Is Power Factor Correction Justified in the Home?

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Though PFC equipment may be warranted in industrial applications, an analysis of the energy savings enabled by this equipment in residential applications suggests its added cost to the consumer may not be justified.

Recently, you may have noticed advertisements for a device that claims to reduce your monthly home electricity bills. The advertising literature states that you are paying for the added electricity that must flow when power factor (PF) is less than "unity" within your house. But to what extent does PF influence energy consumption? And do the energy savings accrued through power factor correction (PFC) justify the purchase of standalone PFC devices? Moreover, do the energy savings justify the addition of PFC components within home appliances where PF is less than one?

Numerous pieces of equipment in the home are candidates for PFC. Some of these equipment types have capacitive inputs (for example, switching power supplies). However, some of the larger loads are the motor-driven appliances such as refrigerators and washing machines, which have inductive inputs. An analysis of these types of equipment examines their typical energy requirements and the impact of PFC on their energy usage within the home.

Power Factor

The electricity provided to your house varies in amplitude and direction of flow in the wires leading to and within the house. It is varying in a sinusoidal manner. You pay for the electricity by paying for the electric power provided multiplied by the time for which this power is delivered. Electric power is simply computed by multiplying the voltage times the current times a "fudge factor" (i.e., the PF).

The work done is computed by determining this product; therefore, the maximum work is done when the voltage and current reach their maxima at the same time (**Fig. 1**). For a fixed amount of power, if the PF is less than unity, additional

