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Power quality monitoring and analysis of aerodrome supply system: A study in Gautam Buddha International Airport, Nepal

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Abstract

The power supply system may contain disturbances leading to variations in voltage and frequency from their nominal value, non-sinusoidal waveform injection, presence of negative and zero sequence components, etc. Power quality is a measure of characteristic disturbances present in the power supply which ensures the importance of quality of service and consumer requirements. Electrical equipment installed in an aerodrome is more sensitive and prone to disturbance present at the power supply end. This study provides results of a theoretical power flow study, power quality monitoring, quality analysis, and probable remedies for power quality issues in an aerodrome electrical supply system in Nepal. Power quality measurement for supply from the utility here, Nepal Electricity Authority, and internal power generations in Gautam Buddha International Airport (GBIA) Siddharthanagar, Rupandehi, Nepal is performed by using theoretical load flow approach and continuous monitoring using a power data analyzer. The scope and origin of various disturbances which may induce power quality issues are analyzed. It is observed that the power supply at GBIA has voltage fluctuations of about ±12% and total voltage harmonic distortion of 6.5% with the presence of negative and zero sequence components. A remedial solution for the power quality problem is proposed for future enhancement of the electrical supply system at GBIA.

Keywords: *Aerodrome, Aeronautical loads, GBIA, Nepal Electricity Authority, Power quality*

1. Introduction

In a power supply system, the quality of the supply voltage provided by the utility affects the current absorbed by the load. Therefore the quality of power depends both on the quality of supply voltage and load characteristics. We can conclude that the system has the best power quality if and only if the supply voltage fulfills specific load requirements without affecting the appropriate operation of the load equipment and there is not any re-injection of the disturbances into the supply end from loads (Carlo, 2010). Different types of disturbances which may affect the power quality as per standards (IEEE Standard 1159, 2009) and (International Electrotechnical Commission, 2003) are as follows:

i) Voltage sag: temporary voltage decrement below the nominal value as specified by grid code/ standards (usually below 90% of nominal value)

ii) Voltage swell: temporarily voltage increment above the nominal value as specified by grid code/ standards (usually above 110% of nominal value)

iii) Voltage fluctuations: randomly changing supply voltage

iv) Frequency variations: increment or decrement of supply frequency from the nominal value

v) Voltage unbalancing: unsymmetrical three-phase voltage system with negative and zero sequence components

vi) Harmonic distortions: injected due to non-linear and time-varying loads parallel to the supply feeder.

To analyze power supply quality and its monitoring, the above perturbations phenomenon are categorized into variations which are the small change from a nominal value such as harmonics, voltage fluctuations, unbalance, etc., and events which are usually large variations from a nominal value such as interruptions, transients, voltage sag, etc. (Bollen & Gu, 2006). The occurrence of the above disturbances can be individually analyzed and treated by using appropriate means. A different study has been carried out for monitoring and mitigating power quality issues that may occur in electricity consumers' periphery. In the study (Barker et al., 1994), a power quality study of two distribution feeders in the Buffalo, New York region is performed, and proposed that the cause(s) of poor power quality can only be identified by simultaneous recording of both primary and secondary disturbances. The effect of voltage variations, transients, and supply interruptions on household equipment is carried out by (Anderson & Bowes, 1990), and presented that there is a loss of memory in electronic devices during under-voltage leading to malfunctioning of the system installed. For the identification and analysis of the source of harmonics in the electrical distribution system, a novel approach to evaluating the direction of the harmonic active powers with the presence of a capacitor is carried out by Locci et al. (2007). The study by Gallo et al. (2010) analyses the accuracy of different algorithms used for the voltage dip measurements and presents that some of the commercial power quality instruments show disagreement in some actual measurements. A novel algorithm for power quality monitoring in a distribution system with minimal installation cost is presented by Eldery et al. (2006). In a study by Daponte et al. (2004), monitoring device for the measurement of the transient disturbances in the distribution system is presented and effective means for the industrial distribution system is proposed. Recent technology incorporating smart networks for power quality monitoring is presented in another study (Morales-Velazquez et al. , 2017).

Aerodrome facilities consist of sensitive aeronautical ground light (AGL) loads (Bloudíček et al., 2017) and highly sensitive communication and navigation system (CNS) equipment (Zhongming et al., 1999) requiring reliable and quality electrical supply. Some past studies (e.g., Kilimi et al., 2021; Lipan and Constantin, 2017) were focused on maintaining supply continuity in the aerodrome and are concerned with limiting supply interruptions by using a different number of sources and an Uninterruptable Power Supply (UPS) system. The study of sources of perturbations and their impact on aerodrome supply quality is lagging. In the case of the Nepalese aerodrome, the power quality analysis and monitoring are not performed yet. In this study, a detailed power quality analysis for the aerodrome supply system is done by using load flow analysis and continuous monitoring of the electrical system at Gautam Buddha International Airport (GBIA). GBIA is facing some challenges of voltage fluctuations because the aerodrome is located in the Rupandehi district with a higher number of industrial loads and there will be larger voltage deviation during day time i.e. during peak industrial load while during night time there are greater overvoltage issues because of lower industrial demand. Due to this effect, there are some issues such as the burning of motor winding, overloading of pumping stations, and many other airport facilities. The remedial solution for handling power quality issues at this aerodrome is also proposed in this study. The main objective of this study is to analyze the power quality issues that may arise in the aerodrome of Nepal having a utility supply as a major power source. The specific objectives are to propose a methodology of system load flow for the determination of weak system buses, continuous monitoring methods for the assessment of power supply quality in the aerodrome, and generating preventive measures to limit individual observed power quality issues.

