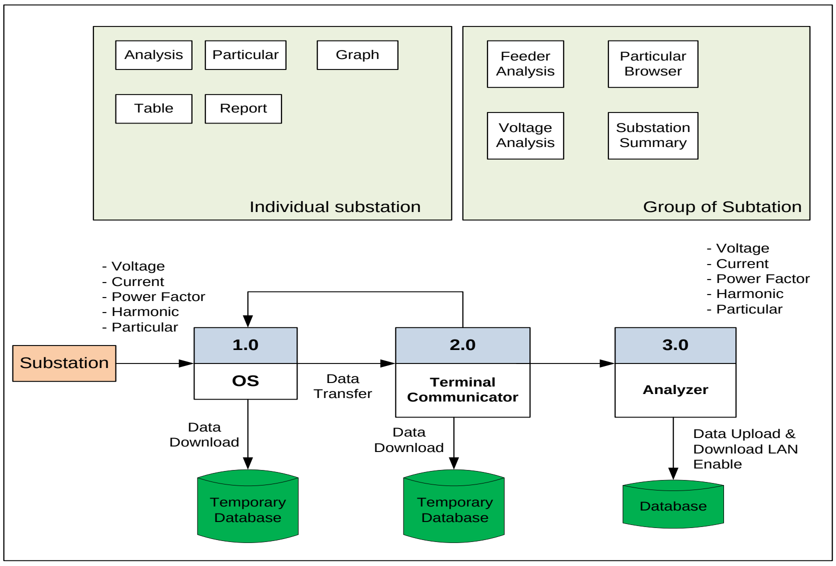

Figure 7. System and data flow diagram

Table 2.
Total channel, phase, and level for each type of harmonic

Type of harmonic	Phase	Channel (Feeder)	Level
Harmonic current	R, Y, B	10 Channel	21 (odd level)
Harmonic voltage	R, Y, B	-	21 (odd level)
Current THD	R, Y, B	10 Channel	-
Voltage THD	R, Y, B	-	-

harmonics, ITHD, and current harmonic. There would be dramatically changed to the database regarding size, the data stored, and the definitions of the table. Figure 7 shows the system and data flow diagram. Four types of harmonic value identified to be used in Software Analyzer database are:

1. Harmonic current
2. Harmonic voltage
3. Current THD
4. Voltage THD

Table 2 describes phase, channel (feeder), and level for each harmonic. The total database table for harmonic value is 363, such as the following calculation. The complete calculation of this total database table for harmonic value is expressed in equation (6) to equation (10).

$$\text{THC} = Phase\ x\ Channel\ x\ Level \quad (6)$$

$$\text{THV} = Phase\ x\ Level \quad (7)$$

$$\text{TCTHD} = Phase\ x\ Channel \quad (8)$$

$$\text{TVTHD} = Phase \quad (9)$$

$$\text{TDT} = THC + THV + TCTHD + TVTHD \quad (10)$$

where THC is total harmonic current, THV is total harmonic voltage, TCTHD is total current THD , TVTHD is total voltage THD, and TDT is total database table for harmonic.

IV. Data logging and result

This logger is used to log the harmonic data at three different types of loads which are industrial, residential, and office building. The data was logged for one day with an interval time of one minute. From the formatted data in binary and comma separated value (CSV), then the data transfer to Excel format. In this format, the spectrum of harmonic and a trend of total harmonic distortion over time was plotted. Figure 8, Figure 9, and Figure 10 show the current harmonic spectrum for the residential, commercial, and industrial building. The total harmonic distortions for residential are 15.02%, 4.77%, and 0.93%, commercial are 3.6%, 3.02%, and 3.52% and industrial are 8.52%, 7.78%, and 7.45% for phase R, Y, and B respectively.

V. Result and discussion

Table 3 and Table 4 describe Certificate of Calibration National Metrology Laboratory by SIRIM Malaysia for each phase. Refer to statistic calculation it is found that the confidence level meets the requirement of the national standard by SIRIM. It shows that the data are valid with the confidence level above 95%.

This data logger was compared with Power Quality Analyzer Fluke 435. The data were taken from three different locations. The comparison data is shown in Table 5, Table 6, and Table 7.

Figure 11, Figure 12, and Figure 13 show the graph of percent harmonic current number three for phase R, Y, and B respectively. The comparable data sets agree on each other.