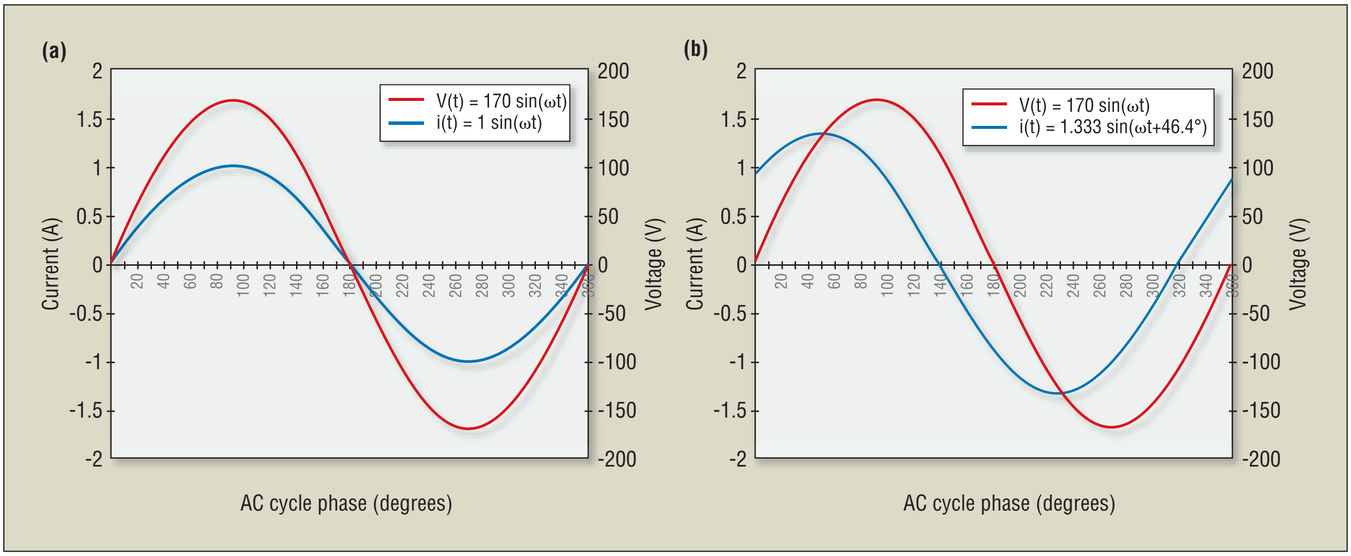


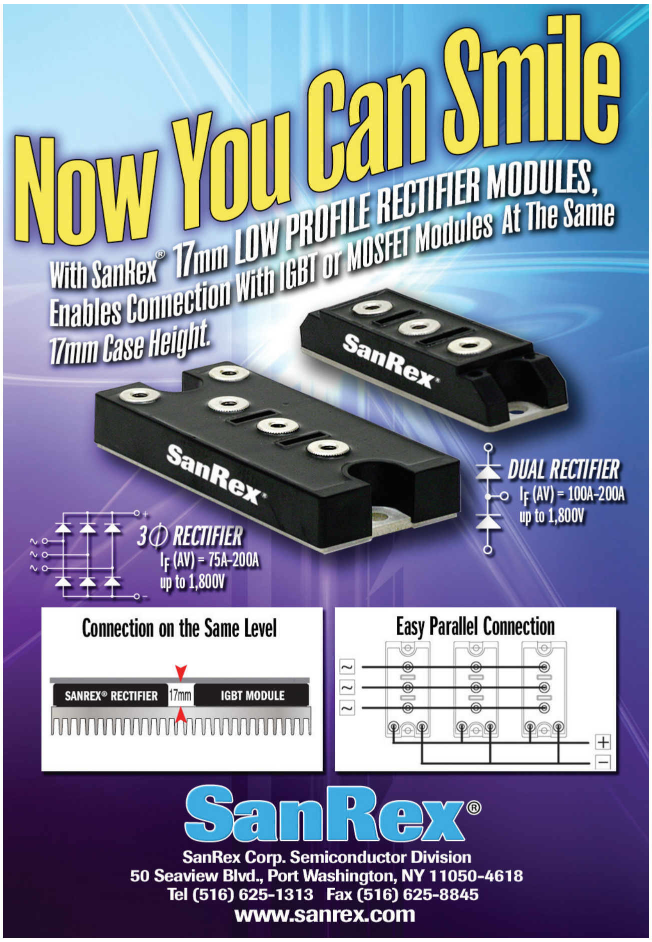
Fig. 1. *Current must vary to deliver the same power to loads with different power factors. If power factor is unity (a), the current level will be less than it would be for any power factor less than one (b).*

current must flow to compensate for the current and voltage that do not have simultaneous maxima.

When the current and voltage simultaneously achieve maxima, the PF is said to be unity. The presence of some types of electrical equipment causes the electrical current to continually play catch-up with the electrical voltage. If the current is always playing catch-up, the circuit is said to have a lagging PF. Electrical motors — in fact, any device that has a coil of wire — will contribute to a less than one lagging PF.

In the instance where a circuit has a PF less than unity, more current must flow to produce the desired electrical work. This additional current flow causes more power losses in the conductors located in the walls of your house, for which you derive no advantage except for a small amount of additional heat generated (this might be considered a benefit in the winter but a detractor in the summer).

Fig. 2 depicts a single-house wiring circuit that is subject to a lagging PF due to the load being an electric motor. Although every house is different, certain assumptions can be made with regard to the elements in this diagram that will allow an analysis of energy consumption with and without PFC. Once the analysis is complete, these assumptions can quickly be evaluated to determine whether variations in home environments, appliances or their usage may alter the analysis.



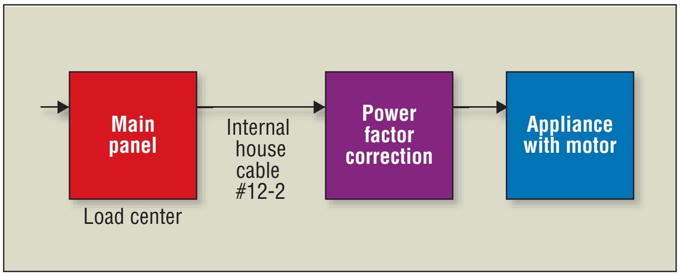


Fig. 2. *The impact of PFC equipment on cable losses in the home can be analyzed by making certain assumptions about appliance power consumption and usage, appliance power factor, and cabling.*

For the purpose of this analysis, the following conditions are assumed:

- Most appliances using an electric motor will be fed by a #12 gauge cable and protected at the load center (main panel) by a 20-A circuit breaker.
- The average two-conductor cable length from the load center to an appliance containing an electric motor is 25 ft. This yields a total conductor length of 50 ft.
- Motor-driven appliances are the devices in a house most likely to contribute to a lagging PF.
- Most motor-driven appliances have a 1-hp motor with an efficiency of 85% and a lagging PF of 0.75.
- The average cost of electricity in the United States is $0.10 per kWh.