2. Methodology

The proposed methodology has been described in the following three subsections. Subsection 2.1 represents a general flowchart for the methods used while subsection 2.2 represents the theoretical load flow study at GBIA using power flow simulation software. Similarly, power quality monitoring and analysis are performed in subsection 2.3.

2.1 Generalized flowchart

Figure 1 represents the generalized flowchart of the proposed methodology. Firstly, system load data and generation bus data are collected and load flow simulation is performed to determine the voltage and angle status of the installed power system network at GBIA. If load flow results in the sag/swell of voltage, then this bus can be used in further study taking as weak bus. With the basic idea about the power quality issues from load flow, continuous monitoring of the supply system using a power data analyzer at low voltage side of different transformer at GBIA for different time frame is performed to generate detailed supply quality issues. If there is some power quality issue, then possible remedial action will be analyzed and proposed for future installation.

2.2 Load flow study of electrical system at GBIA

A load flow study is performed in this study using power factory software to identify obvious voltage profiles and to choose the best location for power quality measurement using the actual system data for component installed at the aerodrome of GBIA. GBIA has five 11/0.4 kV power distribution substations. The single-line diagram of the power distribution at GBIA is presented in **Figure 2**.

There are two 11 kV, incoming feeders, from a Nepalese utility named Nepal Electricity Authority (NEA) taped from Mainahiya Substation, Bhairahawa via a 5 km 11 kV distribution line. These two radial feeders from the substation of NEA are taken for better supply reliability and are connected to a common 11 kV bus bar at the GBIA substation via Vacuum Circuit Breaker (VCB). An individual incomer is provided by an identical isolator and Lightning Arrestor (LA) before synchronizing to a common 11 kV bus. Six numbers of 11/0.4 kV step-down transformers with different power (kVA) ratings are installed in the GBIA substation to supply low voltage (400 V) aerodrome equipment. For the different airport facilities like luminaries, air conditioning systems, baggage handling systems, lifts, water pumps, etc., the voltage is stepped down by using two numbers of 11/0.4 kV, 1250 kVA transformers synchronized with two 400 V, 1000 kVA Diesel Generators (DG) using an Automatic Transfer Switch (ATS). At the firefighting station of GBIA, one 11/0.4 kV, 160 kVA step-down transformer with 400 V, 160 kVA DG along with ATS, and necessary control and protection devices are installed for the supply of firefighting equipment's loads. Similarly, a set of 11/0.4 kV, 50 kVA step-down transformer, 400 V, 30 kVA DG along with ATS and necessary control and protection devices is individually provided for Very High-Frequency Omnidirectional Range (VOR)/ Distance Measuring Equipment (DME), Localizer/Glide Path (GP), Sewage Treatment Plant for the supply of the installed electrical equipment at their premises.

