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Investigation of Voltage Unbalance in a Distribution Network: A Case Study of Federal Polytechnic Ilaro

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Abstract

The existing low voltage distribution systems have various single and three phase loads with dynamic characteristics. Voltage disturbance is one of the most important threats to power systems. There is need to ascertain the condition of distribution in the three phase power network. The voltage unbalance arising at the point of common coupling (PCC) due to a combination of unbalanced three-phase loads or phase to phase loads should be evaluated and analysed for the proper solution in the power system. This paper examines the state of the power quality within the distribution system with respect to unbalanced voltage and current. This study investigates the case of power quality in a power system to ascertain the extent of voltage unbalance in the system. Measurements were carried out with the aid of multimeter and clamp meter to determine voltages (line and phase) and currents in the two locations. The readings were taken at 2:00 pm daily for a period of one week in each location. The result shows that there is no voltage unbalanced in the load distribution at the two locations. The paper concludes by suggesting appropriate measures to prevent voltage unbalance in power network in the future.

1. Introduction

The impact of electrical power quality in distribution network that is causing failure of electrical and electronic equipment such as motors and transformers, light flicker, nuisance tripping of circuit breakers, unexplained fuse operation demands proper evaluation for appropriate mitigation [1]. Among power quality (PQ) indices, unbalanced voltage is one of the common steady state phenomena and it is essential to be aware of it when assessing power quality problems though it is not a type of waveform distortion [2]. In Nigerian distribution network characterized with poor power supply, it is not uncommon to see phase failure with only one or two lines supplying the area. Most often, the customers resort in changing from none available phase to the available one. The consequence of this is increased voltage drop in the terminal of the consumers' appliances. Several distribution network devices contribute to energy losses, such as losses along distribution feeders, losses in transformer windings and losses related to unbalanced loads connected to transformers [3]. According to [4] routine system studies must be carried out to discover and rectify any problem in the network. However, voltage unbalance leads to overheating of equipment, decrease in overall efficiency of the power system apparatus. Poor voltage quality contributes to vast economic losses globally [5].

1.2 Definition and meaning:

A three-phase power system is called balanced or symmetrical if the three-phase voltages and currents have the same amplitude and are phase shifted by 120° with respect to each other. If either or both of these conditions are not met, the system is called unbalanced or asymmetrical. A voltage unbalance therefore is said to be a condition in a three-phase system when the magnitude of the measured r.m.s. values of the phase voltages or the phase angles between consecutive phases are not all equal [6]. Unbalance is more rigorously defined using symmetrical components. The ratio of either the negative- or zero sequence components to the positive-sequence component can be used to specify the percent unbalance. The negatives sequence currents' phasors rotate in the opposite direction of the positive sequence phasors [7]. The most recent standards specify that the negative-sequence method be used.

Voltage unbalance is a significant concern for users that have poorly distributed loads and impedance mismatches. It is a serious power quality problem, mainly affecting low-voltage distribution systems such as commonly encountered in office buildings with abundant personal computers (PCs) and lighting [8, 9]. While these problems can be caused by external utility supply, the common source of voltage unbalances is internal, and caused by facility loads. More specifically, this is known to occur in three phase power distribution systems where one of the legs is supplying power to single phase equipment, while the system is also supplying power to three phase loads.

Ideally, the distribution networks are to be characterized by balanced lines and symmetrical loads and a balanced network is assumed as a first approximation with reference to the direct sequence only more especially if the topology of the network is known. Figure 1 shows a typical model of three-phase power system.

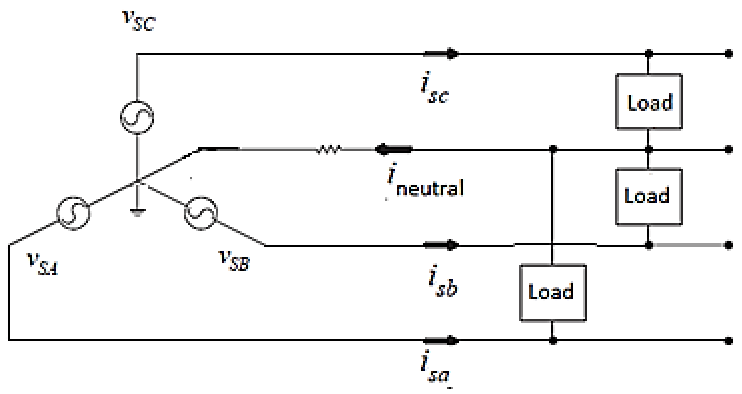


Figure 1. Model of three-phase system

The voltage in each phase which is displaced by 120^0 from each other is expressed as:

$$V_{SA} = \sqrt{2}|V|\sin \omega t \qquad (1)$$

$$V_{SB} = V_{SA}(t - T/3) \qquad (2)$$

$$V_{SC} = V_{SA}(t + T/3) \qquad (3)$$

1.3 Sources of voltage unbalance:

Unbalanced loads or single-phase loads that are not evenly distributed between the phases of a three-phase system will cause voltage unbalance. This condition is mainly caused by unbalanced three -phase loads or by a large number of single-phase loads that are not distributed symmetrically to the three phases [6]. Usually, the unbalance is found within the facility and sometime outside on the utility. The primary source of voltage unbalances of less than 2 percent is single-phase loads on a three-phase circuit. Severe voltage unbalance (greater than 5 percent) can result from single-phasing conditions. Other causes can be due to transformer impedance not matched on banked transformers or possibly a power factor correction bank with a blown fuse or bad capacitor [10]. Voltage unbalance can also be the result of blown fuses in one phase of a three-phase capacitor bank. Thus, sources of voltage unbalance can be categorized into two majors:

(i) The unbalance of load currents
(ii) High impedance or open neutrals, which represent a major wiring fault that needs to be corrected.

1.4 Effects of voltage unbalance:

The impact of unbalance in distribution network ultimately leads to premature equipment aging. Unbalance will cause power supply ripple, severe insulation degradation due to heat generation, and decrease in mean time between failures (MTBF) on all affected equipment. Excessive or reduced voltage can cause wear or damage to an electrical device. Generally, the unbalances show up as heating, especially with solid state motors. A relatively small unbalance in voltage will cause a considerable increase in temperature rise. A three percent (3%) voltage unbalance is said to be capable of causing a 25% increase in motor temperature [6]. Greater unbalances may cause excessive heat to motor components, and the intermittent failure of motor controllers and current protection systems to operate. Voltage unbalance may also have an impact on AC variable speed drive systems unless the DC output of the drive rectifier is well filtered. Load unbalance within the building power distribution system adds to the utility unbalance at the point of utilization. [8, 11] also reported that the unbalance can be responsible for inefficient operation of the often highly loaded transmission systems. Although induction motors are designed to accept a small level of unbalance they have to be derated if the voltage unbalance is 2% or higher. If an induction motor is oversized, then some protection is built into its operation although the motor does not operate at the best efficiency and power factor.

1.5 Standards on voltage unbalance

The rule of thumb is that if the voltage unbalance is greater than two percent (2%) of the nominal voltage it should be addressed. Poly-phase induction motors should not be operated with a voltage unbalance greater than five percent (5%). For a voltage unbalance between one percent and five percent the maximum load of the machine should be derated to reduce the possibility of damage. The European Norm (EN) standard (EN 50160) gives the main voltage parameters and their permissible deviation ranges at the customer's point of common coupling in public low voltage (LV) and medium voltage (MV) electricity distribution systems, under normal operating conditions [12]. As a standard, recommended voltage unbalance limits at point of common coupling which is usually service entrance are specified by the electrical distributor or local utility. In addition to system limits, Electrical Codes specify voltage drop constraints; for instance:

(i) The voltage drop in an installation shall:

- ❖ Be based upon the calculated demand load of the feeder or branch circuit.
- ❖ Not exceed 5% from the supply side of the consumer's service (or equivalent) to the point of utilization.
- ❖ Not exceed 3% in a feeder or branch circuit.

