ACTA IMEKO
ISSN: 2221-870X
March 2023, Volume 12, Number 1, 1 - 9

Real-time power quality measurement audit of government building – A case study in compliance with IEEE 1159

D. V. N. Ananth[1], Naeem Hannoon[2], Mohamed Shahriman Bin Mohamed Yunus[3], Mohd Hanif Bin Jamaludin[3], V. V. S. S. Sameer Charavarthy[4], P. S. R. Chowdary[4]

[1] *Department of Electrical and Electronics Engineering, Raghu Institute of Technology, Visakhapatnam-531162, Andhra Pradesh, India*
[2] *Faculty of Electrical Engineering, UiTM, 40450 Shah Alam, Malaysia*
[3] *Centre of Excellent for Engineering & Technology, Melaka, Malaysia*
[4] *Department of Electronics and Communication Engineering, Raghu Institute of Technology, Visakhapatnam-531162, Andhra Pradesh, India*

ABSTRACT
Power Quality (PQ) measurements and auditing play a vital role for smart grid applications, industrial safety and reliability. The major electrical PQ characteristics and parameters, like Voltage Sags/Swells, Harmonic Distortion, Voltage Unbalance, Voltage Variation & Flicker, and Supply Interruptions, are studied with the aim of maintaining the international or national standards. The electrical characteristics are studied and analyzed for single-phase and poly-phase systems in this IEEE 1159 recommended practice. The significant PQ constraints and parameters, like electromagnetic interference phenomenon deviation from the regular operation due to load equipment or source to load interaction, are described. Further, it is discussed PQ different monitoring devices, roles, and applications. In this paper, power quality monitoring of the equipment using FLUKE instrument and accessories to identify the equipment performance, audit, PQ issues are discussed practically for a two-panel boards switchgear equipment as a case study in Malaysia. Here, trends in voltage and current changes with current imbalances were observed on 1st May 2019 morning 8'o clock and on 7th May 2019 evening at 9'0 clock.

Section: RESEARCH PAPER

Keywords: IEEE 1159 compliance; power quality measurement; switchgear; Fluke device; FACTS devices; custom-power devices; power auditing

Citation: D. V. N. Ananth, Naeem Hannoon, Mohamed Shahriman Bin Mohamed Yunus, Mohamed Hanif B. Jamaaludin, V. V. S. S. Sameer Charavarthy, P. S. R. Chowdary, Real-time power quality measurement audit of government building – A case study in compliance, Acta IMEKO, vol. 12, no. 1, article 21, March 2023, identifier: IMEKO-ACTA-12 (2023)-01-21

Section Editor: Francesco Lamonaca, University of Calabria, Italy

Received May 2, 2022; **In final form** February 7, 2023; **Published** March 2023

Corresponding author: D. V. N. Ananth, e-mail: dvnananth1@gmail.com

1. INTRODUCTION

The power quality (PQ) plays a vital role in utility systems, with emphasis on *a)* Continuity deliver power supply, and *b)* Quality or purity of voltage [1], [2]. This PQ can be defined as the problem taking place in voltage, current or frequency deviations that result in failure or disoperation of electrical equipment or maintain the integrity of power supplied to the system. Poor PQ 'events' such as voltage sag, swells, transients, harmonics, unbalance, interruption, flickering, etc., are the various issues on PQ [3]-[5]. It is crucial to perform a power quality audit to identify any PQ problems in a system. The audit helps to understand the more sensitive types of equipment and devices in the industrial plant and associated issues they face, due to the current and voltage disturbances. Many commercial PQ monitoring instruments have sampling rates of 256 samples per cycle since the majority of PQ events have frequency contents below 5 kHz as observes in the reference paper [6]. The availability of high-end instruments to capture infrequent very high frequency events is limited due to technical and economical hurdles.

The PQ disturbances are mainly classified as short-term and long-term variation. Higher load switching devices like drives are short-term and disturbances such as over-voltage, short-voltage faults come under long term [7]. There are specific standards that are followed to maintain equipment and personnel safety, and it depends on the country and the industry [8]-[9]. Some associations accountable for emergent PQ standards comprise the Institute of Electrical and Electronics Engineers (IEEE), the

International Electronic Commission (IEC), National Electrical Manufacturers Association (NEMA), National Fire Protection Association (NFPA), National Environmental Policy Act (NEPA), and American National Standards Institute (ANSI), etc., [10]. The true value of any PQ monitoring program lies in its ability to analyse and interpret voluminous raw data and generate actionable information to prevent PQ problems or improve the overall power quality performance.

IEEE 1100-1999 and IEEE 1159 are one of the finest sources for describing PQ concerns and providing solutions to equipment and system difficulties. PQ refers to the powering and grounding of electronic equipment in a way that is appropriate for the device's functioning and compatible with the property's wiring system and other connected equipment. Moreover, Practice for Powering and Grounding is IEEE Std. 1100-1999 and Monitoring Electrical Power Quality is IEEE Std. 1159-2009 [11]. The IEC also provides a platform to companies, industries to discuss and develop the standards required like IEC Std. 61000-2-1, Electromagnetic compatibility (EMC environmental description for low frequency carries out disturbances and signalling in the municipal power supply system [11]. The standard definition of IEEE Std. 1159-2009 is "Any power problem manifested in voltage, current, or frequency deviations that results in failure or disoperation of customer equipment depending on deficient power quality" [12].

There is research on IEEE Std. 1159 and different authors suggested notable remarks on maintenance of the standards for equipment and personnel safety. The S-transform method used as input to this hybrid classifier of PQ disturbances shows pleasing results of efficient recognition and classification with the proposed real-time method [13]. An S-transform based semi-supervised approach is discussed to solve classification crises without the necessity of sample data. First, PQ disturbances detection using the S-transform chosen to exact enough PQ time-frequency events characteristic with S-matrix for later categorization under noise, and traits are attained. In the next step, seven to eight binary classifiers are created with the normalized ruler to recognize these disturbances. Finally, these multiple PQ disturbances are classified using this method [14]. A sampling rate of 15 to 18 kHz and de-noised with the help of discrete wavelet transform (DWT) based technique requires signals with superior signal-to-noise ratio classification PQ features with an accuracy of 98.18 % as contrasted to the generalized wavelet algorithm [15].