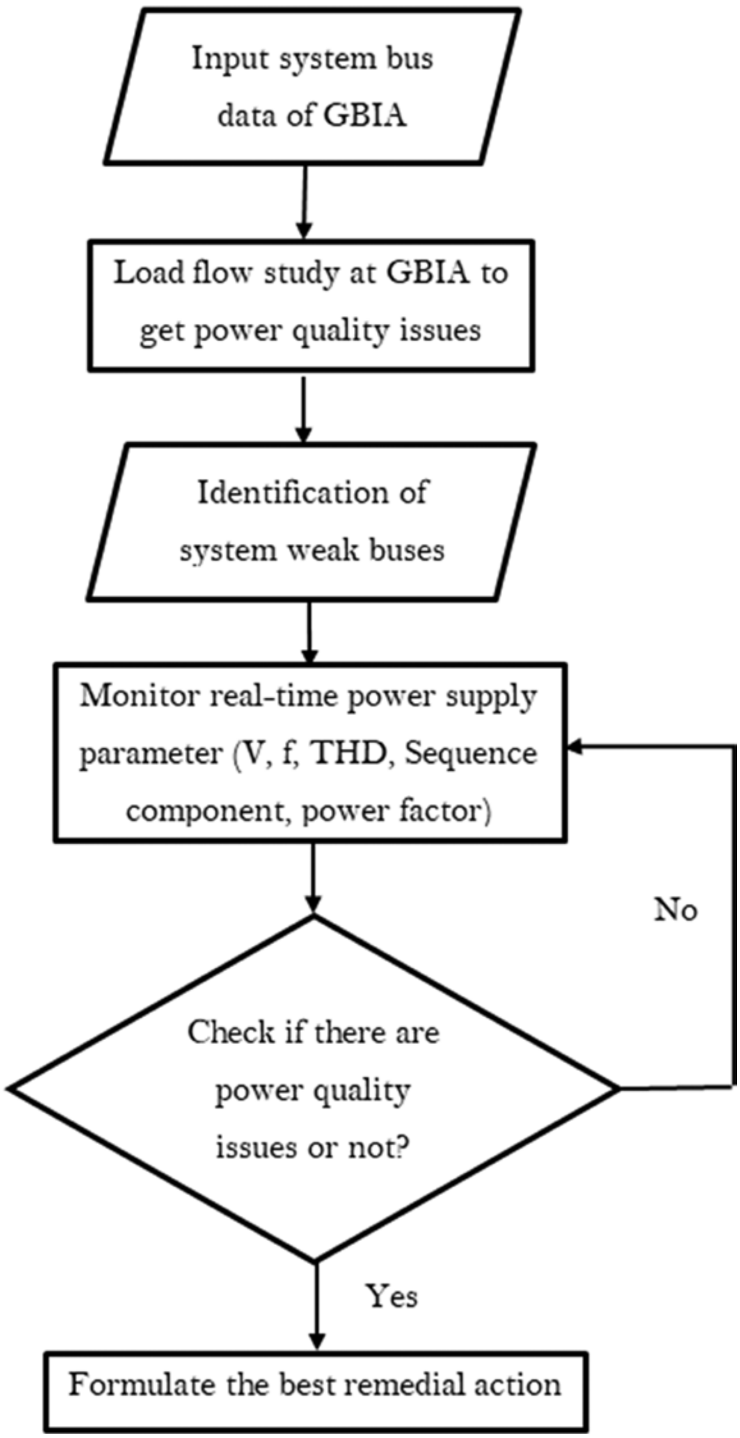


Figure 1: Generalized flowchart for the proposed methodology

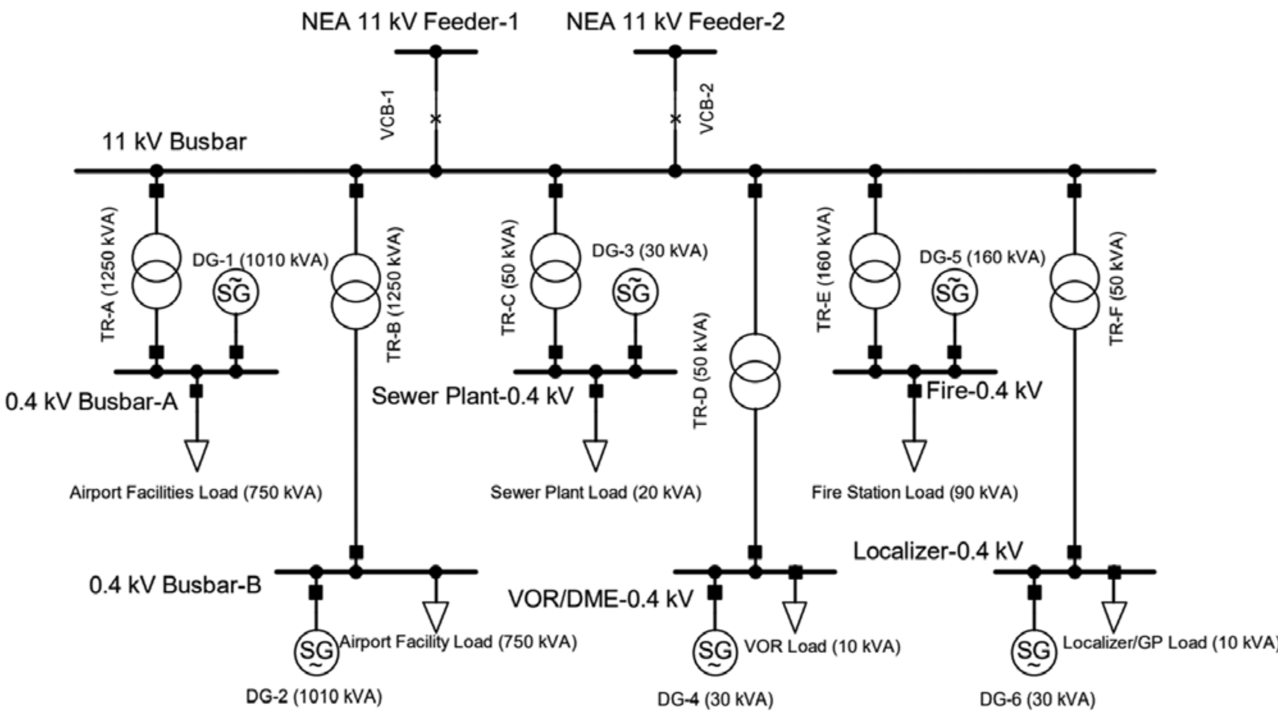
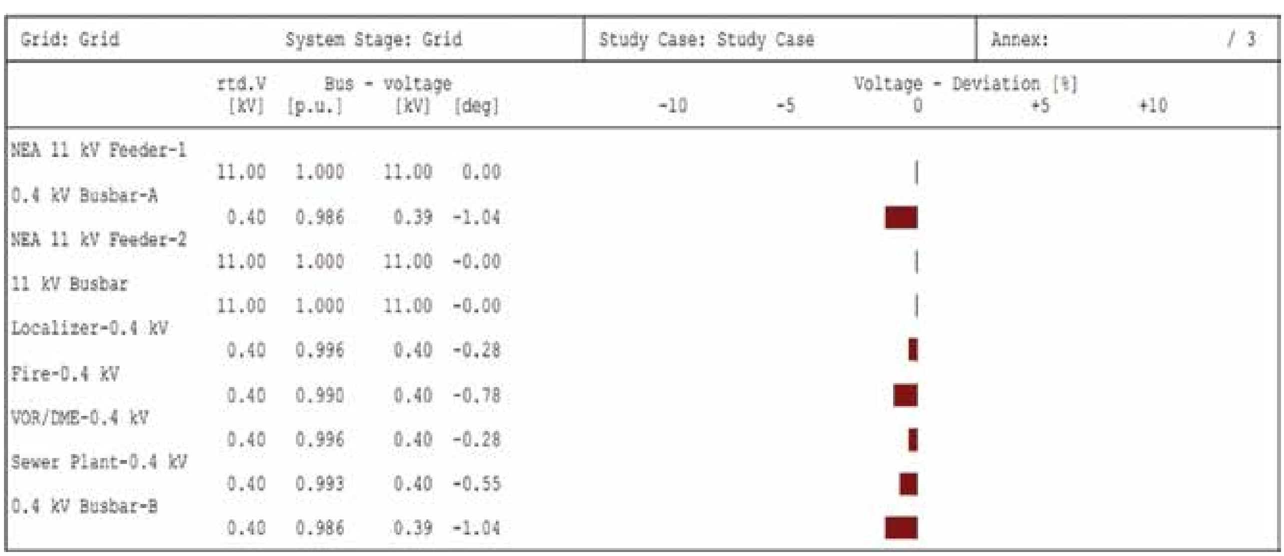