Table 3.
Certificate of calibration national metrology laboratory by SIRIM for voltage harmonic fundamental: 50 Hz, 240 V

Harmonic no	Error (%)			*Uncertainty ± (%)		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
3	0.24	0.18	0.22	0.14	0.04	0.10
5	-1.07	-1.24	-1.48	0.03	0.11	0.14
7	-0.95	-1.09	-1.82	0.03	0.11	0.14
9	-0.83	-0.02	-1.83	0.03	0.05	0.11
11	-0.71	-1.01	-2.20	0.03	0.14	0.17
13	-0.92	-0.96	-2.60	0.12	0.14	0.18
15	-0.84	-0.86	-2.62	0.2	0.13	0.14
17	-0.72	-0.79	-2.26	0.15	0.17	0.17
19	-0.69	-0.57	-1.71	0.17	0.15	0.15
21	-0.37	-0.5	-0.83	0.15	0.16	0.18
THD	0.12	0.12	-2.33	0.18	0.11	0.19

*Coverage factor, k = 2 at 95% confidence level

Table 4.
Certificate of calibration national metrology laboratory by SIRIM for current Harmonic fundamental: 50 Hz, 5 A

Harmonic no	Error (%)			*Uncertainty ± (%)		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
3	-0.05	-0.05	-0.06	0.08	0.05	0.06
5	-0.05	-0.06	-0.21	0.05	0.08	0.11
7	-0.07	-0.06	-0.80	0.07	0.13	0.09
9	-0.08	-0.16	-1.29	0.09	0.08	0.08
11	-0.08	-0.18	-1.69	0.05	0.06	0.14
13	-0.07	-0.19	-1.72	0.06	0.06	0.06
15	-0.09	-0.16	-1.54	0.21	0.08	0.06
17	-0.12	-0.13	-1.38	0.11	0.08	0.06
19	-0.17	-0.16	-1.07	0.19	0.12	0.11
21	-0.13	-0.14	-1.40	0.18	0.13	0.17
THD	-0.31	-0.25	-2.43	0.14	0.12	0.15

*Coverage factor, k = 2 at 95% confidence level

Table 5.
Harmonic current data of Resmos and Fluke 435 for case 1

Harmonic no	RESMOS			FLUKE 435		
	IR	IY	IB	IR	IY	IB
3	1.14	4.7	4.95	1.12	4.65	4.92
5	4.02	3.31	4.27	3.97	3.3	4.25
7	2.39	2.08	3.41	2.37	2.07	3.39
9	0.45	0.91	0.13	0.41	0.89	0.1

Table 6.
Harmonic current data of Resmos and Fluke 435 for case 2

Harmonic no.	RESMOS			FLUKE 435		
	IR	IY	IB	IR	IY	IB
3	1.45	1.4	1.95	1.44	1.39	1.94
5	0.43	1.81	1.45	0.42	1.79	1.42
7	2.18	2.08	2.73	2.1	2.07	2.67
9	0.88	1.05	1.08	0.86	1.04	1.07