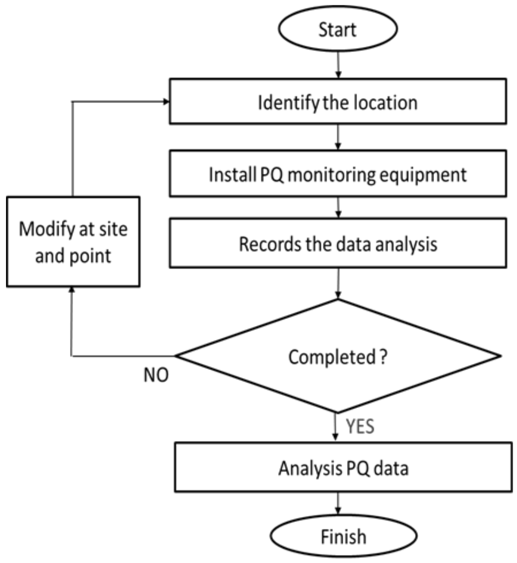
Many practical types of equipment like Flexible AC Transmission System (FACTS) devices improve the overall PQ standards and norms for companies and industries. Two types of FACTS devices were conducted in India in the real-time environment on the distribution power system under the case studies with devices like distribution static compensator (d-statcom) and static VAR compensator (SVC). This helped to exemplify the modelling technique and the efficacy of these FACTS and custom power devices in curtailing financial losses [16]. Another case study using a DVR, for voltage sag mitigation with a conventional PI controller [17]. Here, better dynamic restoration under the voltage disturbance and the ability of post-fault resurgence as a case study is observed on an extensive electrical distribution system. Appropriate evaluation techniques are verified for the outcome without, and with-compensation devices are studied to evaluate the role of heat-maps.

In a similar way, soft computing-based techniques are alternatives for PQ parameter enhancement like voltage regulation, power factor control, harmonics, dynamic loads, and non-linear loads in spite of conventional techniques. The soft-computing techniques for PQ applications are particle swarm optimization (PSO) algorithm [18], Security and cost-optimal allocation of multi- FACTS devices using multi-objective (PSO) [19], few advanced non-linear methods like PQ theory & fractional order PID controller in DPFC for PQ improvement [20]. The PQ performance using FACTS and renewable energy sources (RES) with the technical and economic evaluation is discussed [21], [22]. The payback period calculation applies FACTS devices in the case study with the metallurgical industry [23]. A Malaysian case study on Distributed Generation: A Review on Current Energy Status, Grid-Interconnected PQ Issues, and Implementation Constraints [24]. In this paper, carbon emissions, RES, different countries' electrical PQ standards and regulations, additional FACTS and custom-power devices, techniques for PQ enhancements as a review is made exclusively in detail.

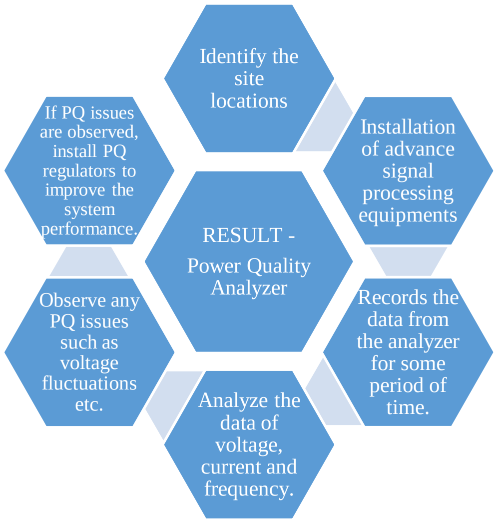
The major objectives of the present work are to record and interpret raw data into useful information, analyse the PQ measurement results and understand the characteristics of PQ variations on the power supply. Many PQ events are organized worldwide to improve the PQ standards for the company and industry [25]-[28]. These are done by American Power Laboratory, Canadian Electrical Associations, UNIPEDE-Europe, and many standard organizations. The major objectives of the work are to record and interpret raw data into useful information, analyse the power quality measurement results and understand the characteristics of power quality variations on the power supply.

Books discussing on various PQ issues, harmonic analysis, sources, distortion and monitoring and further study on equipment overheating, motor failure, capacitor failure, and incorrect power metering are examples of issues with harmonic distortion [29]-[30]. Measurements are made of the components of a single-phase induction motor with closed or semi-closed rotor slots that is capacitor-start and capacitor-run, and a model is developed for the examination of the machine's performance in the frequency domain under the effect of harmonic voltages [31]. The current versions of IEEE and IEC are too restrictive for low-frequency voltage and current (integer) harmonics as they apply to residential power systems, according to experimental and analytical studies of the effects of voltage and current harmonics on induction machines, transformers, appliances, and relays. It is advised that flexible, rather than strict, rules be set up such that various harmonic spectra be allowed that cause the same extra temperature to rise in transformers and induction machines [32]-[33]. Power quality factors are evaluated using a variety of computer algorithms, each with unique benefits. In order to compare the perceived power quality of complicated electric systems, this study improved the Curve Fitting Algorithm (CFA), which has excellent accuracy in the assessment of the signal's power quality characteristics [34]. The tracking of PQ metrics by biggest Italian telecommunications company had it happen inside four medium/low voltage transformer rooms of telecommunication power substations. The tests were carried out using a suitable home-made apparatus that samples the mains' three-phases and neutral lines over the course of around two years and the results are presented [35]-[36].

In this paper, the objective is not to describe the signal processing or artificial intelligent methods, other than quite to discuss challenges and probable appliance of signal processing techniques in spiralling raw PQ measurement data to a much



a)



b)

Figure 1. a) Flowchart showing practical PQ monitoring equipment installation and b) process flow schematic closed-loop operation for PQ analysis.

more valuable commodity-knowledge and information to improve PQ performance. Section 2 of the paper presents Research Methodology with Field Measurement approach, while Sections 3 and 4 provide descriptions on case study background with equipment installation and erection locations and Results and Analysis of the proposed method with Fluke measuring device to analyse raw PQ measurement data. The applications described provide the basis for research efforts done in Centre of Excellent for Engineering & Technology (CREaTE), Malaysia (many of which are under way around the world) to identify new and improved methods for the data analysis and development of important conclusions from the measurement data.
The main key research queries explored are:

- What affects the PQ in the switchgear terminal unit?
- What existing standards help in PQ improvements in Malaysia?
- What is the solution/enhancement for the current imbalance and other PQ issues?

