Colorado Springs Utilities
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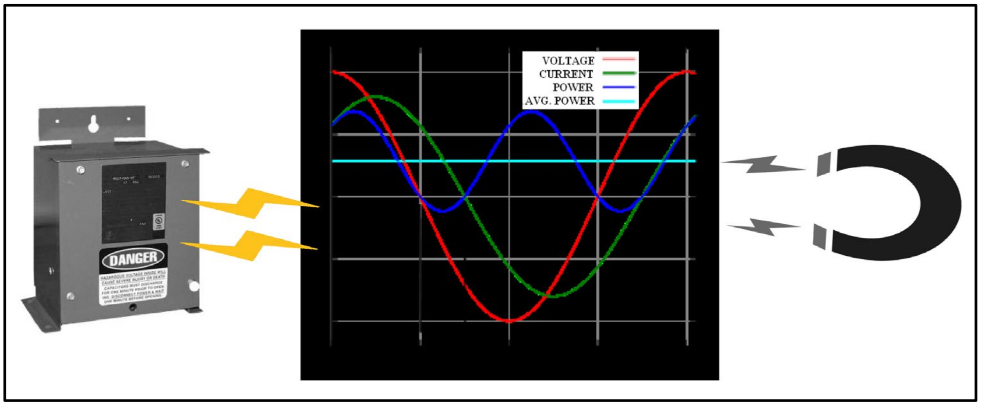
POWER FACTOR CORRECTION

WHITE PAPER #23

What is Power Factor?

(Why does it need 'Correcting' ? Did it make a mistake?)



This paper's purpose is to remove some of the mystery behind power factor. After reviewing this information, the reader will understand why power factor is important to the utility, why there are charges for it, and what can be done to reduce or eliminate those charges. If there are still questions, feel free to contact us. Thank you!

Background on Power Factor

In engineering terms, power factor is about frequency, wave forms, vectors, etc. In more practical terms it is simply the ratio of real power to apparent power.

$$\text{Power Factor} = \frac{\text{Real Power}}{\text{Apparent Power}}$$

Where:
Real Power is what is measured on our utility watt meters
and
Apparent Power is the product of Volts and Amps

In a DC circuit (like a car battery), there is only Volts and Amps. The voltage is steady and isn't oscillating like it does with AC current. Here, Power is easily calculated.

(DC) Power = Volts x Amps

But for AC power, there is more to it, and the extra piece is power factor.

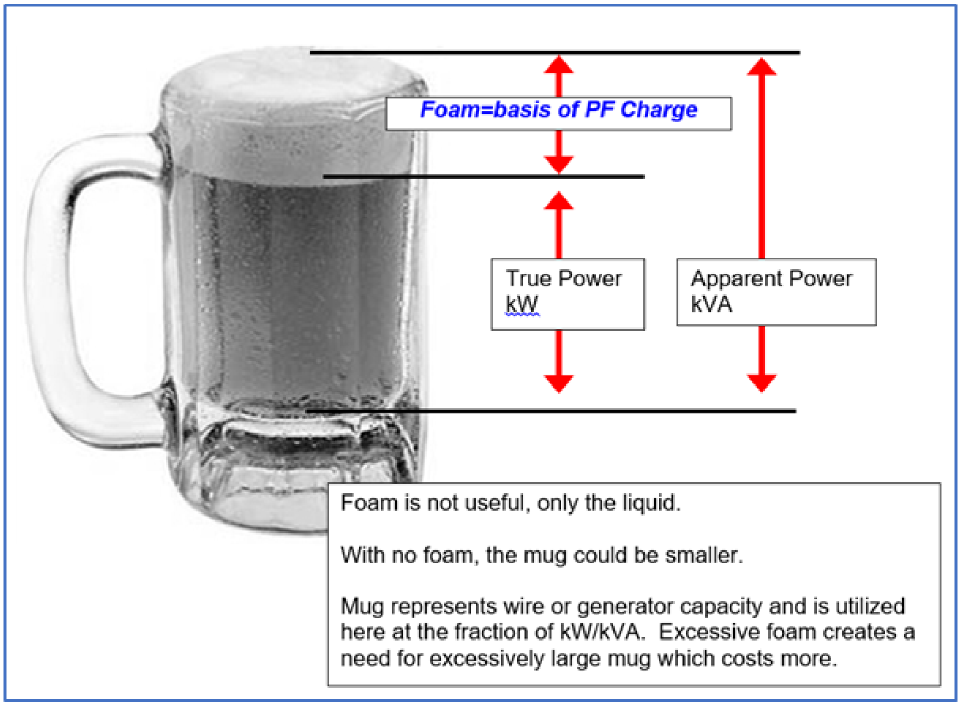
(AC) Power = Volts x Amps x Power Factor