(ii) The demand load on a branch circuit shall be the connected load, if known, otherwise 80% of the rating of the overload or over-current devices protecting the branch circuit, whichever is smaller. The UK document Engineering Recommendation P29 states that unbalance caused by individual loads should be kept within 1.3%, although short term deviations (less than 1 minute) may be allowed up to 2%. In Nigeria, the local standard formulated by the Nigerian Electricity Regulation Code (NERC) [13] on voltage unbalanced is not specific and thus vague. It stated that:

*The maximum Voltage Unbalance at the Connection Point of any user, excluding the Voltage Unbalance passed on from the Transmission System shall not exceed the limit set by the affected **Disco**. The **User** shall ensure that its **System** shall not cause the Voltage Unbalance in the **System** to exceed the limits specified in this Section*

Table 1: Comparison of supply voltage requirements according to EN 50160 & the EMC standards EN 61000

Power quality (PQ) parameter	**Supply voltage characteristics according to EN 50160**	**IEC 61000-2-12**
Supply voltage unbalance	LV, MV: up to 2% for 95% of week, mean 10 minutes rms values, up to 3% in some locations	2%

Source: [12]

2. Methodology

An approximate assessment of unbalance may be made by using calculation method. However, accurate measurement of unbalance requires the use of phase sequence recording equipment and analysis which takes into account the phase angle as well as the magnitude of unbalances from different loads and provides a method to aggregate their effect (Eng Rec No. 10 - Voltage Unbalance v1.0, 2005). A survey was carried out in an environment dominated with the non-linear devices to see the compliance with the standard. This study is to determine the voltage and current unbalanced in a distribution network.

The study was carried out at the Information Communication Technology centres (ICT) of the Federal Polytechnic Ilaro Ogun State. There are two ICT's centres in the Institution. One is located in the East Campus of the Institution and the other is located in the West Campus of the Institution. The total numbers of computers in the East Campus were 64 and that of the West Campus were 72 during the study. Field measurements were taken for two weeks with a week for each location. Voltage and current measurements for both line and phase were taken daily at 2:00pm when the locations are expected to be in operation. A multimeter was the main instrument used to record the line voltages and phase voltages in the two locations.

The unbalance in the system was evaluated by comparing the maximum difference between the average voltage and the value of any single voltage phase divided by the average voltage, usually expressed as a percentage.

3. Results and Discussion

Tables 2 & 3 shows the readings obtained from the two locations during the week. Line and phase voltages were simultaneously taken for each location.

Table 2: Readings at East Campus

		Mon	Tue	Wed	Thur	Fri
Line Voltage (V)	R & Y	416.0	418.0	421.0	390.0	405.0
	Y & B	411.0	415.0	417.0	382.0	400.0
	B & R	415.0	411.0	415.0	385.0	407.0
Phase Voltage (V)	R & N	245.3	248.5	247.6	227.8	235.0
	Y & N	242.2	243.4	244.8	222.8	230.0
	B & N	239.2	234.5	241.5	224.5	239.0

Table 3: Readings at West Campus

		Mon	Tue	Wed	Thur	Fri
Line Voltage (V)	R & Y	390.0	399.0	392.0	399.0	395.0
	Y & B	382.0	389.0	380.0	392.0	386.0
	B & R	385.0	399.0	390.0	394.0	387.0
Phase Voltage (V)	R & N	225.0	231.1	233.2	234.7	236.5
	Y & N	227.5	233.8	234.0	225.6	233.5
	B & N	222.8	230.5	232.2	221.7	231.1

3.1 Data Analysis

Tables 2 and 3 were used to compute the unbalanced voltage in the system. Table 4 shows the variation i.e. differences in voltage between week 1 and 2. The values of the lowest and the highest for each day were recorded and the difference between them. The difference between the highest and minimum voltage which should not exceed 4% of the lowest supply voltage was used to compute the tolerance for each day. Tables 4 & 5 show the results obtained from the computation at each location. The remark (in/out) was used to indicate compliance or not. That is "In" indicates it is within the standard while "Out" means otherwise.