In this reverence, the explicit research objectives on PQ events are:

1. Analyse the PQ events and their impact on the supply system and sensitive loads;
2. Explore the precise PQ events distressing CREaTE switchgear terminal unit and the distribution units;
3. Perform a pilot survey on PQ events to review the contentment level with the services accessible;
4. Monitor the PQ events and suggest suitable monitoring instruments.

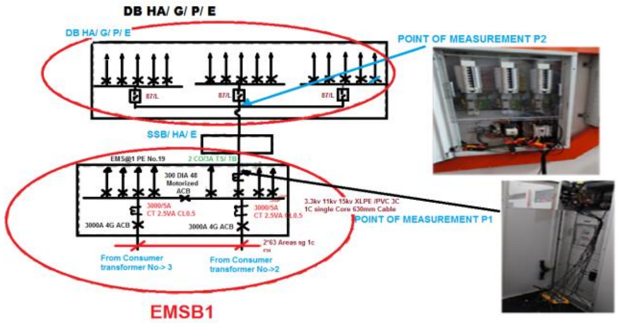
2. RESEARCH METHODOLOGY (FIELD MEASUREMENT)

The PQ monitoring and analysis in a practical environment using the Field-Measurement method in the flowchart representation are shown in Figure 1a. A closed-loop circular diagram representation is shown in Figure 1b. In this diagram, we can observe the equipment location at one point or multiple points has to be chosen initially. Later, these PQ monitoring devices are installed based on voltage and power specifications. The data is stored and retrieved for the PQ analysis, with any deviation from typical values under current unbalance or voltage disturbances are analysed and recorded. After this, the PQ equipment and devices are changed in other switchboards, and the process is repeated for auditing and measuring. Finally, characteristics tables are drawn, deviations in parameters shown in tables, and graphs are stored for records.

The Figure 1a and Figure 1b depict, analyse and classify the power quality problems. This paper focuses on Field Measurement analysis technique to analyse PQ waveforms and signals like voltage and current. With the installation of the PQ measuring devices, the PQ events are recorded, summarized and analysed to understand the sequence of the event, influence on the nearest, farthest and sensitive loads are examined in detail. Field Measurement based auding technique with Fluke like PQ measuring device is very popular in understanding the PQ events. This method presents a good time resolution for narrow window while the large window is useful for good frequency resolution. In addition, this method has advantages as the system parameters dependency is decreased, mathematical modelling, reduced complex erections and therefore it is easy to implement and also the measuring devices involved are all not necessary. This paper presents the development of PQ monitoring system by using Field Measurement analysis technique which is an auding based using PQ measuring devices. From Fluke device, parameters of the power quality signals are estimated such as RMS and fundamental value, total harmonic distortion (THD), current to neutral and current through ground for voltage and current. Then, characteristics of the signals are measured using these devices and calculations are made from the signal parameters based on IEEE Std. 1159-2009 as shown in flow chart in Figure 1a. From the time illustration, PQ parameters are measured such as Instantaneous of RMS voltage, RMS fundamental voltage, total waveform distortion, total harmonic distortion and total non-harmonic distortion. Then, characteristics of power quality signals are calculated from the signal parameters and are used for signal classification. The signal parameters and characteristics and their influence on the system are studied in detail in the further Sections.

3. CASE STUDY BACKGROUND

The Centre of Excellent for Engineering & Technology (CREaTE), Malaysia industrial erection to understand the PQ auditing, recommended practice, current disturbance, and impact, location of the PQ devices is studied. Two sets of PQ



a)

b)


c)


d)

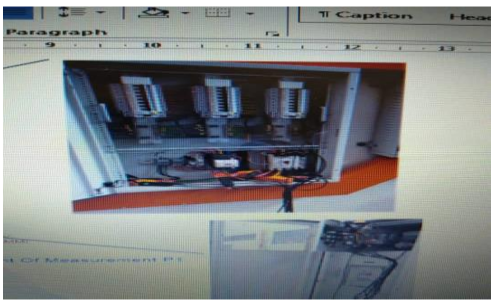

e)

Figure 2. a) Layout of the indoor switchgear board with the PQ equipment erection, b) Fluke PQ based components used in our case-study, c) The Indoor switchgear board at PC-1 ready for erection, d) Fluke PQ based components erected and ready for testing, e) point of measurement-1 erection unit.

Table 1. Model and type of the PQ equipment.

Meter used	Purpose	Model No.
Fluke 1750 Power Recorder	Power Quality Analyzer	1750
Multi Clamp Leaker	Measurement of leakage currents	140
Fluke True RMS multimeter	Voltage Measurement	117
Fluke Clamp meter	Current Measurement	376

Fluke devices are located at Point of Measurement 1, and 2 with layout diagram is shown in Figure 2a. Here, the parameter symbols DB HA/ G/ P and E represent distribution generator (DG), ground (G), phase (P), earth (E) for our switchgear electrical medium voltage switch board-1 (EMSB) as shown in Figure 2a. The total PQ devices, individual components, and accessories used for the measurement and data storage are shown in Figure 2b. After connection and erection of the PQ devices, the switchgear board unit looks as in Figure 2c. The Fluke device and other PQ devices after erection at the switchgear unit at CREaTE, Malaysia in Figure 2d. The Point of measurement-1 erection unit equipped is shown in Figure 2e. The model and type of the PQ equipment used in paper are shown with their purpose and type number in Table 1.

The CREaTE electrical medium voltage switch board-1 (EMSB-1), Malaysia looks to improve the PQ standards and norms and reliability of supply to the building for research analysis. Between May to September 2019, CREaTE used this project with self-study analysis to install power quality measuring devices and parameter values in various selected sub-locations in the switchgear terminal. In April 2019, complete quality of service came to the picture, and the results are recorded for retrieving and analysis. It is established to track the PQ monitoring and reporting features under normal and abnormal current balance conditions.

The research proposes that, if put into practice will provide a better solution in solving the PQ events and maintenance of the IEEE 1159 Compliance recommended in Table 2. Based on the IEEE 1159 compliance, Table 2 describes the range and nominal operating conditions constraints. The power interruption must be more than 1 minute of time with voltage less than 10 % of its nominal value of 230 V (< 23 V). The over-voltage is defined as voltage greater than 10 % and under-voltage is less than 6 % of nominal 230 V. The voltage unbalance is referred to 2 % change in any phase voltage from the nominal value and current unbalance is 30 % of operating load current. The highest neutral

Table 2. categories and compliance standards with IEEE 1159.