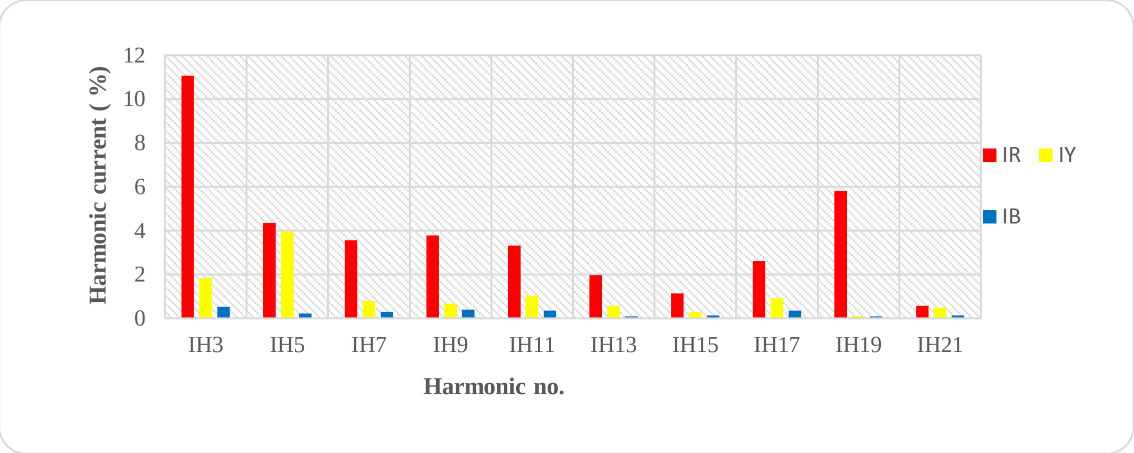

Figure 8. Current harmonic spectrum for residential load

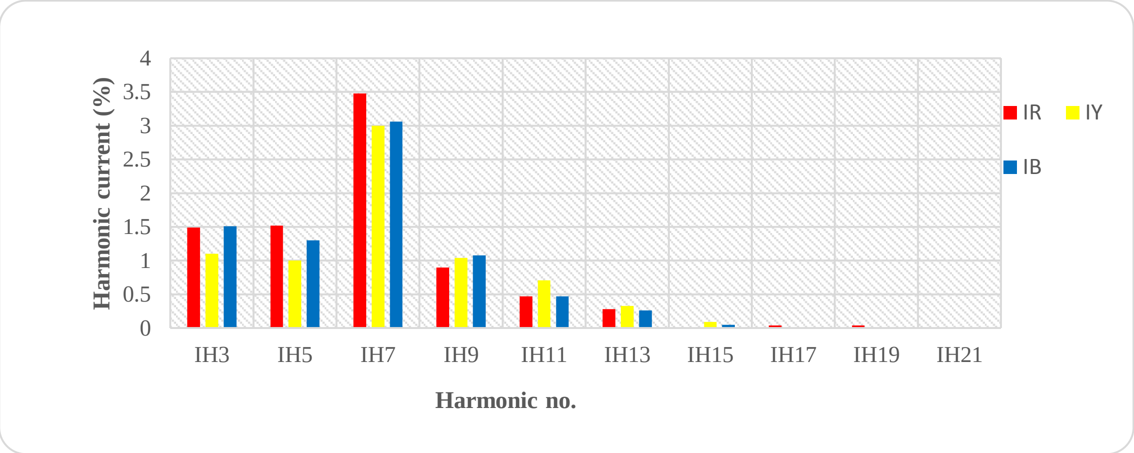

Figure 9. Current harmonic spectrum for commercial load

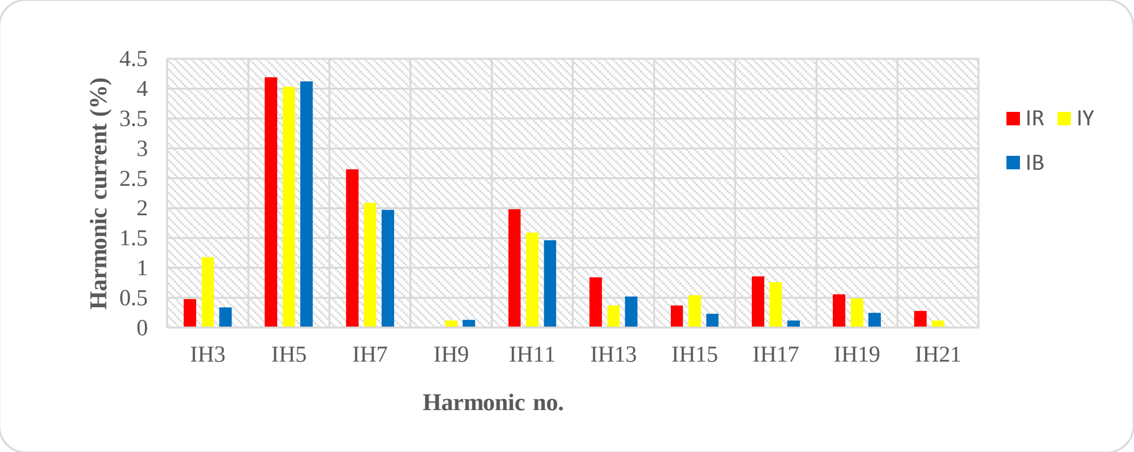

Figure 10. Current harmonic spectrum for industrial load

Table 7.
Harmonic current data of Resmos and Fluke 435 for case 3

Harmonic no.	RESMOS			FLUKE 435		
	IR	IY	IB	IR	IY	IB
3	1.12	1.23	1.28	1.05	1.22	1.25
5	2.89	1.18	1.81	2.8	1.17	1.59
7	4.59	1.48	5.69	4.09	1.46	5.11
9	1.12	1.21	1.38	1.05	1.19	1.24