Therefore, whenever the power factor is less than 1, the real power is less than the apparent power. Why is this important? Two reasons:

1. Generators, transformers, switches, cables, and our cost of service are based on apparent power (volts and amps, mostly amps).
2. Our revenue collection is largely based on real power (watts).

So, customer loads that have a low power factor cause us to deliver more volts and amps (mostly just more amps) for the same amount of power (watts) used, compared to a customer with a higher power factor. Without the power factor adjustment, this would increase the cost of service for some customers to compensate for others. With the power factor charge, only those customers with low power factors pay the charge, and it is fair to all. Sometimes a visual aid helps with this concept. Consider a mug of root beer. The 'mug' represents the current carrying capacity of the generator or cable. When there is foam, there is less room for root beer; when there is low power factor there is less capacity for transmitting power. With less foam, the mug holds more root beer - more power can be transmitted without having to buy bigger cables. That's why we like high power factors!

Some equipment includes built-in power factor correction, others do not. In the end, each customer's facility is a mixture of different individual loads and power factors, stirred together and connected to the utility transformer. For customers large enough to be on a demand-based rate, we use meters to record the demand. These same meters record power factor.



Foam is not useful, only the liquid.

With no foam, the mug could be smaller.

Mug represents wire or generator capacity and is utilized here at the fraction of kW/kVA. Excessive foam creates a need for excessively large mug which costs more.

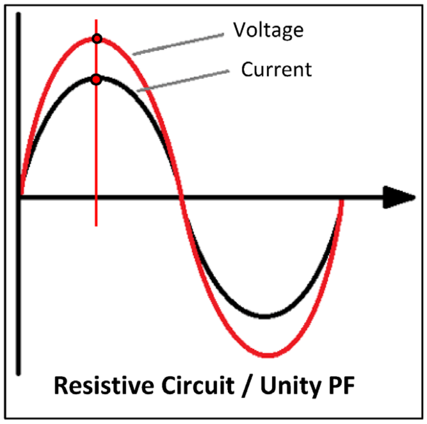
What causes low power factor?

Understanding 'why' will lead to the answer of what to do about it. What drives low power factor is when the current and voltage are out of synch. See the wave form chart at the top of the paper. If "time" is proceeding to the right, you can see that the current wave is behind the voltage wave. In a perfect world they would occur simultaneously. When the current lags behind as shown, the power factor starts to droop – the more it lags the worse the power factor. What causes the lag is usually something in the building utilizing an electromagnetic principle to operate. The build-up of a magnetic field takes some time. In the case of DC this process occurs once, but in the case of alternating current it is forever building and collapsing the magnetic field……and that's when current lags voltage. Common things that contribute to low power factor (***think magnetic***):

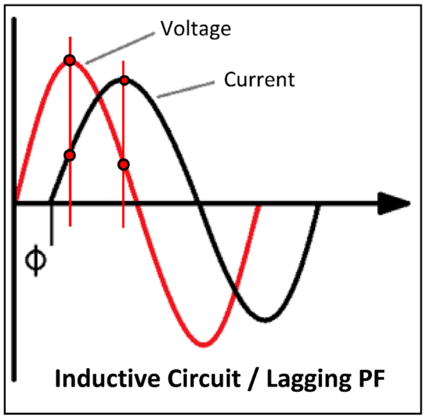
- Motors, especially when oversized
- Transformers, especially when oversized
- Older magnetic lighting ballast
- Solenoids and lifting magnets
- Welders
- Battery chargers, inverters, rectifiers some power supplies

Need more on what power factor really is?   OK. If you get the 'watts = volts * amps', then you will get this explanation which involves waves that are used in alternating current (AC) electricity delivery. Look closely at the two waves (one is voltage, and one is amps). Power factor (PF) is explained visually.

