

IC.3.1—Voltage Balance

1. Scope

This document defines PacifiCorp's guidelines for voltage balance.

2. General

Voltage imbalance can cause various problems. Three-phase motors may run hotter and unless the motors are operated below their rated capacity (de-rated) may wear prematurely. Unbalanced voltages have caused malfunctions in variable speed drives.

A major cause of unbalanced voltage is unbalanced load current. This imbalance can be due to customer load imbalance, utility system imbalance, external influence or self induced.

3. Definition of Voltage Unbalance

The definition of voltage imbalance is found in Appendix D of ANSI Std. C84.1, *Voltage Ratings for Electrical Power Systems and Equipment*. That standard was concerned with the effect on motors; therefore, phase-to-phase voltages were used in the example. Voltage unbalance of a polyphase system is defined as follows:

$$\% \text{ voltage unbalance} = 100 \times \frac{(\text{maximum deviation from average voltage})}{(\text{average voltage})}$$

Example:

With phase-to-phase voltages of 230, 232, and 225, the average is 229; the maximum deviation from average is 4; and the percent unbalance is $(100 \times 4) / 229 = 1.75$ percent.

4. Voltage Unbalance Limits

Relatively small voltage imbalances are often achievable close to substations on circuits with well-balanced loads. Farther out on circuits it can be extremely difficult and very expensive to achieve a high level of voltage balance.

An excessive level of voltage imbalance can have serious impacts on induction motors. Induction motors are designed to tolerate a small level of imbalance, but they have to be de-rated if the imbalance is excessive, which is an added cost for the installation. Applying the recommendations of ANSI Std. C84.1. is a reasonable middle ground in an attempt to optimize voltage balance and minimize total cost to the customer and the utility.

Those recommendations are:

1. Electric supply systems should be designed and operated to limit the maximum voltage imbalance to *three percent* when measured at the electric utility revenue meter under no-load conditions. This corresponds to a motor de-rating to 90% of it's full load rating according to ANSI C84.1.

2. If an electric supply system is operating near the upper or lower limits of the ANSI Std. C84.1 voltage ranges, each individual phase voltage should be within the listed limits. (These voltage ranges are listed in 1C.2.1, Voltage Level and Range, in this Handbook.)

It is important to recognize that operation under strict limits for voltage balance would require major system changes, which cannot be economically justified from the standpoint of the customer or PacifiCorp. In other instances, unique or changing system conditions may make it impractical to remain within specific limits for all operating situations. However, PacifiCorp makes every reasonable effort to maintain voltage balance to meet the needs of typical customer equipment and the most efficient utilization of the distribution system.

5. Voltage Balance Measurements

Voltage imbalance in a three-phase system exists when the magnitudes of phase or line voltages are different, the phase angles differ from the balanced conditions, or both. This can occur due to unequal system impedances or unequal distribution of single-phase loads.

Many three-phase loads are served from transformers with four-wire wye connected low-voltage windings, such as 208Y/120 volts, or 480Y/277 volts. Voltage should be measured line-to-line and line-to-neutral. Balance may be evaluated for both cases. Appropriate actions should be considered to resolve conditions at places where unacceptable imbalance exists.

Example: Three line-to-neutral voltage readings of 122.0, 118.0 and 118.0 volts are recorded. The average is 119.3 volts with maximum deviation of 2.7 volts and an apparent imbalance of 2.23%.

The same case using voltage measured line-to-line yields a different result. The line-to-line voltages would be 207.8, 204.4 and 207.8 volts. This would give an average of 206.7 volts, a maximum deviation of 2.3 volts and a voltage imbalance of 1.12%.

This shows the difference in voltage imbalance on the line-to-line calculations and the need to measure voltages from phase-to-phase as well as phase-to-neutral.

Motor windings are often delta connected and are sensitive to the phase-to-phase voltages. Line-to-line and line-to-neutral measurements provide the data needed to evaluate either case. Failure to collect all the data may yield incomplete conclusions. In some complete cases, time recordings are required to see actual change of values through a loading cycle and the apparatus results. Some recording volt/amp meters may give vector values but the six simple voltages measured at the time of impact provide the required information to determine the magnitude of the imbalance and possibly determine alternatives for a solution.