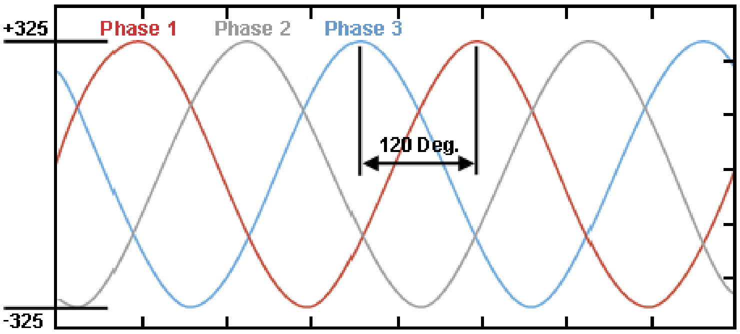
Power Quality Issues - Part 4 - Voltage Imbalance

Voltage imbalance is not a power quality issue in the sense of the quality of the sinus of the electrical supply or events occurring on it, like harmonics and transients for example, but is nevertheless of critical importance for a variety of reasons.

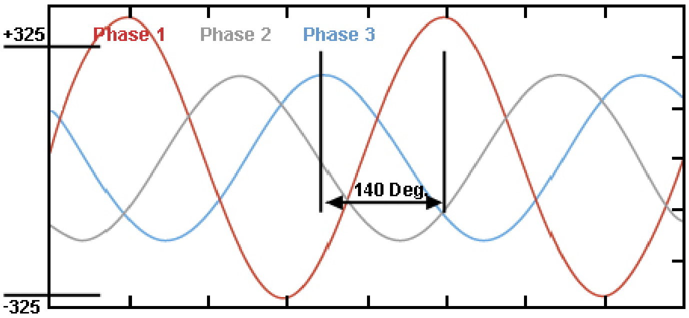
In the 4th part of this series on power quality issues **Julian Grant – General Manager at Chauvin Arnoux UK**, explains what it is and the implications of voltage imbalance on the electrical supply of an installation.

In a balanced 3 phase ac power system, the voltages are all equal in magnitude and each of the 3 phases are 120 degrees apart.



Balanced Phases

Accordingly, an unbalanced 3 phase ac power system has voltages that are not all equal in magnitude and/or each of the 3 phases are not 120 degrees apart.



Unbalanced Phases

Voltage imbalances are caused by big single-phase loads, such as induction furnaces, traction systems, and other large inductive machines, drawing a current on the phase they are connected to that does not appear on the other two phases. Some equipment may also be connected between two phases such that current is only drawn on two out of the three. Either way, this causes the higher loaded phases to experience a greater voltage drop, reducing the voltage on those phases, or one particular phase, for all other equipment connected to the same supply.

The uneven distribution of general single-phase loads across a 3-phase system can also sometimes be bad enough to cause a slight voltage imbalance. This more often than not occurs over time as an installation, originally balanced during its construction, has additional circuits and equipment added to it. The unequal degradation, or failure of one or more PFC capacitor units in a bank can also cause voltage imbalance, and temporary voltage imbalances can be produced by a fault on any one of the phases either within the facility or further back up the supply network.

Having balanced phase voltages is arguably one of the most important requirements for an industrial installation, particularly if it contains 3 phase motors, and crucially if they are operating at or near their full load capacity. Unbalanced voltages at motor terminals can cause a phase current imbalance of up to 10 times the percentage voltage imbalance for a fully loaded motor. Accordingly, motors operating on imbalanced supplies need to be de-rated with significant reductions in available loading for relatively minor voltage imbalances.

Imbalances can also require the necessary de-rating of power cables due to increased I^2R losses in the cable.