- When the two waves are exactly in sync, the peaks of each wave occur at the same time (left image 'High Power Factor'). This is a power factor of 100% or 1.0 and is as good as it gets - the wires carrying the electricity can be fully utilized, meaning if a wire can carry 100 kVA at its limit, it can also deliver 100 kW of power (kW/kVA=1.0).
- *When the waves are not in sync*, the same 100 kVA cannot provide 100 kW anymore – at a power factor of 0.8, this wire could only provide 80 kW at max capacity…. and the wire is underutilized. Worse, if the circuit load required 100 kW that comes with 120 kVA, a larger wire would be required; hence the power factor charge.



High Power Factor
Volts and amps peak together. kW=kVA.



Low Power Factor
Volts and amps peak at different times. When current is max, voltage is less than max, and vice versa. kW<kVA and the max kW this wire or transformer can deliver is reduced.

Power factor correction equipment restores the capacity by pushing the two waves closer together.

How are power factor penalties billed?

Our billing system collects revenue for low power factor by raising the demand charges. We correct our power factor leaving the generating station to 95% or higher, and any customer with a power factor of 0.95 (95%) or higher will not have a power factor charge. But, for each percent below 95% the demand charge is increased by an equal amount. For example, if the customer's power factor is 85%, that is 10 percentage points below the 95% limit – thus the demand charge is increased by 10%. It's not a separate line item but knowing how the bill is calculated allows any customer to determine what their power factor charge is. This is described in more detail in **White Paper #22 'Understanding Large Commercial Electric Bills.'**

How can power factor costs be reduced?

By improving the power factor, the charges will be proportionally reduced; if the power factor is raised to 95% or higher consistently, there will be no power factor charges at all.

How to improve facility power factor

Step 1. Determine how much is being spent on power factor.
Step 2 Find the source of low power factor.
Step 3. Correct the power factor.

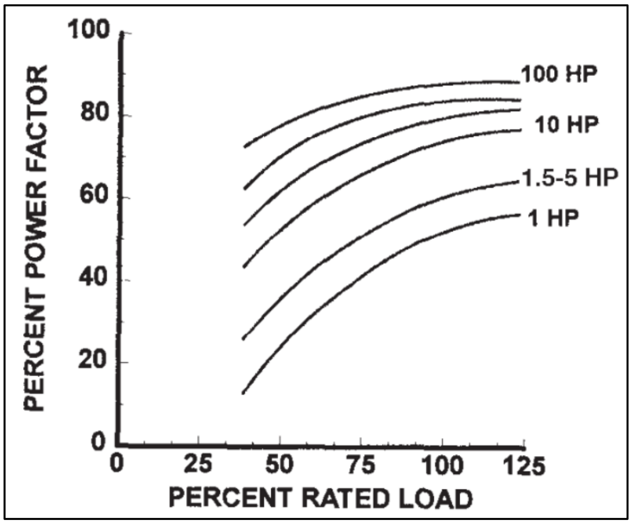
Step 1. Determine how much is being spent on power factor. This does two things for the customer

- It shows how much can be saved (maximum savings = the amount of power factor charges). This provides a sanity check for evaluating the cost of the corrective measures in Step 3. For example, if the cost of correcting power factor is $10,000 it would probably make sense to do if the potential savings are $5,000 per year (2 year payback), but probably would not make sense if the potential savings are only $1,000 per year (10 year payback). This is a customer choice.
- It shows the consistency pattern of the low power factor. When the low power factor is consistently or seasonally low, the remedies are more straight forward than when power factor charges occur randomly throughout the year.

Step 2. Find the source of low power factor. This step is best done with people specializing in power factor correction

- Taking measurements with specialized meters will show where the low power factor is coming from (which equipment) plus other important measurements like 'harmonics' (see **Appendix**). In some cases, the power factor may come from one large unit. In others it may come from a group of motors in one room. In other cases, the power factor issue comes from lots of smaller equipment spread around the building.