Categories	Compliance IEEE 1159
Power Interruption	More than 1 minute, 10 % (23 V)
Overvoltage	> 253 V (+10 %)
Under-voltage	< 216.2 V (-6 %)
Voltage Unbalance	2 %
Current Unbalance	30 %
High Neutral to Earth Voltage	3 V
NE Impulse	> 20 V
Transient	-
Voltage Dip (Sag)	23 V – 207 V
Voltage Swell	> 253 V
Voltage Fluctuations	6 %
THD (Voltage)	5 %
THD (Current)	3 %
DC Offset	0.10 %

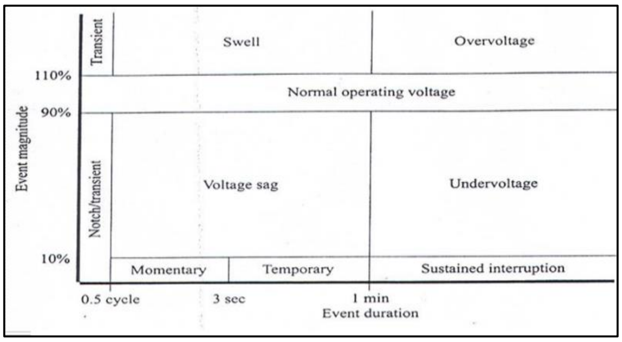


Figure 3. PQ voltage event description with the duration time stamp.

(N) to earth (E) voltage must be within 3 V and the impulse voltage is said to be greater than 20 V between these NE terminals. The voltage sag is defined for a nominal voltage of 230 V is between 23 to 207 volts and swell if the voltage is greater than 253 volts. The voltage fluctuation is said be when there is ±6 % variation in voltage range from 230 volts and this repeats for every millisecond of time with the nominal voltage. The maximum allowable Total Harmonic Distortion (THD) voltage is 5 % and current is 3 % and the dc offset or dc component on the ac supply should be less than 0.10 %. These are the allowable ranges for the standard IEEE 1159/ 2009.

The PQ event under voltage-time stamp is shown in the pictorial form in Figure 3. Here, 90-110 % of the voltage event magnitude on the Y-axis represents regular operation, and 100 % is ideal voltage. The voltage between 0 to 90 % is under-voltage and beyond 110 % is over-voltage. In the X-axis, the time up to 0.5 cycles considered to be notch or transient for under-voltage and over-voltage. A momentary fault is from 0.5 cycles to 3s, and to 1 minute is called the temporary fault, or beyond 1 minute is called sustained interruption. After discussing the practical layout and basic background on the work, results are discussed based on practical case studies in the next section.

4. RESULTS AND DISCUSSION

In this section, different case studies are studied and analysed at (EMSB1 point)-Voltage Values based on the practical reading. Here, voltage waveforms and data recorded are explored in the first case under steady-state analysis. Later in the second case, load variation is dealt and in the last case, under very light load conditions is analysed.

4.1. Case 1: Voltage flow diagram of the three phases under normal operating conditions

The three phases voltage distribution at EMSB discussed in Figure 2 switchgear terminal location is shown in Figure 4. Here, the RMS voltage variation in all the three phases shown in the red, blue, and black waveform is between 248 to 240 volts under current imbalance regular operation in an industrial/company location. Voltage surges observed in the fluke meter having amplitudes 221.8 V and 219.4 V because of load shifting observed in the figure. This current imbalance leads to voltage sag-like behaviour but is within limits. Table 3 shows the deviation from the expected value with maximum and minimum values in three different phases and the neutral point at various times from 1st May to 6th May 2019.

The system can also be utilized to capture continuous sampling as well as collecting and recording the real time signal. The data is then analysed to be stored in database. This system can set specific time to store data into computer automatically.

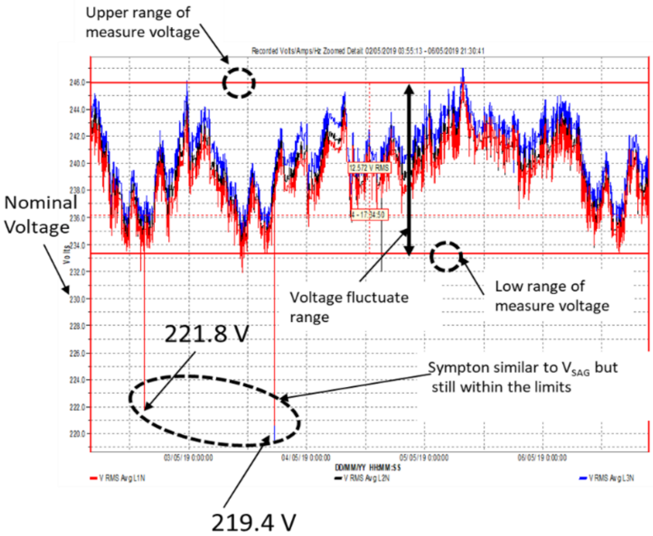


Figure 4. RMS voltage of the three phases recorded in May 2019 at EMSB-1 at the point of connection-1.

Table 3. Maximum and minimum RMS voltage of three phases and neutral from 1st May to 6th May 2019.

Phase	Max (RMS)	Time	Min (RMS)	Time
V RMS Avg L1N	246.20 V	01/05/2019 08:00:00	233.59 V	03/05/2019 10:50:00
V RMS Avg L2N	246.37 V	01/05/2019 07:30:00	234.06 V	03/05/2019 10:50:00
V RMS Avg L3N	247.47 V	01/05/2019 07:30:00	234.93 V	03/05/2019 10:50:00
V RMS Avg NG	2.91 V	06/05/2019 07:10:00	1.29 V	03/05/2019 17:10:00

Figure 8 shows examples of data which has been stored in notepad by using this system. Based on the measured values for voltage and current using the system, the results obtained are comparable to the measured values using the existing equipment which is fluke power quality analyser. The development of the real-time power quality monitoring system is shown in Figure 2a to Figure 2f. The system is capable of measuring all standard power line measurements such as voltage (RMS), current (RMS), frequency, real power, reactive power, apparent power and power factor that are also plotted in graph as shown in Figure 4. In addition, the voltage and current signals are shown in time and frequency domain as illustrated and tabulated. Based on Table 3, the significant observations found are Maximum average RMS voltage VL1N, VL2N & VL3N at P1 are 246.2 V (7.04 %), 246.37 V (7.12 %), and 247.47 V (7.60 %), respectively, which refer to a nominal voltage of 230 V. The Average RMS VNG is 2.91 V, which is lower than the maximum requirement (3 V). The voltage fluctuation is 5.45 %, which complies with the standard requirement (< 6 %) for a trend of 10 minutes of data.