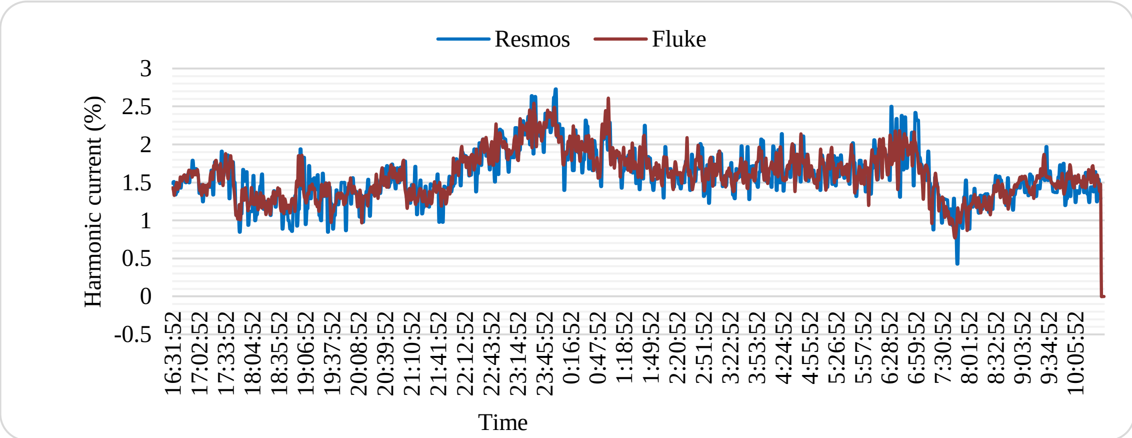

Figure 11. Comparison data IH3R Resmos and Fluke

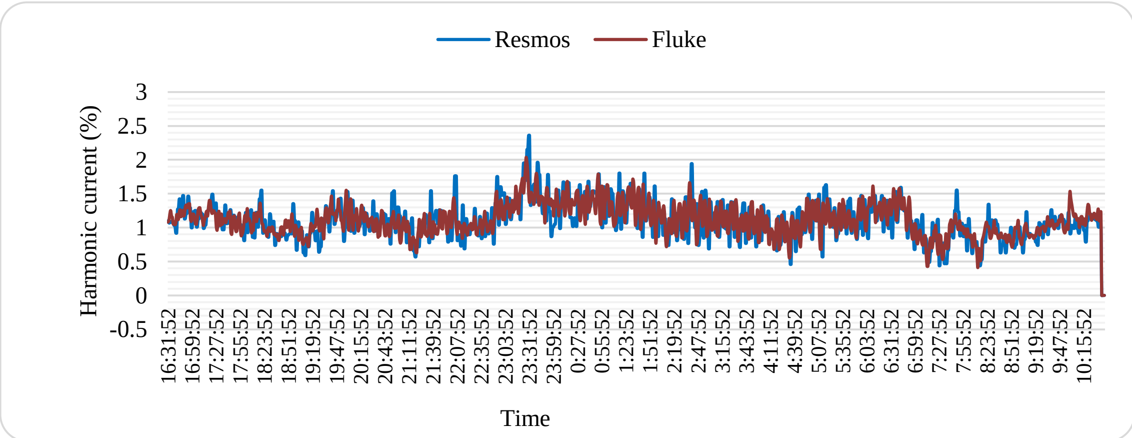

Figure 12. Comparison data IH3Y Resmos and Fluke

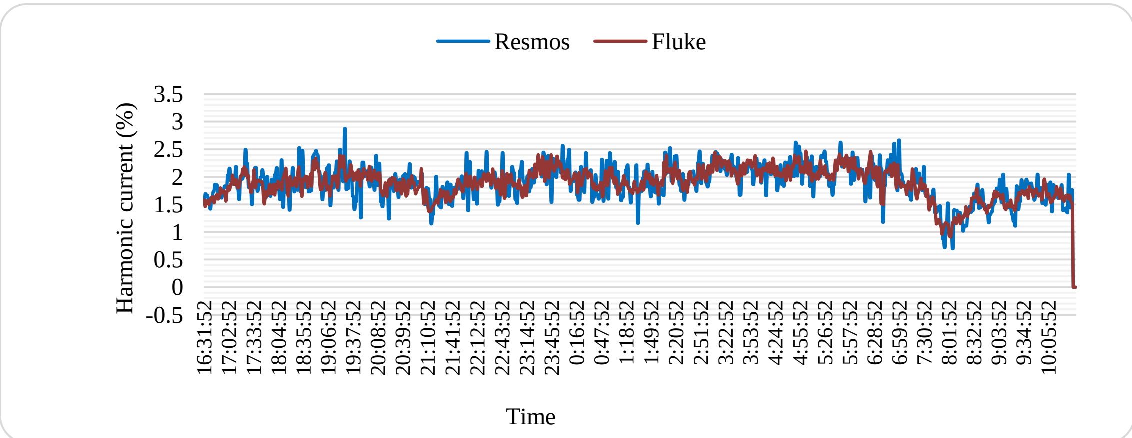

Figure 13. Comparison data IH3B Resmos and Fluke

VI. Conclusions

PC-based data logging systems provide the most customizations, flexibility, and scalable data logging solutions to meet numerous challenges. The device can be used to measure harmonic level and power quality with a confidence level above 95% and percentage error under 2.43% for THD and 1.72% for voltage harmonics. Considered the comparison data sets, particularly the current harmonic data, the data agree on each other. The advantage of this tool can be used to measure power quality at the same time for ten channels and equipped with software making it easier for data analysis with low operational costs versus power quality equipment. For data storage, the binary data format in RTU allows storage of data can be done more because of the use operating system under DOS.

Acknowledgement

The authors gratefully acknowledgement to the Centre of Electrical Energy Systems, University Technology Malaysia, and the Dataran Berlian Sdn.Bhd for the financial support.

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