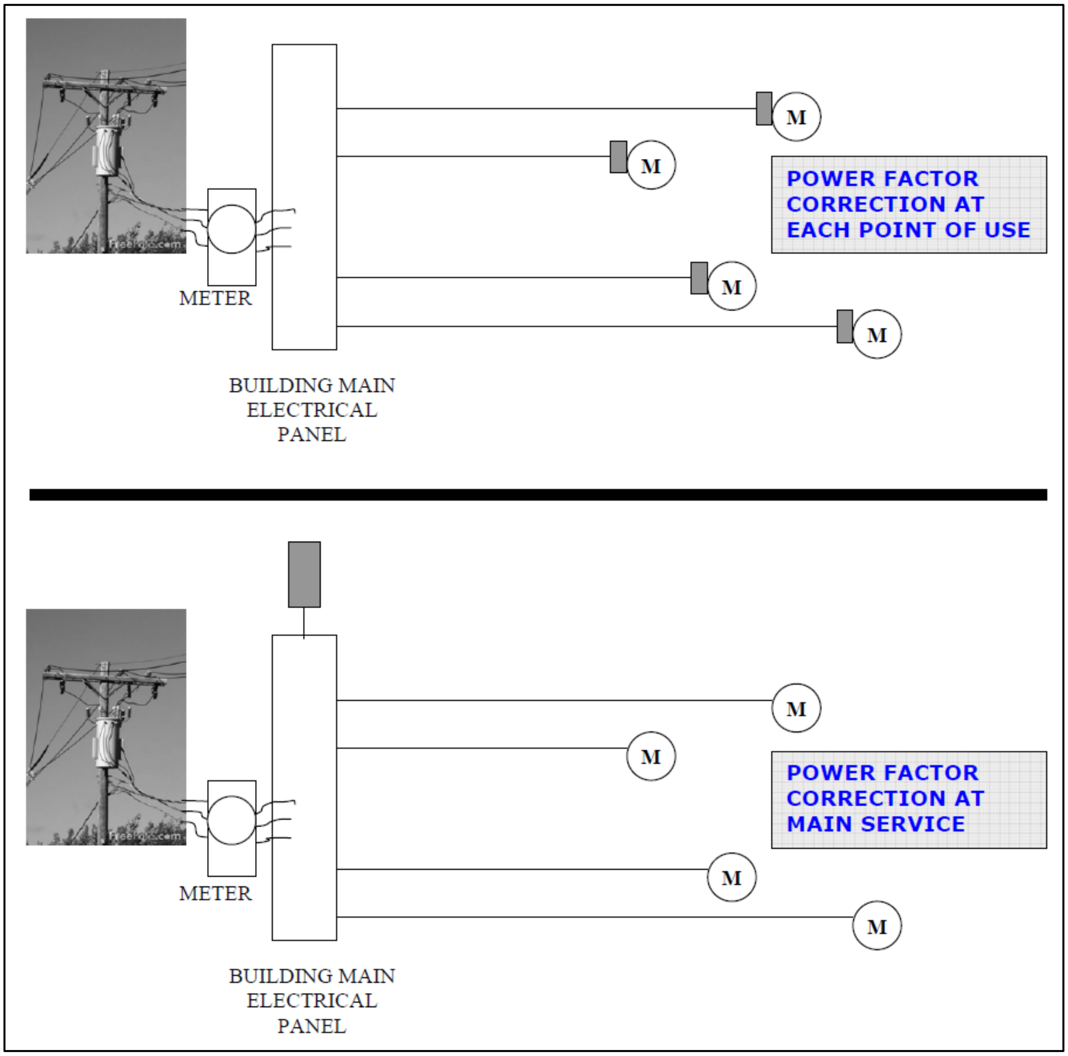
- It is interesting to note that the power factor of a piece of equipment is not a fixed value – it may be one value at full load or on a nameplate and another at reduced load. Oversized equipment that runs at a light load most of the time will make the power factor worse in most cases. For motors this has been well documented.