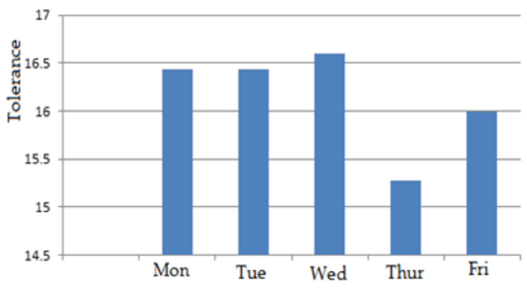
Table 4: Line Voltage Unbalance & Balance Percentage Difference [East Campus]

Days	Line Voltage Range (V)	Difference	Tolerance Evaluation (4% of the lowest V)	Remark (In/Out)
1st Day	416 - 411	5	16.44	In
2nd Day	418 – 411	7	16.44	In
3rd Day	421 - 415	6	16.60	In
4th Day	390 – 382	8	15.28	In
5th Day	407 - 400	7	16.00	In
Average	410.4 – 403.8	6.6	16.15	In

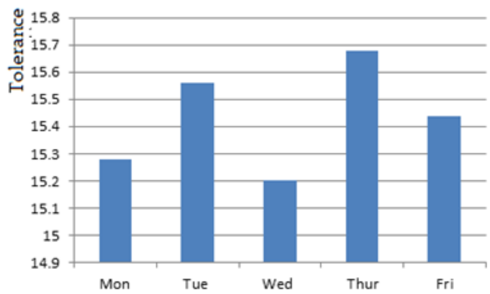
Table 5: Line Voltage Unbalance & Balance Percentage Difference [West Campus]

Days	Line Voltage Range (V)	Difference	Tolerance Evaluation (4% of the lowest V)	Remark (In/Out)
1st Day	390 - 382	8	15.28	In
2nd Day	399 - 389	10	15.56	In
3rd Day	392 - 380	12	15.20	In
4th Day	399 - 392	7	15.68	In
5th Day	395 - 386	9	15.54	In
Average	395 – 391.4	9.2	15.45	In

Figures 2a &b show the plots of tolerance evaluation at each location while Figures 3a & b show that of difference for each location during the week.

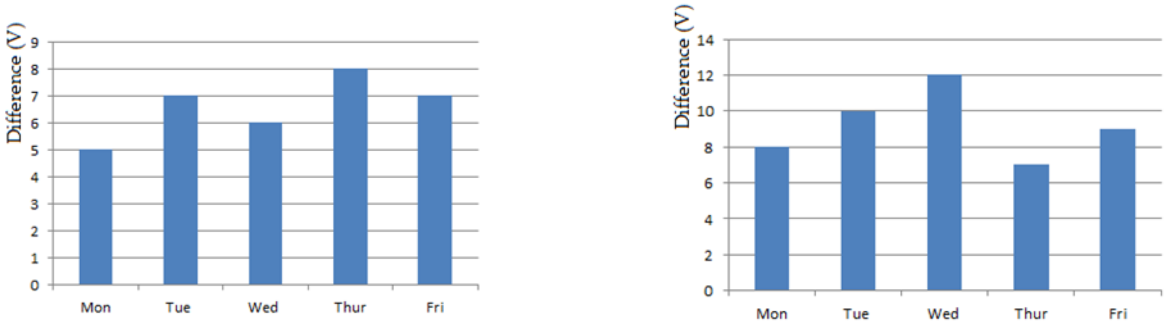


(a) East Campus



(b) West Campus.

Figure 2. Plots of tolerance evaluation



(a) East Campus (b) West Campus.

Figure 3. Plots of differences between maximum and minimum voltage for each day

3.2. Discussion of results

The areas under study show good degree of compliance with the standard as they are all within the tolerance value. This shows that the loads are well distributed within the phase. Optimum distribution of single phase and double phase loads between three phases network is said to be one of the important factors in reduction of the difference in the amplitude of loads between the three phases and power losses consequently [14]. Within each week on each site the range of difference is between 5V and 9V. It should be noted that a three phase non-linear load will have a very large current unbalance with only a small voltage unbalance. Therefore, as more loads are added, there is need to investigate the current unbalance. Adequate measure to ensure that the unbalance of load currents remains within the standard should be put in place during additional installation or retrofit.

4. Conclusion

In conclusion, the problems of unbalance in the distribution network have been discussed in this study. Results obtained from practical measurement during field survey have been presented. Base on the data from this study, the result shows that voltage unbalance is within the tolerance band for most of the readings. However, this type of survey should be periodical to ensure compliance. This is necessary due to the possibilities of additional loads in the future. Also, more parameters such as line and neutral currents should be obtained with types of loads for thorough power quality analysis.

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