Figure 2: Single-line diagram of the electrical supply system at GBIA



Grid: Grid	System Stage: Grid				Study Case: Study Case	Annex: / 3
	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10	
NEA 11 kV Feeder-1	11.00	1.000	11.00	0.00		
0.4 kV Busbar-A	0.40	0.986	0.39	-1.04		
NEA 11 kV Feeder-2	11.00	1.000	11.00	-0.00		
11 kV Busbar	11.00	1.000	11.00	-0.00		
Localizer-0.4 kV	0.40	0.996	0.40	-0.28		
Fire-0.4 kV	0.40	0.990	0.40	-0.78		
VOR/DME-0.4 kV	0.40	0.996	0.40	-0.28		
Sewer Plant-0.4 kV	0.40	0.993	0.40	-0.55		
0.4 kV Busbar-B	0.40	0.986	0.39	-1.04		

Figure 3: Snip showing load flow result at GBIA using DIgSILENT software

Airport lighting system creates the light pattern which is important for approaches and landing of the aircraft. This facilitates the air traffic controller as well as aircraft operator in the nighttime and bad weather condition. The intensity and health of aeronautical light may mislead air traffic controllers as well as aircraft and thus they are treated as highly sensitive loads supplying higher quality (Bloudíček, Štefan, Rydlo, & Hon, 2017). GBIA is an aerodrome with an aeronautical ground lighting system installed maintaining the precision category-I. Another main aerodrome load is communication and navigation equipment which facilitates high-frequency radio communication between aircraft and air traffic controllers and is considered highly sensitive equipment in aviation (Zhongming, Edward , PONG, & Ping, 1999). For the simulation using power factory software, the rated active power, reactive power and power factor is provided for each station loads as indicated in **Figure 2.** As real time load pattern can't be reflected using software, different scenarios like maximum demand case, lightly load case and loss of largest load such as switching HVAC loads are performed by using software to get exact voltage fluctuations. **Figure 3** below shows the load flow result by modeling the actual supply system at GBIA with the installed line, load, and generator parameters. By considering the supplied parameter of the external grid (NEA) as per grid code, it can be observed that there is no such large voltage deviation in the system buses. Therefore, from a load flow solution using software, no power quality issues seem to be present in the supply system as a real-time scenario may not be replicated while providing system bus parameters to software. But in actual practice, operators are facing problems related to large voltage fluctuation in grid supply due to parallel connection of industrial load around GBIA, and therefore load side buses seem to be sensitive buses and can be taken under study with power quality monitoring.