Analysis

For a 1-hp motor, the mechanical output power expressed in watts instead of horsepower is 746 W. Therefore, the input power is given by:

$$P_{OUT} = \text{Efficiency} \times P_{IN}$$

$$746\text{ W} = 0.85 \times P_{IN}.$$

$$\text{Therefore, } P_{IN} = \frac{746\text{ W}}{0.85} = 877.6\text{ W}.$$

$$\text{Also: } P_{IN} = |V_{IN}| \times |I_{IN}| \times PF = |V_{IN}| \times |I_{IN}| \times \cos\theta,$$

where θ is the angle between the voltage and current.

$$877.6\text{ W} = 120\text{ V} \times |I_{IN}| \times 0.75.$$

$$\text{Therefore, } |I_{IN}| = \frac{877.6\text{ W}}{120\text{ V} \times (0.75)} = 9.75\text{ A}.$$

If the PF is unity:

$$P_{IN} = |V_{IN}| \times |I_{IN}| \times PF = |V_{IN}| \times |I_{IN}| \times \cos\theta,$$

where θ is the angle between the voltage and current.

$$877.6\text{ W} = 120\text{ V} \times |I_{IN}| \times 1.$$

$$\text{Therefore, } |I_{IN}| = \frac{877.6\text{ W}}{120\text{ V} \times (1)} = 7.31\text{ A}.$$

The length of the #12 gauge cable is 50 ft. Referring to page 60 of *Introductory Circuit Analysis* by Robert Boylestad, 6th edition, table 3.2 shows that the resistance for #12 gauge copper wire is 1.588 Ω per 1000 ft at 20°C. In our example, 50 ft of wire connect the appliance to the main panel. Therefore, the cable will exhibit a resistance of:

Appliance	Hour per day	Hour per month	kWh per month	Motor operation cost per month	Cable loss (kWh) per month (unity PF) at 4.24 W	Cable loss cost per month at unity PF	Cable loss (kWh) per month (0.75 PF) at 7.55 W	Cable loss cost per month at 0.75 PF	Cable loss cost difference
Refrigerator	6	180	157.9	$15.80	0.7632	$0.08	1.36	$0.14	$0.06
Washing machine	1	30	26.32	$2.63	0.1272	$0.01	0.23	$0.02	$0.01
Clothes dryer	1	30	26.32	$2.63	0.1272	$0.01	0.23	$0.02	$0.02
Freezer*	6	180	157.9	$15.80	0.7632	$0.08	1.36	$0.14	$0.06
Air conditioner*	18	540	473.9	$47.39	2.2896	$0.23	4.08	$0.41	$0.18
Well pump*	1	30	26.32	$2.63	0.1272	$0.01	0.23	$0.02	$0.01
Sump pump*	0.3	9	7.898	$0.79	0.03816	$0.00	0.07	$0.00	$0.00
Garage door opener*	0.2	6	5.265	$0.53	0.02544	$0.00	0.05	$0.00	$0.00

Table. *Household appliances versus their energy requirements and cost of energy loss in feed cables. *Indicates an appliance that may not exist in many households or an appliance that is used seasonally.*

$$R_{50} = \frac{1.588\ \Omega}{1000\ \text{ft}} \times 50\ \text{ft} = 0.0794\ \Omega.$$

Thus, the power loss in a #12 gauge cable of 50-ft length supplying a 1-hp motor at unity PF is given by:

$$P = I^2 \times R = (7.31\ \text{A})^2 \times 0.0794\ \Omega$$
$$P = 4.24\ \text{W}.$$

For the same cable, supplying power to a 1-hp motor with a PF of 0.75 will result in a cable power loss of:

$$P = I^2 \times R = (9.75\ \text{A})^2 \times 0.0794\ \Omega$$
$$P = 7.55\ \text{W}.$$

The **table** above provides estimations as to the number of hours per day and month that various motor-driven appliances are used. It also contains computed power losses in the cables supplying the appliances for a unity PF and 0.75 lagging PF condition. The purpose of developing this **table** is to demonstrate the power losses under both PF conditions and to illustrate the small increase in cost involved in not using the equipment being offered for PFC.