4.2. Voltage flow diagram of the three phases under load variation conditions

A fluctuating balanced load and the voltage behaviour at the EMSB-1 are analysed in this case study here. The current is varying from 50 A to 160 A under light load to full load usage condition is shown in the right side of the graph plat, and voltage RMS parameters are shown in the left side of the plot. The voltage deviation is observed between 223 volts to 247 volts for all three phases, neutral and ground, shown in Figure 5. It can be observed, the maximum and minimum RMS current of all the

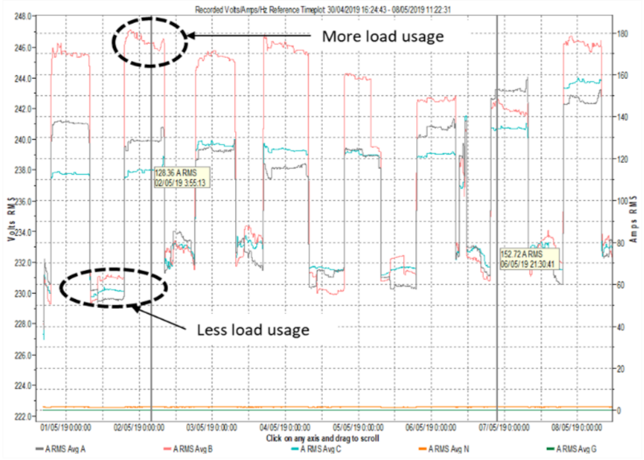


Figure 5. RMS voltage of the three phases at EMSB-1 at the point of connection-1 under various loading conditions.

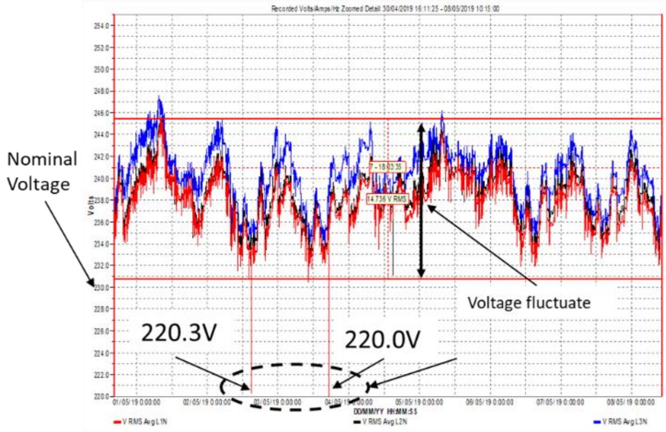


Figure 6. RMS voltage of the three phases at EMSB-1 at the point of connection-1 under very light load conditions.

Table 4. Maximum and minimum RMS current of three phases and neutral from 30th April, May to 8th May 2019 under current imbalance operation observed at EMSB-1.

Phase	Max (RMS)	Time	Min (RMS)	Time
A RMS Avg L1N	158.81 A	07/05/2019 07:40:00	51.54 A	01/05/2019 10:30:00
A RMS Avg L2N	181.25 A	01/05/2019 21:10:00	50.86 A	30/04/2019 18:40:00
A RMS Avg L3N	158.51 A	08/05/2019 00:20:00	53.58 A	01/05/2019 10:20:00
A RMS Avg N	1.57 A	01/05/2019 04:00:00	1.41 A	01/05/2019 09:40:00
A RMS Avg G	0.12 A	01/05/2019 08:30:00	0.07 A	30/04/2019 17:20:00
% A Unbalance	14.94	03/05/2019 19:10:00	2.40	06/05/2019 07:20:00

three phases and also in the neutral line, the current imbalance is observed at the switchboard EMSB-1 during the that during the period 30th April May to 8th May 2019. The details are tabulated as shown in the Table 4.

The maximum and minimum 10 min trends data for currents at EMSB1(P1) is recorded for the analysis. The maximum average RMS current L1, L2 & L3 at P1 is 158.81 A, 181.25 A and 158.51 A, respectively. The current unbalance is 14.97 % is lower than the maximum permissible value (< 30 %). The foremost concern for Malaysian electrical power system is to sustain reliable power supply, maintain almost constant voltage with variable load condition. The present real-time study plays a vital role in understanding the effect of line or phase of the power system, timing at which it influences, unbalance, neutral current concern and grounding technique are the main factors observed in this case study.

4.3. Voltage flow diagram of the three phases under very light load variations conditions

In this case, light loads like lighting only are applied, and the voltage fluctuations are analysed. A light-load is in general, results in increase in the voltage and hence to be regulated to reach the nominal value. The voltage behaviour at the EMSB-2is analysed for 10-minute time scale between 1st to 5th May 2019 in this present case study. The voltage varies from 232 V to 248 V under light load usage condition is shown with voltage RMS parameters recorded at DB HA/G/P/E (P2) for all the three phases, neutral and ground, at RMS Current of L1, L2 dan L3 phases shown in

Table 5. Maximum and minimum RMS current of three phases and neutral from 1st May to 7th May 2019 under light load operation at EMSB-1

Phase	Max (RMS)	Time	Min (RMS)	Time
V RMS Avg L1N	245.07 V	01/05/2019 08:30:00	232.15 V	03/05/2019 10:50:00
V RMS Avg L2N	245.30 V	01/05/2019 08:30:00	232.86 V	03/05/2019 10:50:00
V RMS Avg L3N	247.59 V	01/05/2019 07:30:00	234.05 V	03/05/2019 10:50:00
V RMS Avg NG	3.50 V	02/05/2019 08:00:00	1.56 V	07/05/2019 19:30:00

Figure 6 and Table 5. The normal RMS current of three phases is 18 A, and neutral current is 6 A is observed at EMSB-1 is summarized as depicted in Figure 7 and Table 6.