2.3 Power quality monitoring

It is performed to acquire ideas about the scope and sources of the disturbances such as transients, faults, voltage sags/swells, etc. The power data analyzer has been installed at the low voltage side of the individual transformer at GBIA for the continuous monitoring of power supply quality. Different electrical parameter like the voltage, current, frequency, power factor, real power, reactive power, sequence component, harmonics, phase unbalancing, etc. has been recorded using the physically installed power logger at the low voltage side of individual transformer for the different time frame. The result obtained using the data analyzer is presented in the following subsections:

2.3.1 Voltage sag/swell

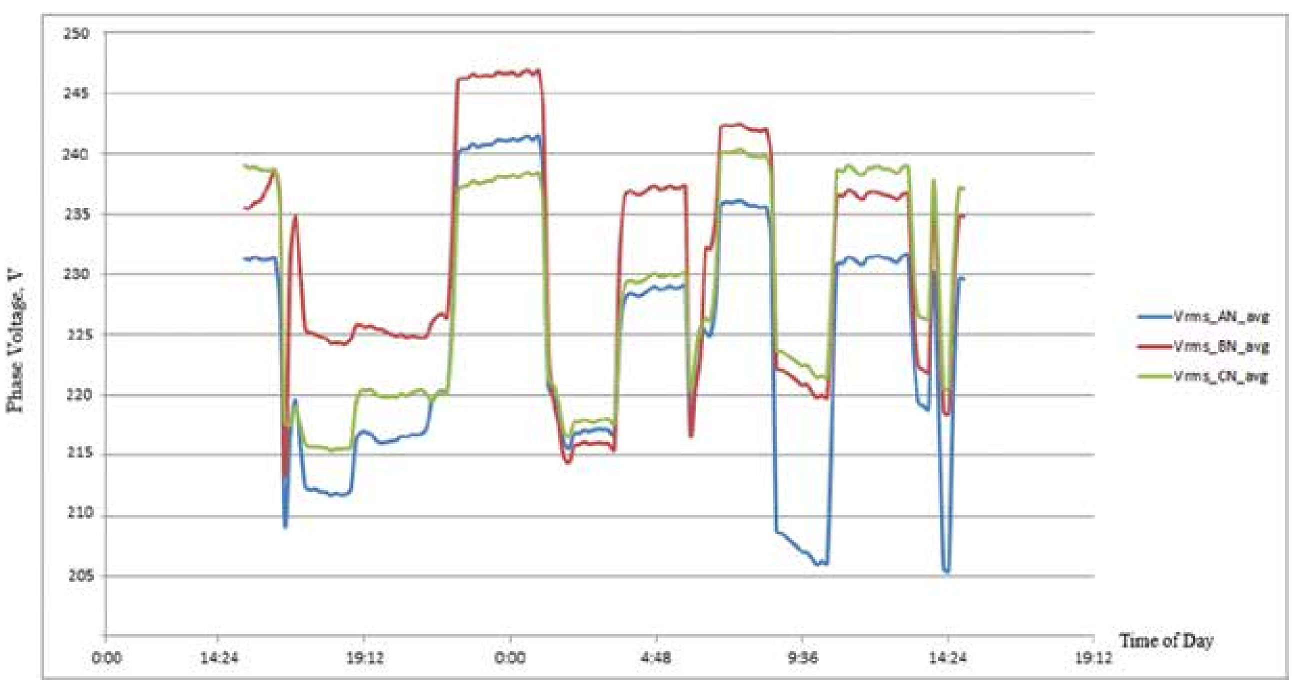


Figure 4: Voltage deviation plot for utility supply at GBIA

A large voltage deviation is seen in the utility supply at GBIA as presented in **Figure 4**. As per the grid code of NEA, the maximum allowable voltage deviation is ±5% for the distribution line but here at GBIA, up to 12% voltage deviations at the load terminal are measured. The main reason for this voltage fluctuation is the parallel operation of industrial and aerodrome loads. As there is no voltage regulating equipment at the supply end in GBIA, the voltage deviation is measured at the load bus terminal and hence affects the aerodrome loads. The major load at GBIA are Heating Ventilation and Air Conditioning (HVAC), aeronautical ground lights, communication and navigation system equipment, etc. and these loads are gradually turned on as per airport requirements. GBIA is present at Rupandehi, Bhairahawa which consists of a very large industrial area and thus heavy inductive loads. Switching off those heavy inductive loads whose feeder is connected in parallel with the airport load, may drop system voltage leading to large deviation at the load terminal at GBIA.

2.3.2 Frequency deviation

Figure 5 represents the power analyzer output for frequency deviation at GBIA. As per the graph, it is noted that there is no violation of the NEA grid code which states that the maximum allowable variation in frequency is ±2.5%. Therefore, GBIA does not have a frequency deviation issue.