Effect of lightly loaded or oversized motors on power factor

Step 3. Correct the power factor. Get expert advice before choosing equipment to correct the power factor.

- Where practical, it is best to correct the power factor (raise it) at the device itself; e.g. at the motor. The reason for this is subtle but can be important.
    - *First*, the power factor correction effect is only felt upstream of the correction equipment. Consider a large motor with an 80% power factor. With a PF correction capacitor at the motor, the extra current carried from low power factor is only ‘felt’ by the wiring between the correction equipment and the motor – a short distance. But if the correction capacitor is located at the main service entrance, all the building wiring between the two points still ‘feels’ the extra current.
    - *Second*, correction equipment at a main service often needs the additional feature of variable correction to compensate for changing loads (different equipment running) – when installed at individual equipment the solution is often simplified since it is only in effect when that equipment is turned on. Each facility will have its own ‘best’ solution that balances performance with practicality and cost.



Power Factor Correction Equipment Connection Locations

- Fixed capacitors for PF correction
  - In many cases, the power factor is low due to motor loads and can be easily corrected with properly sized fixed capacitors. ‘Fixed’ means it creates a certain amount of ‘VARs’ at all times.
  - ***In general, it is not recommended to have a leading power factor in the building, so careful sizing of capacitors is needed to prevent it. Leading power factors cause voltage rise which may not be terrible, but they can also cause generators inside your building to trip. Also, if a capacitor was sufficiently over-sized, power factor charges would appear all over again since the utility charges for low power factor lagging or leading.***

- Variable capacitance PF correction equipment
    - When the points of correction are spread around and not convenient to treat separately, it can make sense to treat power factor at one point, at the main service entrance. In this case, the power factor correction equipment must have a provision to modulate its capacity with the load - a fixed capacitor at the main service would over-correct in times of light load.
    - Some variable capacitance systems use an assortment of capacitors that are switched in and out as needed. These are simple and economical but need to be watched because they occasionally fail and may not give a warning. For these systems:
        - Include a PF meter on the front of the panel that you can habitually watch
        - Include transient suppression to avoid equipment within your building seeing the voltage spikes created each time the contactors connect or disconnect a capacitor
        - Check the electric bills regularly to make sure the PF charges go away and stay away
    - Other variable capacitance solutions for the main service are ‘VAR Compensators’. These are high speed electronics and filters. These cost more than simpler methods but are attractive because there are no side effects and they are durable. They are also immune to harmonics.
    - Another solution for variable capacitance is a synchronous motor – by the nature of this special motor it serves to adjust power factor - the motor turns but isn’t connected to anything mechanically. Bulky and higher cost, but a proven technology.
- Harmonics
    - While capacitors won’t create harmonic issues, *harmonics can create issues for capacitors*. The presence of high amounts of harmonics can cause significantly reduced life span of a capacitor which spoils the planned economic return for the project. The reasons for this lie in engineering analysis, but the bottom line is that if the customer facility has a lot of harmonics in it, the chances are it will not be compatible with fixed capacitor solutions. Facilities with significant amounts of high tech equipment like switching power supplies, computer controlled robotics, are red flags for harmonics concern. To be certain harmonics do not haunt your efforts in power factor correction, a gentle reminder that the survey (**Step 2**) should include harmonic measurements as well as power factor measurements.