In this case study, a 10-minute trend in the voltage at the point of connection (P2) is analysed and shown in Figure 7. The maximum average RMS voltage VL1N, VL2N & VL3N at P2 are 245.07 V (6.55 %), 245.30 V (6.65 %), and 247.59 V (7.65 %), respectively, which refer to a nominal voltage of 230 V. The average RMS VNG is 3.5 V, which is higher than the maximum requirement (3 V). The voltage fluctuates 7.2 %, which is higher than the standard IEEE 1159 requirement (< 6 %) and within limits. By managerial control, harmonic spread among areas and the system unbalance are dealt with and general PQ development of the proposed Field Measurement is provided.

The maximum and minimum of 10 min trends data for currents at DB HA/G/P/E at the point of connection (P2) are analysed in this case study. The average RMS current maximum

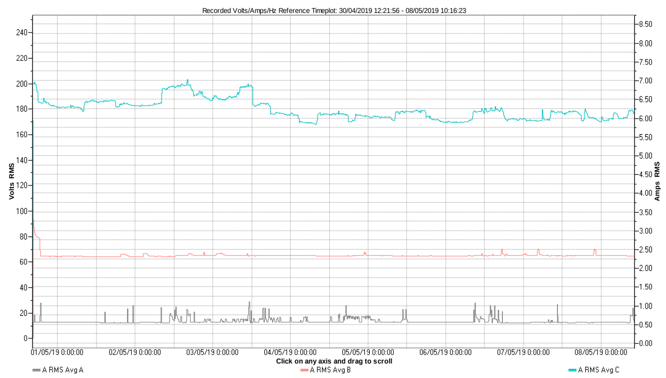


Figure 7. RMS current for the three phases at DB HA/G/P/E Point-current values at EMSB-2 from 30th April to 4th May 2019.

Table 6. Maximum and minimum RMS current of three phases and neutral from 30th April May to 8th May 2019 under light load operation observed at EMSB-2.

Phase	Max (RMS)	Time	Min (RMS)	Time
A RMS Avg L1	1.11 A	3/05/2019 11:20:00	0.55 A	02/05/2019 10:30:00
A RMS Avg L2	2.94 A	0/04/2019 17:00:00	2.31 A	01/05/2019 11:00:00
A RMS Avg L3	7.04 A	2/05/2019 16:10:00	5.84 A	04/05/2019 07:50:00
A RMS Avg N	6.68 A	0/04/2019 17:00:00	5.60 A	04/05/2019 18:30:00
A RMS Avg G	0.16 A	0/04/2019 17:00:00	0.05 A	04/05/2019 18:00:00
% A Unbalance	54.85	02/05/2019 14:40:00	45.58	04/05/2019 05:10:00

L1, L2 & L3 at P2 are 1.11 A, 2.94 A, and 7.04 A. The current unbalance is 54.85 %, which is higher than the requirement by IEEE 1159 (< 30 %), which is also within limits.

The final summarized form of the Computer and Business Equipment Manufacturer's Association (CBEMA) Curve Methodology (Field measurement) is described in Figure 8. In this graph, the Y-axis represents voltage deviation, and the X-axis denotes a time scale. It is observed that 289 under-voltage disturbances for a maximum of 8.3 ms are observed in one year from May 2019 to April 2020. Also, 98 under-voltage (sags), 18 interruptions, 164 over-voltage (swell) and 19 transients are observed under the CBEMA curve. Hence, this type of analysis with PQ equipment and chart-based analysis with the help of the CBEMA curve aid in understanding the PQ disturbances and formulations to be done for the company/industry based on the IEEE 1159 standards.

Consequently, it is observed that the PQ problem of CREaTE electrical medium voltage switch board-1 (EMSB-1) and EMSB-2, system requires to be concentrated more as the PQ condition in one sub-area in one sub-station or one electrical terminal will definitely influence the other electrical terminals PQ level due to unbalance, neutral current flow and harmonic propagation. The proposed method is recommended and the use of Fluke and other PQ devices with necessary testing equipment needs to be installed at the electrical sub-system or main point where the sensitive loads are connected at the point of the system. The PQ assessment, practices are observed with the auditing technique involved and observed under the existing unbalance and sudden load varying condition.

In this paper, the development of real-time monitoring system for power quality signal is developed by using field

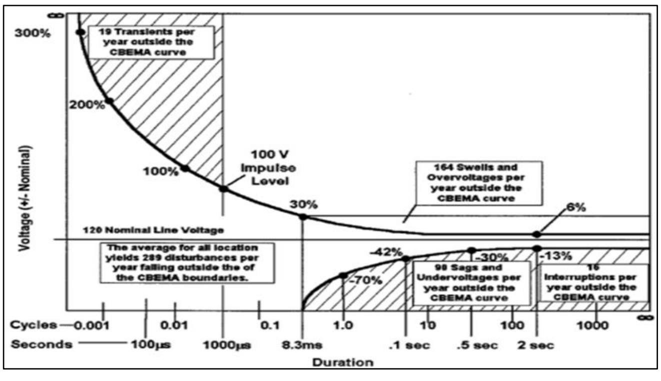


Figure 8. Computer and Business Equipment Manufacturer's Association (CBEMA) Curve Methodology (Field Measurement).

measurement method. The system performs power line measurement such as voltage and current in root mean square (RMS), real power, apparent power, reactive power, frequency and power factor. From the TFR of power quality signal, parameters of the signal are estimated such as RMS voltage, RMS fundamental voltage, total waveform distortion, total harmonic distortion and total non-harmonic distortion. Based on the monitoring testing, the system exhibits excellent accuracy in calculation due to low percentage error compared to the existing equipment.