As presented in **Figure 5**, the frequency deviations are within the permissible range, and therefore no preventive action is needed at present.

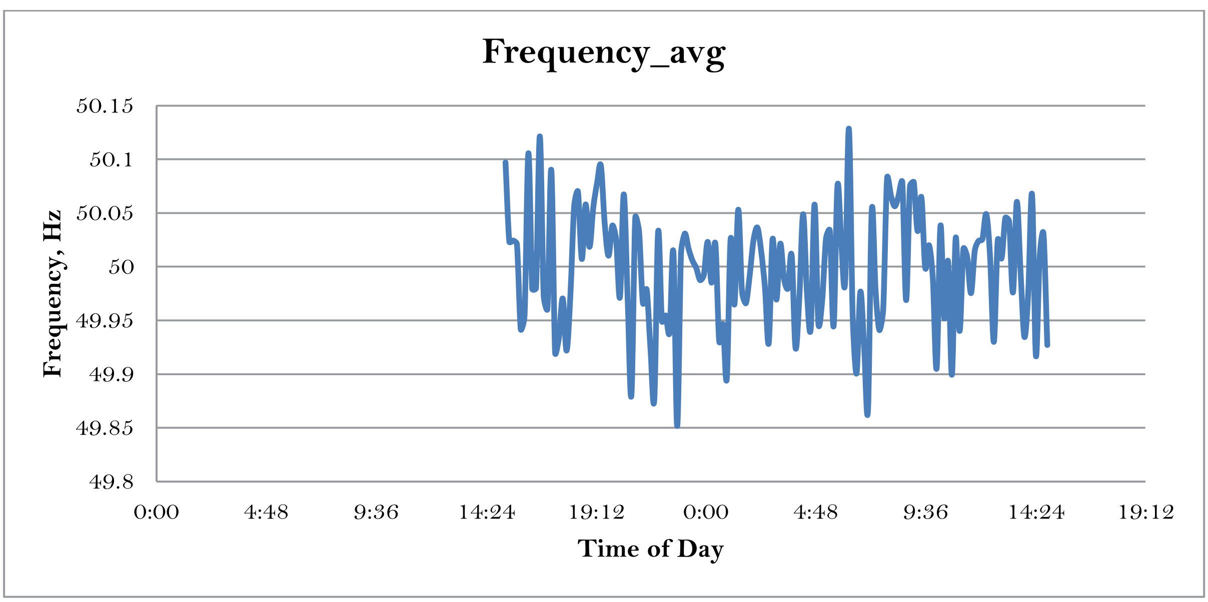


Figure 5: Frequency deviation plot for utility supply at GBIA

2.3.3 Harmonic distortion

Harmonics contains waveforms with a frequency other than fundamental frequency and causes a heating effect on equipment thus reducing its efficiency and life span. From data recorded using a power analyzer, the harmonics content in the utility supply at GBIA is plotted and presented in the figures below:

From **Figure 6** and **Figure 7**, the harmonics present in the utility supply seem to be greater than the maximum allowable limit specified by the grid code.