www.capacitorconvertors.com

Fixed Capacitor

www.syntron.co.in

Automatic Switching Adjustable Capacitor Unit

www.squared.com

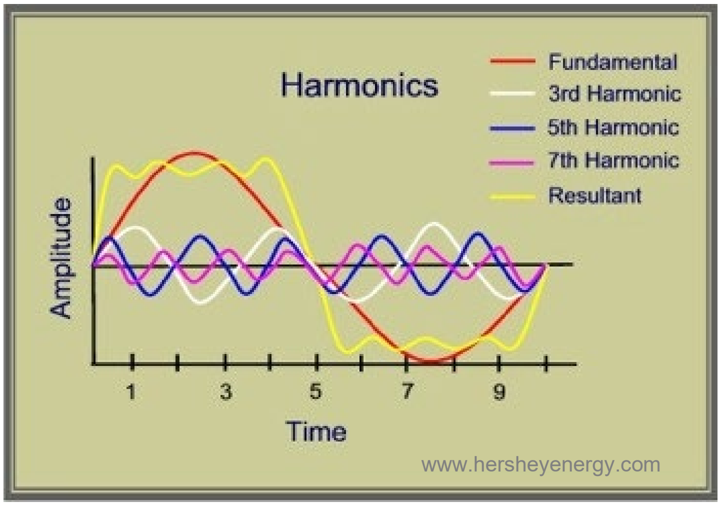
VAR Compensator

www.pscpower.com

Synchronous Motor

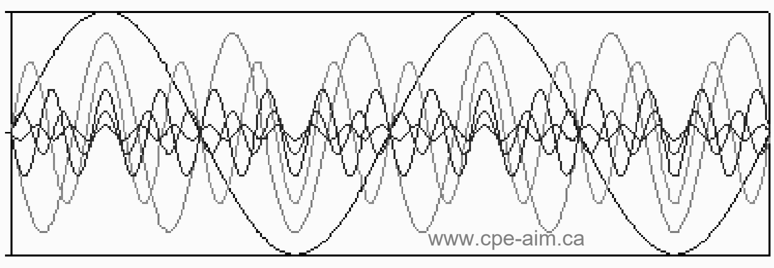
Power Factor Correction Equipment

APPENDIX: Harmonics



Harmonics are becoming more and more common with technology advances, so a basic understanding of what it is and what to watch out for are good tools to have.

An electrical engineer could spend hours discussing this subject because it is very complex. This paper will limit the discussion to why it can be of concern in a building.



Harmonics are resonant frequencies. Usually they operate at higher frequencies than standard 60 cycle line current, but one thing all harmonic frequencies have in common is that they have wave forms that match the 60 cycle utility supply at some point and do so repeatedly. This has the effect of adding to the wave's size and distorting it.

For example, a wave operating at 120 Hz would align with the 60 cycle wave form every other peak. This is called the first harmonic. As it happens, the most troublesome harmonics are the 5th to 7th but all harmonics are a potential source of trouble. These rogue waves superimposed on top of the utility wave shape create “harmonic distortion” because it changes the wave's shape. Too much distortion creates issues with sensitive electronic equipment; the ‘noise’ (irregularities in the wave form” can confuse some equipment. For this reason, facilities like data centers will often use special power conditioning equipment to clean up the waves to a clean sine wave.

In the case of power factor correcting capacitors, a different issue exists with harmonics, having to do with the frequency. Due to the nature of capacitors, the harmonic component on the lines “looks like” a short circuit and pass through the capacitor; this effect is more pronounced at higher frequencies. If sufficient quantity of this harmonic current exists the capacitor will be stressed, overheat and fail prematurely – as in a year's time or less.

Other harmonic-related issues include nuisance tripping of circuit breakers and heating of neutral conductors. It's all bad. IEE-519 is a standard that prescribes the maximum amount of harmonics a customer should generate to avoid issues with utility services (we don’t want it either) or your neighbors. Of course, all of it goes away if there are no harmonics in the first place. But some equipment vital to business operation inherently creates harmonics, so what to do? Consider typical equipment that is notorious for creating harmonics:

- Switch Mode Power Supplies
- Variable Frequency Drives (VFDs)

Where possible, specifying this equipment with on-board filters or inherent designs that limit harmonic generation will pay dividends by making the whole problem smaller. Using our example certain power supplies or certain VFDs emit fewer harmonic, or accessories can be provided to snub them at the source. As a second tier action item, isolating large harmonic creation equipment with filters or isolation transformers can restrict it to just that area. The other approach is to invest in building power conditioning equipment to actively neutralize it. Usually the business operations personnel are aware of the phenomena when harmonics are prevalent in their industry, and the consulting engineers that design the buildings and infrastructure to support the business are trained to deal with it. Suppliers of power factor correction equipment are also good sources of knowledge on harmonics. Seeking the advice of such experts is a good place to start.