5. CONCLUSIONS

A real-time power auditing with field measurement proposed scheme in this paper to advance the PQ of a sub-station when the PQ requirements and challenges are different. The Voltage fluctuation rate at DB HA/G/P/E is 7.2 %, which is higher than 6 % (IEEE 1159), which is expected due to high impedance in the installation. Voltage unbalance, current sudden changing with load variation, harmonics, are observed using PQ measurement devices like FLUKE etc., and auding is done and then our technique is applied in this paper. High neutral to the ground voltage (average VNG RMS) at DB HA/G/P/E is more than 3 V (3.5 V at the site) which is expected due to intermittent termination or loose contact at the grounding system. The activity of high VNG impulse observed at installation, which is expected due to intermittent single line-to-ground fault, which can affect electrical equipment. From the real time observation, it is found that, we can increase the efficiency of power distribution in an industrial network is possible with proper electrical auditing. It is found that, the solution for harmonic and unbalancing in a power sub-station to the load point. This will mainly influence the sensitive loads like computer, SCADA, small lighting systems etc. In addition, the proposed technique is useful to enhance the PQ of existing sensitive load buses (or CPs) without installation of a new active power filters or external devices in the respective buses. It is due to incorporated PQ upgrading of the sub-system is addressed employed with the available devices. PQ should also be adopted as part of a preventive maintenance program. This type of data analysis done in CREaTE electrical medium voltage switch board-1 (EMSB-1 and 2), practically helps in studying environmental, economic, and engineering impacts on the power systems. The main contribution of the proposed technique is pertaining an effective array of available PQ devices, advanced CBEMA methods in the electrical power auditing process so that the effect of one parameter on the other parameter, grid influence, role of neutral and ground are understood and helped in PQ improvement. To this aim, PQ events and suggest suitable monitoring instruments are done in this paper. The effect of light load, current imbalance, and standard operating conditions also considerably influences the system's voltage deviations. Because of the harmonic propagation, current unbalance and mutual effects of unbalances between sub-stations and the load points, the loading order of each sub-station is of vast significance and this concern is addressed by using a scheduling framework and regular power auditing is observed with the proposed process. If non-linear and unbalanced loads are considered, the impact of voltage deviations is very high, which is to be carefully investigated in future studies. The cost of PQ devices, location, type of loading, disturbance play a vital role in PQ improvement. The concluding section contains the major achievements of the research presented in the manuscript. It should be concise but informative. When numerical results are an essential part of the research, for instance a wider measurement range, higher uncertainty [6], they should be included in the conclusions.

REFERENCES

[1] B. Mohit, A. K. Singh, Grid integrated renewable DG systems: a review of power quality challenges and state-of-the-art mitigation techniques, International Journal of Energy Research 44, no. 1 (2020), pp. 26-69. DOI: https://doi.org/10.1002/er.4847

[2] K. Varun, A. S. Pandey, S. K. Sinha, Grid integration and power quality issues of wind and solar energy system: A review, 2016 Int. Conf. on Emerging Trends in Electrical Electronics & Sustainable Energy Systems (ICETEESES), IEEE, 2016, pp. 71-80. DOI: https://doi.org/10.1109/ICETEESES.2016.7581355

[3] Chattopadhyay, Surajit, Madhuchhanda Mitra, Samarjit Sengupta, Electric power quality, In: Electric power quality, pp. 5-12. Springer, Dordrecht, 2011.

[4] G. Bucci, F. Ciancetta, E. Fiorucci, A. Fioravanti, A. Prudenzi, An internet-of-things system based on powerline technology for pulse oximetry measurements, Acta IMEKO 9 (2020) 4, pp. 114-120. DOI: https://doi.org/10.21014/acta_imeko.v9i4.724

[5] M. Suresh, A. Kumar Panda, Power quality issues: current harmonics. CRC press, 2018. DOI: https://doi.org/10.1201/9781315222479

[6] M. M. Sabarimalai, S. R. Samantaray, I. Kamwa, Detection and classification of power quality disturbances using sparse signal decomposition on hybrid dictionaries, IEEE Transactions on Instrumentation and Measurement 64, no. 1 (2014), pp. 27-38. DOI: https://doi.org/10.1109/TIM.2014.2330493

[7] G. Artale, A. Cataliotti, V. Cosentino, S. Guaiana, D. Di Cara, N. Panzavecchia, G. Tiné, N. Dipaola, M. G. Sambataro, PQ Metrics Implementation on Low Cost Smart Metering Platforms. A Case Study Analysis, In 2018 IEEE 9th International Workshop on Applied Measurements for Power Systems (AMPS), pp. 1-6. IEEE, 2018. DOI: https://doi.org/10.1109/AMPS.2018.8494866

[8] H. Chandana, V. J. Gosbell, S. Perera Power quality (PQ) survey reporting: discrete disturbance limits, IEEE transactions on power delivery 20, no. 2 (2005), pp. 851-858. DOI: https://doi.org/10.1109/TPWRD.2005.844257

[9] A. Terje, M. Ylönen, The strong power of standards in the safety and risk fields: A threat to proper developments of these fields?, Reliability Engineering & System Safety 189 (2019), pp. 279-286. DOI: https://doi.org/10.1016/j.ress.2019.04.035

[10] A. Mariscotti, Uncertainty of the Energy Measurement Function deriving from Distortion Power Terms for a 16.7 Hz Railway, Acta IMEKO 9 (2020) 2, pp. 25-31. DOI: https://doi.org/10.21014/acta_imeko.v9i2.764

[11] Tenaga Nasional, Welcome to myTNB Portal, Online [Accessed 21 March 2023] https://www.mytnb.com.my/

[12] D. Alizzio, A. Quattrocchi, R. Montanini, Development and characterisation of a self-powered measurement buoy prototype by means of piezoelectric energy harvester for monitoring activities in a marine environment, Acta IMEKO 10 (2021) 4, , pp.201-208. DOI: 10.21014/acta_imeko.v10i4.1161

[13] R. Kumar, B. Singh, D. T. Shahani, A. Chandra, K. Al-Haddad, Recognition of power-quality disturbances using S-transform-based ANN classifier and rule-based decision tree, IEEE Transactions on Industry Applications 51, no. 2 (2014): 1249-1258. DOI: 10.1109/TIA.2014.2356639

[14] L. Ganyun, Z.Yang, Y. Jin, and Y. Ding, A novel method of complex PQ disturbances classification without adequate history data, In 2016 IEEE Power and Energy Society General Meeting (PESGM), pp. 1-5. IEEE, 2016. DOI: 10.1109/PESGM.2016.7741119

[15] M. A. S. Masoum, S. Jamali, N. Ghaffarzadeh, Detection and classification of power quality disturbances using discrete wavelet transform and wavelet networks, IET Science, Measurement & Technology 4, no. 4 (2010): 193-205. DOI: 10.1049/iet-smt.2009.0006

