

## Line Impedance

It is a common misconception that most power disturbances are generated outside of the facility. In this view, the electric utility is guilty of providing "dirty power" that the facility must cope with.

While some power problems do originate outside of the facility, many disturbances are caused internally. These disturbances are created by load currents interacting with the electrical system's *Line Impedance*.

### Voltage Regulation

The voltage seen at the receptacle or point of use is rarely the ideal, or nominal voltage. This utilization voltage is usually some small percentage lower than the nominal voltage. The percentage of difference between the nominal level and the actual voltage is known as the *Voltage Regulation*.

Voltage Regulation has two main causes.

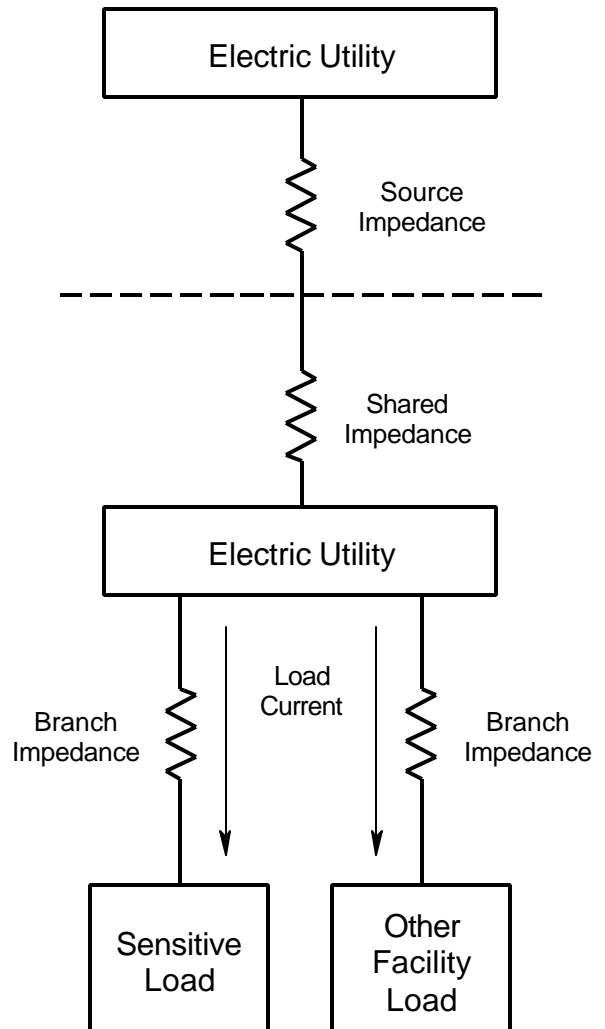
Some regulation is caused by utility variations in the capacity and utilization of electricity. To the end-user within the facility, this regulation appears to be independent of facility load, and is called **Line Regulation**.

A second type of variation is caused by variations in loading within the facility. This is known as **Load Regulation**. Load Regulation is caused by the load current, acting on the impedance or resistance inherent in the electrical system.

Load Regulation can be expressed using a simple form of "Ohms Law". For a 10 Amp load, a 120 VAC source, and a mains impedance of 0.25 ohms, the voltage drop can be calculated:

Voltage Drop	= Load Current x Impedance
Voltage Drop	= 10 Amps x 0.25 Ohms
	= 2.5 Volts
Percent Drop	= 2.5 Volts / 120 Volts
	= 2.1 %

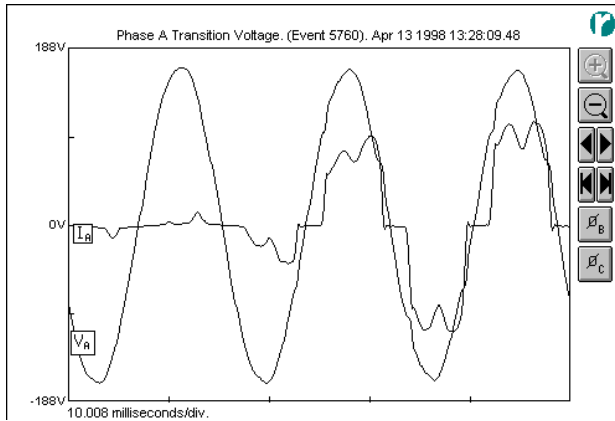
## Application Note - AN-10



## Line Impedance

Line impedance is the sum of resistance, inductance, and capacitance found in every electrical device. Common sources of line impedance include copper conductors, transformers, contactors, fuses, and terminals. Every electrical device contributes a small amount to the total line impedance.