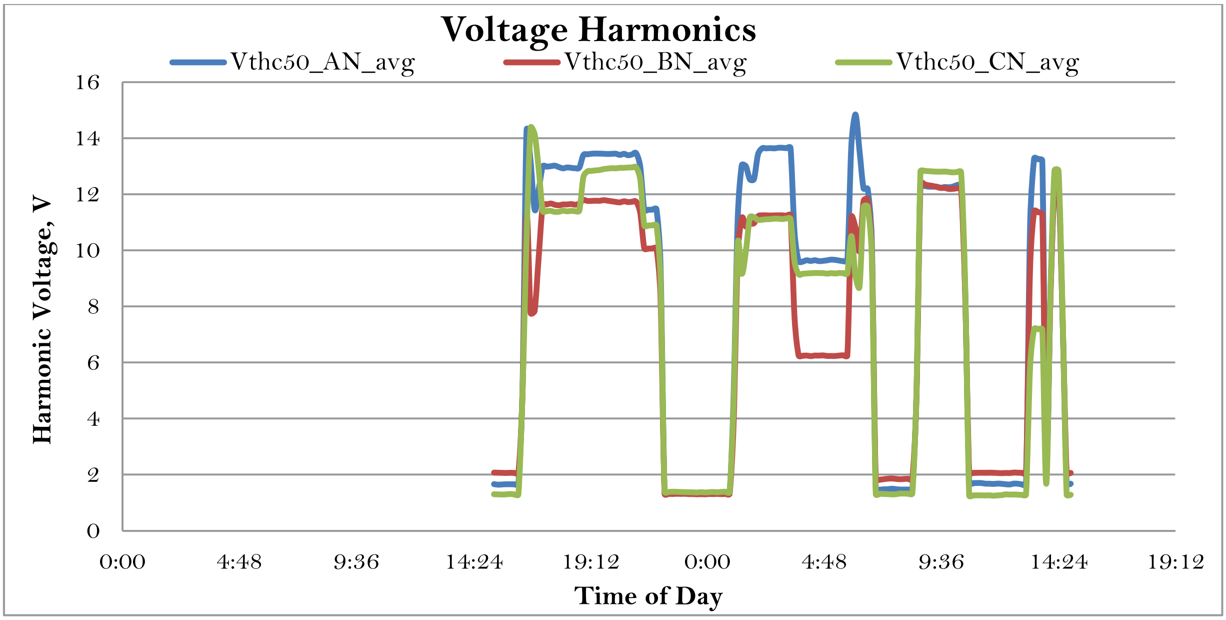


Figure 6: Total harmonic distortion (voltage) in utility supply at GBIA

Figure 6 represents the total voltage harmonics present in the incoming utility feeder and the harmonic distortion observed by the power analyzer. There is about 6.5% of voltage harmonics that violates the maximum permissible voltage harmonics, 5%, that can be present in distribution voltage as per the grid code of the Nepal Electricity Authority.

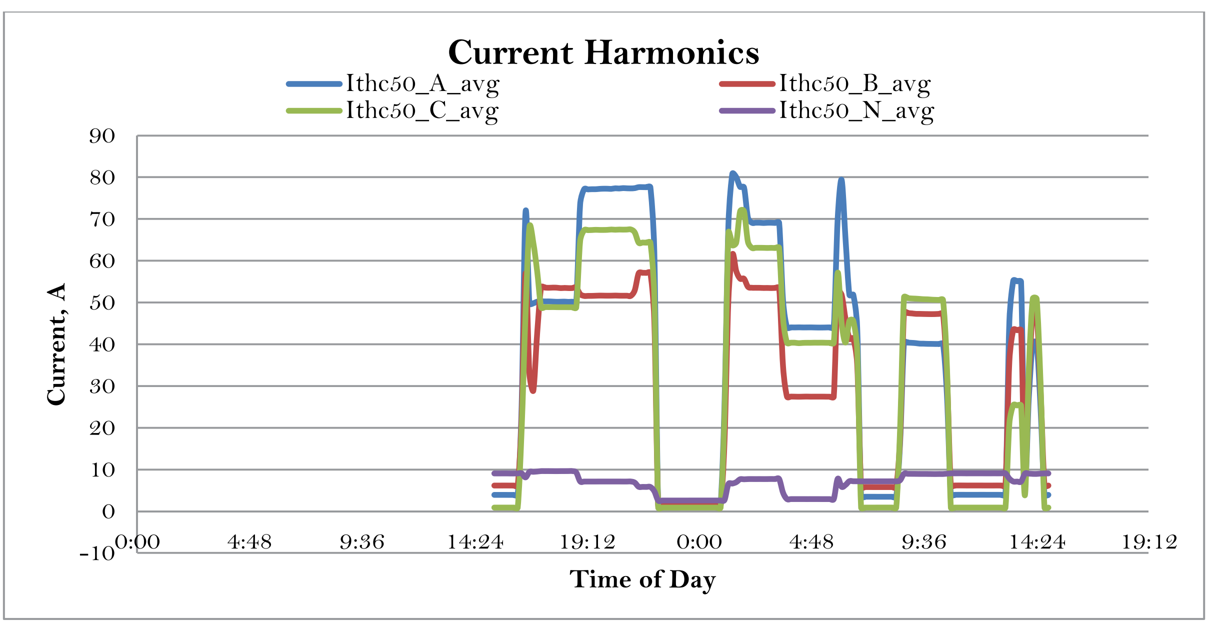


Figure 7: Total harmonic distortion (current) in utility supply at GBIA

2.3.4 Presence of sequence component

The presence of a negative sequence component will induce a current of double frequency in machine winding and will cause serious overheating if become excessive (Bayliss & Hardy, 2012). The graph showing the sequence component measured in GBIA substation-1 is presented in **Figure 8.**

