International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Analyze Voltage Unbalance in Electrical Distribution Power Network in Low Voltage

Mohammed Abdulhadi Almahdi Alsaddeeq

Om-Alaranb College of Science & Technology, Libya

Abstract: ***Voltage unbalances are associated to variations in voltages and currents for three-phase systems when the RMS voltage values or the phase angles become not equal between the three phases. Voltage unbalances can occur when there is a load imbalance due to an uneven distribution of single phase loads over three-phase power systems. They can also occur due to a large single-phase loading such as when one of the fuses become not operational for three-phase motors. Voltage unbalances can generate overheating within the windings of induction and synchronous machines. In this paper we are presenting to measure, monitoring and controlling voltage unbalance in electrical power distribution networks.***

Keywords: Distribution electrical network, RMS, voltage, induction, single phase power supply, PCC

1. Introduction

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 analyzed for the proper solution in the power system.

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. The distribution of single-phase and double-phase loads along the network and their random instant demand values can be considered as the main causes to voltage unbalance in three-phase distribution systems. Contrary to some other disturbances in electrical power systems, for which the performance is evident for the ordinary customer, voltage unbalance belongs to those disturbances in which their perceptible effects are produced in the long run. Voltage unbalance leads to a sharp decrease on the efficiency of three-phase induction motors. In gulf, 50% of the electric energy is absorbed by industrial customers. Since induction motors represent the largest portion of industrial loads, it is seen that the voltage unbalance should be carefully studied and controlled.

Voltage unbalance in three-phase distribution systems regards the changing in phase angles and/or in the magnitude of voltage phasors. The main causes leading to voltage unbalance are the following ones.

a) Unsymmetrical distribution systems that is equipment and phase conductors present different impedance values.
b) Unsymmetrical loads, such as arc furnaces, single and double phase loads;
c) Different voltage drops due to differences in mutual impedances between phase conductors and between phase conductors and ground. This depends on the spatial configuration of conductors.

Low voltage distribution networks – the main focus of this paper – introduce a small amount of voltage unbalances due to their impedances. The main cause can be considered as the current unbalance, due to the distribution of single-phase and double-phase loads along the network, such as public lighting and residence.

2. 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. 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 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 de-rated 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.

The voltage unbalance index is generally related to the negative symmetrical component system. This is due to the large number of pieces of equipment that have their efficiency and life affected, mainly the ones like generators and motors (based on rotating magnetic fields), where the major part of electrical energy is transformed. Phase-to-phase and phase-to-ground voltage unbalance indices (DQV2) are equal and given by the following equation.

$$DQV_2 = \frac{|V_{AN2}|}{|V_{AN1}|} = \frac{|V_{AB2}|}{|V_{AB1}|}$$

Where V_{AN1}, V_{AN2} are positive and negative sequence phase-to-ground voltages and V_{AB1}, V_{AB2} are positive and negative sequence phase-to-phase voltages.

Equation (1) allows for the computation of voltage unbalance in a system by using phase-to-phase voltages only. Such computation is carried out by utilizing voltage magnitude only whereas methods based on phase-to-ground voltages require the magnitude and phase angles. However such method demands lots of arithmetic operations. The CIGRÉ method was chosen to be used, since it is derived from the CO-SENOS method that keeps the accuracy. The voltage unbalance index can be readily determined by the following equation

$$DQV(\%) = \sqrt{\frac{1 \ \sqrt{36\cdot\beta}}{1+\sqrt{36\cdot\beta}}} \times 100$$

$$\text{Where:}\beta = \frac{|V_{AB}|^4 + |V_{AB}|^4 + |V_{AB}|^4}{\left(|V_{AB}|^2 + |V_{AB}|^2 + |V_{AB}|^2\right)^2} \quad (2)$$

Voltage Unbalance Indices

There are some references to those indices in norms that regulate equipment tests and standards. Table 1 shows a comparative figure of adopted limits in world-wide standards

Table 1: Voltage unbalance limits

	Voltage Unbalance Immunity Levels		Compatibility Level (95% probability of not exceeding	
Standards	Normal condition	Majority of single and double phase loads	Sampling	Period
EN50160	3 %	5 %	15 min	1 week
NRS-048	3 %	5 %	15 min	1 week

Influence of network impedances on Voltage Unbalance

Networks can contribute on voltage unbalance due to the unsymmetrical spatial configuration of conductors. This leads to different phase voltage drops due to different mutual impedances. In order to evaluate this effect on the voltage unbalance, a number of simulations were carried out on low voltage networks. Voltage drops due to mutual inductances are proportional to the flowing electric current and to the conductor length. Thus, a typical distribution network branch was assumed to have the current fixed by the maximum allowed voltage drop. In order to ensure the current balance, a three-phase balanced resistive load was considered to be installed in the receiving bus.

Table 2 presents the computed voltage values and the corresponding voltage unbalance indices (*D%*) along the branch, for different distances (*L*) from the source.

Table 2: Voltage unbalance due to different conductor configurations

	Vertical Configuration (a)				Triangle configuration (b)			
L (m)	*Vab* (V)	*Vbc* (V)	*Vca* (V)	*D%*	*Vab* (V)	*Vbc* (V)	*Vca* (V)	*D%*
120	219.10	219.10	219.10	0.00	219.09	219.09	219.09	0.00
150	211.14	212.53	211.80	0.38	211.75	211.75	211.75	0.00
180	206.45	208.68	207.54	0.62	207.47	207.47	207.47	0.00
200	203.36	206.15	204.76	0.79	204.67	204.67	204.67	0.00

Results shown in Table 2 confirm the small influence from conductor configuration on the voltage unbalance indices.