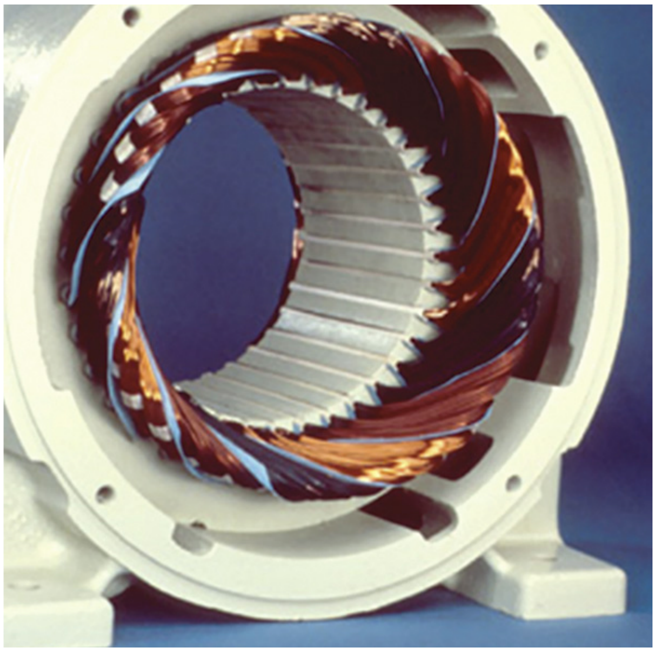
Voltage Imbalance	Required Motor Derating
1%	98%
2%	95%
3%	88%
4%	82%
5%	75%

Motor derating requirements due to voltage imabalance

According to the IEC, voltage unbalance is defined as the ratio of negative sequence voltage to the positive sequence voltage. Briefly explained, the three phase voltages can be mathematically expressed as a sum of positive, negative and zero sequence components. Positive sequence voltage creates flux in the direction that the motor is intended to rotate, and negative sequence voltages rotate in the opposite direction. This creates flux in the opposite direction, however, since the positive sequence voltages are always much larger than the negative sequence voltages the direction of motor rotation is not affected.

IEC 60034-1 imposes a 1% negative phase sequence voltage limit on the supply feeding machines. However, EN 50160 states that imbalances of up to 3% can be expected, and indicates that an acceptable supply system standard is that "under normal operating conditions, during each period of one week, 95% of the 10-minute mean rms values of the negative phase sequence component of the supply voltage shall be within the range 0 to 2% of the positive phase sequence component".

The counter rotating negative sequence flux caused by negative sequence voltages creates additional heating in the motor windings that will eventually lead to insulation breakdown and premature motor failure. A continuous operation at 10 °C above the normal recommended operating temperature can reduce rotating machine life by a factor of two. Shortened motor operating lifetimes are obviously hugely disruptive and expensive. The impact of this problem is evident by the existence of many businesses developing and manufacturing devices that monitor voltage balance to protect motors.



Darkened insulation on overheating winding due to voltage imbalance.

Apart from the motors themselves, many solid-state motor controllers and inverters also include components that are especially sensitive to voltage imbalances. Depending on the product, some of these will protect themselves and the motor in the event of voltage imbalance and refuse to operate. For less sophisticated devices reduced life of Variable Frequency Drive (VFD) front end diodes and bus capacitors are a common result of voltage imbalance.

UPS, polyphase converters, and inverter supplies also perform with reduced efficiency in the face of voltage imbalances on the supply, creating unwanted ripple on their DC side and, in many cases, also creating increased harmonic currents on the supply.

Fortunately, the measurement of voltage and load (current) balance, and therefore the identification of imbalance, is easily achieved using a power and energy logger (PEL). Connected at the incoming supply the loading across the phases for the whole installation can be monitored over time to see how it might vary during the normal operating day or week. PELs can be quickly moved around the installation, non-intrusively connected, and utilised to measure individual equipment or circuit loads and voltages to achieve balance throughout the installation, and then reconnected to the incoming supply for ongoing monitoring. As well as voltage and load balance this will enable measurement and monitoring of other power quality parameters including power factor and harmonics.

There are two obvious precautions or actions to reduce voltage imbalance and its effects. Firstly, use separate circuits for large single-phase loads, and connect them as close to the point of the incoming supply as possible. This will ensure that the load does not cause a voltage drop on any wiring utilised by other equipment that would then be subjected to that voltage drop. Secondly, ensure that all single-phase loads, large and small, are balanced evenly across all three phases. Two simple steps that could save a lot of headaches and expense.

The Power Energy Logger (PEL)

Chauvin Arnoux Ltd
Unit 1 Nelson Ct, Flagship Sq, Shaw Cross Business Park
Dewsbury, West Yorkshire - WF12 7TH
Tel: +44 1924 460 494
Fax: +44 1924 455 328
info@chauvin-arnoux.co.uk