Note that the top three cells in the far right column of the **table** total $0.09. If one estimates that the monthly electric bill — with the inclusion of the cost of appliances that do not affect the PF (i.e., unity PF devices such as lighting, entertainment equipment, electric stoves, toasters, hot water heaters and the heater elements of electric clothes dryers) — is $60 to $80, then the $0.09 is negligible at approximately 0.1% of the total monthly electric bill.

It would seem prudent to determine the period necessary to compensate for the capital expenditure for the PFC equipment. The data would tend to suggest that the additional cost of PFC equipment would not justify the expenditure.

A survey of the Internet for PFC

equipment revealed that PFC items, both inductive and capacitive, were advertised on eBay. The prices ranged from $5.99 to $2000. Some of the lower-priced units did not contain a description of whether the items were solid state, inductive or capacitive. A Square D PFC capacitor in a mounting box, the PFC4005FR, was listed at $49.99.

It is worth noting that a one-size-fits-all PFC capacitor or inductor is not feasible. For example, the PF introduced by an appliance motor depends on the motor design, its power rating and its loading. The mechanical load presented to a motor may vary. For instance, the amount of clothing in a clothes washer will affect the mechanical load on a washer motor. The PF specified by a motor manufacturer is the value measured at rated conditions. All one can do is select a PFC device that is nominally appropriate for the load.

Although the energy savings calculated in the **table** do not justify the PFC equipment costs, supposing that PFC equipment were installed, one question that arises is: "Where should a PFC module be located?" There are three possible locations.

One possibility would be to locate the module in parallel with the feed line to a particular appliance. But this should not be done since, in theory, the source impedance is very low and, therefore, the feed line would be treated as an independent load (i.e., the parallel connection of the PFC device would be ignored).

Another option would be to connect the PFC device, commonly a capacitor (or conceivably triacs), in series with the feed line. However, this exhibits the disadvantage that both the input and output terminals of the PFC device are off of ground (floating).

A third place for the PFC device would be in parallel with the load. This is the most desirable location for two reasons. First, one terminal of the device would be at ground potential. Second, the load voltage will be almost equal to the source voltage. The appliance manufacturer designs equipment for a typical source voltage in the United States of approximately 117 Vac. This value varies with location, time of day and other factors.

So Why PFC?

PFC devices are used in some commercial or industrial applications where a company may have a large number of electrical motors that would have a significant effect on the PF of utility transmission lines, which span much longer distances than the cables in the home. Utilities may assess commercial or industrial customers a penalty for PF significantly less than one.

Some appliance manufacturers are incorporating PFC into their finished products. The European Union's International Electro-Technical Commission adopted the IEC61000-3-2 standard that required, by Jan. 1, 2001, all equipment needing 75 W of power or greater and less than 16 A to meet standards for harmonic generation and, thus, meet PFC requirements. Thereafter, Britain, China and Japan adopted similar standards. North America does not presently have these requirements.

Where the mechanical load is reasonably constant (e.g., an air conditioner compressor motor), a PFC capacitor can be specified to produce a desired effect. Appliance manufacturers are faced with an interesting dilemma when including PFC into their finished products. They must convince their potential customers that over the product life, energy cost savings would equal or surpass the additional initial selling price, vis-à-vis a non-PFC item.

What is the long-term outlook for PFC? PFC may be driven by many factors. One of the most important is likely the cost of energy. The production of all types of energy is interrelated and, over time, the per-capita energy consumption will likely increase with all countries continuing to compete for energy resources. The increasing ratio of energy demand versus energy supplies will continually drive energy prices upward. It may be that the energy savings enabled by PFC on a global scale will, through a combination of legislation and economics, cause PFC to be incorporated universally into all electrical equipment. **PETech**