Line impedance causes several power quality problems. Excessive impedance causes **voltage sags** when facility loads are energized, especially loads that have high inrush currents. **Long term voltage fluctuations** are caused as facility loads are switched on and off during the day. Finally, **harmonic distortion** and **voltage transients** are caused by high frequency currents drawn by electronic loads within the facility.



*Line impedance causes line voltage to change as load current changes.*

Line impedance is responsible for many of the power problems within a facility. Close attention to line impedance during the design phase can result in a large improvement in power quality without expensive power conditioning devices.

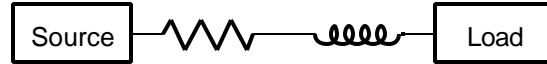
## High Frequency Impedance

Impedance is often modeled as a pure resistance (For example, when making voltage drop or fault current calculations. This is valid at low power levels and at the fundamental frequency (50 / 60 Hz).

In reality, impedance is better modeled as a resistance and a series inductance. This impedance becomes much higher at higher frequencies, making impulses, distortion, and high frequency noise much worse than expected with a 60 Hz or resistive impedance model.



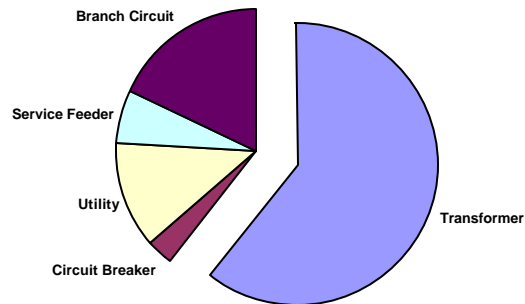
*Simple "Resistive" Impedance Model*



*More Accurate Impedance Model*

## Sources of Impedance

Impedance is distributed throughout the facility. Although it is often modeled as a lump sum (single resistance and/or inductance), total line impedance is made up of the impedance of many separate components. One of the highest impedance devices that can be found in a facility is a transformer or power conditioner.



## Measuring Impedance

Impedance calculations are common for facility engineers for safety reasons: circuit protection, touch voltages, and conductor sizing all depend upon an accurate gauge of line impedance. These calculations depend upon:

- Source impedance as reported by the electric utility.
- Transformer impedance as specified by the manufacturer
- Wire drop calculations, made by an engineer using standard conductor tables
- Contact, fuse, and switch impedance as reported by the device manufacturer.

In cases where impedance calculations are not available, Mains Impedance or Line Resistance Meters can be used to measure impedance. These devices work by measuring the voltage, applying a small load, measuring the resultant voltage, and calculating the mains impedance.

These meters are not commonly available at the facility level, so in most cases, a calculation or estimation of mains impedance is used.

## Minimizing Impedance

There are a number of design techniques that can be used to reduce or minimize the line impedance. It is important to remember that line impedance is made up of many components, each of which has a varying contribution to total impedance. It is much more productive to make impedance improvements in the highest impedance components, such as transformers and long conductor runs, than to concentrate on smaller factors such as contact impedance.

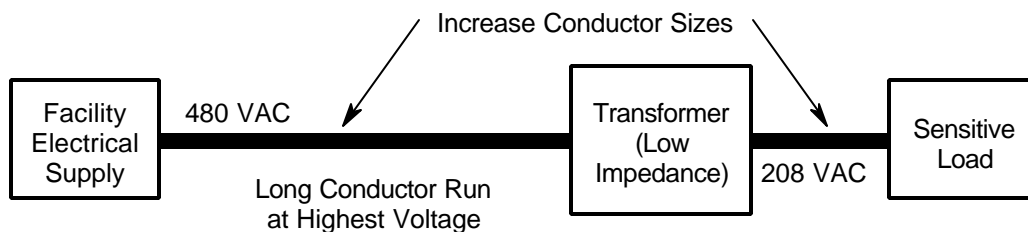
Recommended practices, in order of improvement magnitude, include:

- Never use multiple transformers to achieve proper load voltage.
- Select low impedance transformers. Typical transformer impedance of 5% - 8% can be reduced to 1% - 3%.
- Design long conductor runs for the highest available voltage. (Use a higher voltage, such as 480 VAC, if available instead of lower voltages such as 208 VAC)
- Increase conductor sizes above the minimum sizes specified by thermal design.

## Improving High Frequency Impedance

Improving the 60 Hz impedance can improve the power quality to any critical load. However, for the greatest improvement in power quality, a transformer or power conditioner specifically designed to minimize 60 Hz and higher frequency impedance is required.

*Teal Electronics* has pioneered the art of designing low impedance transformers to enhance power quality and reduce load generated voltage disturbances.



*Techniques to Minimize Impedance*