Evaluation of voltage drops by measurement and by the distribution network management system

The existing distribution management system running at COPEL does not determine voltage unbalance indices. It only provides the distribution of total power flows in each of the three phases of the transformer, estimated from the billed customer energy values.

However, the system provides the minimum voltage level in the distribution network, by considering the nominal voltage (220V) in the low voltage transformer bus. The voltage drops are evaluated at each branch, as a function of load demands and cable characteristics, what leads to the determination of the maximum network voltage drop.

Table 3 shows voltage drop values (ΔV%) determined by the distribution management system and obtained from the field measurements. The latter are the voltage drop values considering probability lower than 3%.

Table 3: Voltage drop values (measurement and distribution management system)

Case #	Net Code	Network Management System				Field Measurement		
		ΔV%		V (volt)		V (volt)		
		Ideal	Actual	Ideal	Actual	Vab	Vbc	Vca
1	C0148	6.69	10.05	205.28	197.89	209.00	209.00	208.00
2	C0950	6.16	8.81	206.45	200.62	210.00	209.00	206.00
3	C0994	3.32	7.74	212.70	202.97	206.00	207.00	207.00
4	C1317	3.93	10.64	211.35	196.59	218.00	212.00	212.00
5	C3807	4.70	8.50	209.66	201.30	205.00	205.00	205.00
6	C4211	2.20	6.13	215.16	206.51	216.00	212.00	212.00
7	C4835	6.24	8.41	206.27	201.50	207.00	205.00	205.00
8	C4974	6.91	9.87	204.80	198.29	203.00	201.00	200.00
9	C5174	5.31	8.42	208.32	201.48	211.00	209.00	209.00
10	C6212	3.81	10.47	211.62	196.97	214.00	215.00	213.00

It is seen that the network management system provides more conservative results, mainly for the values with probability lower than 3%.

Taking case #1, for instance, there was a 199V instantaneous registered value, closer to the one evaluated by the network management system. However such value does not affect negatively customer equipment due to its low probability (0.0025%). In such location, a 206.5V voltage level corresponds to the 1% probability whereas 208.5V corresponds to 3% probability.

Voltage unbalance indices using the Monte Carlo Simulation Method

Table 4 compares the maximum voltage unbalance indices obtained from simulation and from measurement.

By analysing the maximum values of voltage unbalance indices shown in table 4, one sees that the simulation method is rather more conservative. However one should not discard such simulations from a network management system. The main causes for such differences can be explained by the methodology adopted, where 500 possible load unbalance scenarios were analysed for each selected instant in the daily curve. Such a high number of network conditions leads to the evaluation of extreme cases and thus leading to more conservative results. Also, while loads were modelled by 15 minute measurements, simulations were considered in 3 hour intervals.

Table 4: Maximum voltage unbalance indices

Case #	Network Code	Simulation	Instantaneous Measurement
1	C0148	5.87	3.7
2	C0950	6.43	5.5
3	C0994	7.65	2.9
4	C1317	5.27	4.5
5	C3807	8.10	3.5
6	C4211	4.83	4.1
7	C4835	9.05	3.9
8	C4974	7.87	4.3
9	C5174	5.63	3.0
10	C6212	8.58	3.9

3. Conclusion

Voltage unbalance indices determined in field measurements are considered to be low, possibly due to network management procedures adopted in the company. In such procedures, load current unbalance are avoided by an appropriate distribution of single-phase and double-phase customers along the distribution network. Simulation results were validated mainly when considering that 95% of the time the voltage unbalance index is inferior to 3%. The probabilistic method should therefore be incorporated into the company´s network management system. Low cost measurement instruments were shown to be effective enough for monitoring voltage unbalance indices. Although results point out that simulation should be included in the distribution management system, when considering the 96 simulations (one every 15 minute period) throughout a daily cycle (24h) and the large number of low voltage distribution networks (COPEL has approximately 300,000 distribution transformers), the computation time could restrict the application of the method. A very interesting approach would be to consider techniques based on Artificial Neural Networks (ANN). In such approach, the procedure is divided into two phases: training and application. The training phase is based on the data base for load curves and customers connected to the system, on simulations and on measurement campaigns. The voltage unbalance indices would be stored for each type of distribution network, where the type would be defined by given attributes such as load balance amongst phases, network length, cable characteristics, voltage drops, number of customers in each category, monthly energy, etc. In the following phase, having known the network attributes and corresponding loads, the software would be able to estimate the resulting voltage unbalance index. A similar procedure was successfully applied to a distribution transformer loading management

References

[1] NEMA Standards Publication n. MG-1-1987
[2] BERNDT, M. M.; SCHMITZ, N. L. Derating of Polyphase induction motors operated with unbalanced line voltages.
[3] W. EDWARD REID, O. Power quality issues – standards and guidelines. IEEE Transactions on Industry Applications. V.32, n.3, p.625-632, May/June. 1996.
[4] EUROPEAN STANDARD– EN50160. Voltage characteristics of electricity supplied by public distribution systems. Brussels, CENELEC, 1994.
[5] NRS 048-1:1996 ELECTRICITY SUPPLY – QUALITY OF SUPPLY Overview of implementation of standards and procedures. South Africa. 1996.
[6] EUROPEAN COMMITTEE FOR ELECTROTECHNICAL STANDARDIZATION – CENELEC Voltage caracteristics of Electricity Supplied by Public Distribution systems.