[16] A. K. Goswami, C. P. Gupta, G. K. Singh, Minimization of voltage sag induced financial losses in distribution systems using FACTS devices, Electric Power Systems Research 81, no. 3 (2011), pp. 767-774. DOI: 10.1016/j.epsr.2010.11.003

[17] H. Liao, J. V. Milanović, On capability of different FACTS devices to mitigate a range of power quality phenomena, IET Generation, Transmission & Distribution 11, no. 5 (2017), pp. 1202-1211. DOI: 10.1049/iet-gtd.2016.1017

[18] E. Naderi, M. Pourakbari-Kasmaei, H. Abdi, An efficient particle swarm optimization algorithm to solve optimal power flow problem integrated with FACTS devices, Applied Soft Computing 80 (2019), pp. 243-262. DOI: 10.1016/j.asoc.2019.04.012

[19] H. R. Baghaee, M. Mirsalim, G. B. Gharehpetian, A. K. Kaviani., Security/cost-based optimal allocation of multi-type FACTS devices using multi-objective particle swarm optimization, Simulation 88, no. 8 (2012), pp. 999-1010. DOI: 10.1177/0037549712438715

[20] R. Naidu, P. Kumar, S. Meikandasivam, Power quality enhancement in a grid-connected hybrid system with coordinated PQ theory & fractional order PID controller in DPFC, Sustainable Energy, Grids and Networks 21 (2020): 100317. DOI: 10.1016/j.segan.2020.100317

[21] M. Ghiasi, Technical and economic evaluation of power quality performance using FACTS devices considering renewable generations, Renewable Energy Focus 29 (2019), pp. 49-62. DOI: 10.1016/j.ref.2019.02.006

[22] M. Ghiasi, S. Esmaeilnamazi, R. Ghiasi, M. Fathi, Role of renewable energy sources in evaluating technical and economic efficiency of power quality, Technology and Economics of Smart Grids and Sustainable Energy 5, no. 1 (2020), pp. 1-13. DOI: 10.1007/s40866-019-0073-1

[23] M. S. Balabanov, K. H. Yoboue, R. N. Khamitov, I. A. Gonzalez Palau, Method for calculating the payback period of FACTS devices in the metallurgical industry, Dynamics of Systems, Mechanisms and Machines (Dynamics), IEEE, 2017, pp. 1-6. DOI: 10.1109/Dynamics.2017.8239431

[24] J. Y. Lee, R. Verayiah, K. H. Ong, A. K. Ramasamy, M. B. Marsadek, Distributed Generation: A Review on Current Energy Status, Grid-Interconnected PQ Issues, and Implementation Constraints of DG in Malaysia, Energies 13, no. 24 (2020): 6479. DOI: 10.3390/en13246479

[25] E. W. Gunther, H. Mebta, A survey of distribution system power quality-preliminary results, IEEE transactions on Power Delivery 10, no. 1 (1995), pp. 322-329. DOI: 10.1109/61.368382

[26] J. V. Milanović, J. Meyer, R. F. Ball, W. Howe, R. Preece, M. H. J. Bollen, S. Elphick, N. Čukalevski, International industry practice on power-quality monitoring, IEEE Transactions on Power Delivery 29, no. 2 (2013), pp. 934-941. DOI: 10.1109/TPWRD.2013.2283143

[27] E. Schwindt, J. López Gappa, M. P. Raffo, M. Tatián, A. Bortolus, J. M. Orensanz, G. Alonso, M. E. Diez, B. Doti, G. Genzano, C. Lagger, G. Lovrich, M. L. Piriz, M. M. Mendez, V. Savoya, M. C. Sueiro, Marine fouling invasions in ports of Patagonia (Argentina) with implications for legislation and monitoring programs, Marine Environmental Research 99 (2014), pp. 60-68. DOI: 10.1016/j.marenvres.2014.06.006

[28] P. Martins Estevão Teixeira, M. Oleskovicz, A. L. da Silva Pessoa. A Survey on Smart Grids: concerns, advances, and trends, IEEE PES Innovative Smart Grid Technologies Conference-Latin America (ISGT Latin America), IEEE, 2019, pp. 1-6. DOI: 10.1109/ISGT-LA.2019.8895296

[29] J. Arrillaga, D. Bradley, P. S. Bodger, Power System Harmonics; John Wiley & Sons: Hoboken, NJ (1985) USA
[30] J. Arrillaga, B. C. Smith, N. R. Watson, A. R. Wood, Power system harmonic analysis (2013), Power System Harmonic Analysis, ISBN: 978-111887831-6; 0471975486; 978-047197548-9
DOI: 10.1002/9781118878316
[31] D. Lin, T. Batan, E. F. Fuchs, W. M. Grady, Harmonic losses of single-phase induction motors under non-sinusoidal voltages (1996),IEEE Transactions on Energy Conversion 11 (2), pp. 273-279.
DOI: 10.1109/60.507179
[32] E. F. Fuchs, D. J. Roesler, M. A. S. Masoum, Are harmonic recommendations according to IEEE and IEC too restrictive?, IEEE Transactions on Power Delivery 19 (4), 2004, pp. 1775-1786.
DOI: 10.1109/TPWRD.2003.822538
[33] E. F. Fuchs, D. J. Roesler, K. P. Kovacs, Sensitivity of electrical appliances to harmonics and fractional harmonics of the power system's voltage. Part II: Television sets, induction watthour meters and universal machines, (1987), IEEE Transactions on Power Delivery 2 (2), pp. 445-453.
DOI: 10.1109/TPWRD.1987.4308128
[34] M. Caciotta, F. Leccese, A. Trifiro, From power quality to perceived power quality (2006), Proc. of the IASTED Int. Conf. on Energy and Power Systems, Chiang Mai, Thailand, 29-31 March 2006, pp. 94-102.
[35] F. Leccese, Rome, a first example of perceived power quality of electrical energy: The telecommunication point of view (2007), Proc. of the Int. Telecommunications Energy Conf. (INTELEC), Rome, Italy, 30 September - 4 October 2007, pp. 369-372. DOI: 10.1109/INTLEC.2007.4448800
[36] F. Leccese, M. Cagnetti, S. Di Pasquale, S. Giarnetti, M. Caciotta, A new power quality instrument based on raspberry-pi (2016) Electronics (Switzerland), 5 (4), art. no. 64.
DOI: 10.3390/electronics5040064