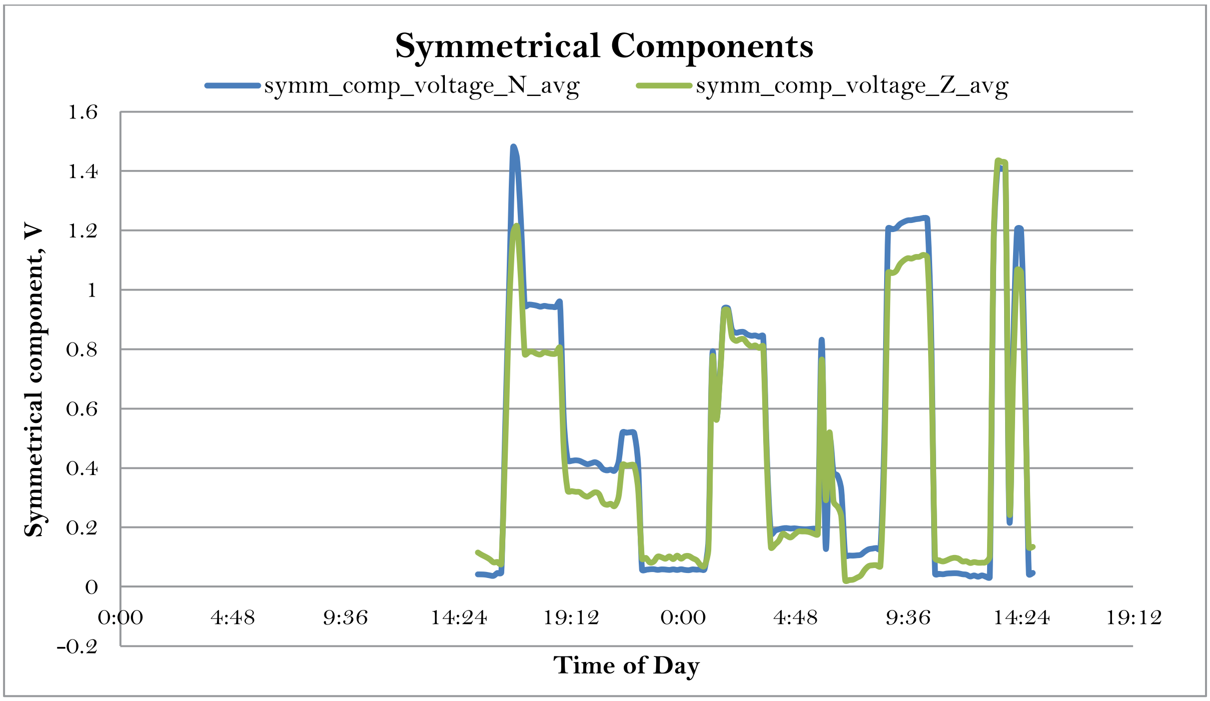


Figure 8: Negative and zero sequence components measured in utility supply at GBIA

From **Figure 8**, it can be concluded that there is the presence of negative and zero sequence components in the utility supply at GBIA leading to overheating and burning of motors installed at conveyors, HVAC compressors, hoists, etc.

2.4. Corrective action

It highlights the possible solutions and alternatives for power quality enhancement to achieve techno-economic benefits for GBIA. The major power quality issues at GBIA are voltage deviation, the presence of harmonics, and negative and zero sequence components in the utility supply. To maintain voltage sag/swell in the permissible range, the Automatic Voltage Regulator (AVR) should be installed at the incoming end of the utility supply. The capacity of AVR should be selected such that the voltage fluctuations present at the utility supply which is about ±12% should lie within the range of ±5% as specified by the grid code of Nepal Electricity Authority. Similarly to mitigate harmonics present in the utility supply, the harmonic filter of the required size should be designed and installed at the incoming feeder from NEA. This will absorb the wave with higher order frequency and hence total harmonic distortion can be limited to the permissible limit of 5%. Similarly, different filtering techniques are available for the protection of systems with negative and zero sequence components. Therefore, with the installation of AVR and power quality filtering scheme at the utility supply end at GBIA, those power quality issues can be limited.

4. Results and Discussion

With the simulation of the theoretical load flow of the electrical system at GBIA, it is known that there are some weak load buses up to which the effect of voltage fluctuations and other power quality issues can be measured. Therefore, for confirmation, the power analyzer is installed and continuous monitoring of the system power quality parameter is achieved. By continuous monitoring, it is confirmed that the utility supply at GBIA has issues of voltage sag/swell (about ±12% in normal workdays), total harmonic distortion (about 6.5% voltage), presence of negative and zero sequence components, etc. These ranges violate the power quality standards as per the grid code of Nepal Electricity Authority and hence should limit to a permissible range. Therefore some corrective solutions such as the installation of an Automatic Voltage Regulator at the incoming end of the aerodrome substation, current and voltage harmonics filter circuit at the incoming feeder as well as negative and zero sequence component filters before the high voltage side of the step-down transformer of aerodrome substation are proposed to maintain the power quality at GBIA.

The load flow result provides buses at the GBIA substation where there is the probability of large voltage fluctuations in real time. Simulating with actual load data and by treating the grid supply as a reference bus, voltage estimation at different load points can be determined which is further used for real-time monitoring with higher study priority. Similarly, by the installation of a power data logger at the low voltage side of the different transformers, actual power quality issues at GBIA such as the presence of sequence components, voltage harmonics distortion, voltage sag, and voltage swell are highlighted. By using the result thus obtained, preventive action which can solve the issues that arise is derived for future implementation.

5. Conclusions

From this study, it is highlighted that for the most essential loads such as aerodrome load, the power quality problems have a greater effect and larger loss of revenue. System load flow and real-time monitoring of power supply parameter at the aerodrome provides the issues related to supply quality. These issues can be limited by small corrective actions as discussed in earlier sections.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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