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Energy Savings Estimate for Power Factor Correction in Televisions

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Introduction

This document shows the calculations used to estimate the energy savings attributable to power factor correction (PFC) for televisions. The analysis specifically assesses the California Energy Commission's (CEC) proposed 0.9 minimum power factor standard for TVs.

Any appliance that has a low power factor draws more input current than is necessary for its power consumption. This excess current causes unnecessary heating of the building wiring and wastes energy. PFC reduces this type of energy waste.

The first section lays out the base data and assumptions used in the analysis. The following section presents the calculations and results. The last section addresses the incremental cost of PFC.

Data and Assumptions

The energy consumption is calculated for a variety of screen sizes, from 19" to 60". The "average" screen size is calculated from data in the CEC staff report (CEC-400-2008-028-SD). The current market share for sales of LCD, Plasma, CRT and DLP televisions are 88.2%, 10.5%, 0.8% and 0.5% respectively. The average screen size for each technology is 533 sq-in, 1003 sq-in, 440 sq-in and 1750 sq-in, respectively. The weighted average screen size is 588 square inches, which is a 35" diagonal display.

We wish to calculate the energy losses in the home distribution wiring, and in particular, the amount that can be saved by using PFC for the TV. This is complicated by the fact that the distribution wiring losses are not additive. The energy saved by altering the TV varies depending on the current drawn by all other appliances through the same wires. To do this calculation precisely requires a great deal of information: the layout of the house wiring, what appliances are plugged in where, which appliances are operating in which mode at the same time, and the current waveform for each appliance in each mode. We have proposed field studies to attempt to gather this data, but at this time the data is not available. We have used professional experience to make reasonable assumptions where hard data is not available.

The basic methodology used is similar to that used by Fortenbery and Koomey (2006). Although they addressed a different situation (PFC for computer power supplies in commercial buildings), these results are in general agreement with theirs.

When we alter the TV, this will change the current in the circuit from the breaker box to the TV and also the current from the meter to the breaker box. The current in all other circuits remains the same. These losses in these other circuits will cancel when we take the difference between TV's with and without PFC.

We have done a number of calculations of the energy lost in homes with typical assortments of appliances. These calculations show that the energy lost is about 20%

from the meter to the breaker box and about 80% from the breaker box to the plugs and lights. While the wire from the meter to the box may be comparable in length to the other circuits and it handles much more current, it is also a much larger gauge wire. While this 80/20 split is not precise, it does show that we can identify most of the energy lost even if we ignore the meter-to-box wiring. We will therefore focus our attention to the losses between the breaker box and the plug.

There are additional losses upstream of the meter, but these losses are borne by the utility rather than the consumer. Of course, the consumer ultimately pays for these indirect losses, but we consider here only the direct losses.

It is assumed that the cabling from the breaker box to the TV outlet is 65 feet of 14/2 copper Romex wire, with a resistance of 0.32 ohms. To crudely account for the losses in the wiring from the breaker box to the meter, we add 25% to the resistance. This brings the total resistance to 0.4 ohms. (0.4 ohms is also the value that has been advocated as the typical source impedance of 120V grid power sources (Larry Albert, PTI, private communication).)

All power consuming appliances on the same circuit with the television affect the losses in the wiring. Typically, this will include the peripheral appliances used with the television (such as set top boxes (STB), VCR, DVD, digital video recorders (DVR), audio amplifiers and speakers, and game consoles) as well as unrelated appliances (such as lamps and possibly computers, telephones, etc.). For this analysis, we assume that there are peripherals but no unrelated appliances.

For TVs and the peripherals, we need to know the input current waveforms. Though these have not been reported, we get some clues from their typical power factor. For all of these devices, the power factors are clearly bi-modal. Most units have either a power factor between 0.4 and 0.6 or between 0.95 and 0.99. This is not really surprising. A switch-mode power supply which is not power factor corrected has a maximum power factor of 0.59 and values below that are common. A switch mode power supply that is power factor correct can achieve a power factor close to 0.99. Therefore, we will assume that devices with a power factor of 0.4 to 0.6 will have the current waveform of an uncorrected switch-mode power supply and those 0.9 and above are a PFC power supply.

Of the peripheral devices listed, almost all are in the uncorrected category, as shown in the table below. These have an average power factor of about 0.50. The one exception is game consoles. Here, 75% are uncorrected (0.4 to 0.6) and 25% are PFC (0.9-0.99). To simplify the analysis, we will assume that game consoles are also uncorrected. Since a game console is used only about 5% of the time that a TV is used, this is a small error. A more detailed analysis would perform a separate calculation for the 25% of game consoles that are PFC.

Product type	Power factor estimate	Source
DVR	0.49	(Foster Porter et al. 2006)
Amplifier	0.54	(Foster Porter et al. 2006)
DVD recorder	0.48	(Foster Porter et al. 2006)
Game consoles	0.63	(Ecos 2008)
DVD-VCR	0.43	(Foster Porter et al. 2006)
STBs	0.59	(Ecos 2007)
DVD player	0.35	(Foster Porter et al. 2006)
TVs	0.67	(ENERGY STAR, 2008)
DTAs	0.42	(Cadmus 2007)
Speakers	0.61	(Foster Porter et al. 2006)
VCR	0.52	(Foster Porter et al. 2006)

For the TV, about 40% are uncorrected and 60% are already PFC. Our base case is a 588-square-inch TV with a power factor of 0.53 and which otherwise just meets the CEC's proposed Tier 1 or Tier 2 energy standard (149.6 W or 95.6 W respectively). *The improved case is the same power consumption, but with the power factor corrected to 0.98.*

Typical power consumptions for the peripheral devices are shown in the following table. This data is from NRDC testing and the Ecos residential field study. Since we will approximate the power factor of each peripheral as being 0.50, the analysis does not depend on which peripherals are turned on at any given time. All we need to know is the total power being drawn by all the peripherals collectively.

	Active Mode Power		
Device	**Low End**	**Middle**	**High End**
STB	20		32
VCR		13	
DVD		11	
DVR	10		30
DTA	17		
Game Consoles	118		188
Stereo+Sound	14		48

Finally, we need to know hours of use, and in particular, hours of coincident active-mode use. The estimate for TVs is from the April 1, 2008 PG&E CASE report (PG&E 2008) and the other values are from Nielsen and the Statistical Abstract on Media.

Device	Annual Hours of Use	Hours/day
TV	1,907	5.22
STB	1,083	2.97
VCR	68	0.19
DVD	68	0.19
DVR	374	1.02
Game Consoles	87	0.24
Stereo+Sound	1,713	4.69

For our calculations, we assume that peripherals are only being used when the TV is in active mode. Thus we interpret the table as showing hours of coincident use. While the peripherals may be left on and draw current while the TV is in standby, we do not calculate this energy. Energy losses during these periods can be reduced by improving the power factor of the peripheral, but not by improving the TV.

Calculations

The instantaneous power consumption of the peripherals can vary from 0 W to 339 W, if all were on at the same time. We constructed a hypothetical breakdown of the uses of peripherals with the TV. This breakdown is consistent with the power consumption data and hours-of-use data summarized above. We believe that this breakdown reasonably represents the range of common uses.

- 87 hours with a game console (160W), STB (32W) and sound (48W)
- 511 hours with VCR, DVD or DVR (15W), STB (26W) and sound (36W)
- 573 hours with STB (20W) and sound (24W)
- 736 hours with DTA (17W) and sound (14W)
- 1907 total hours

The detailed formulas for the calculations are given in the appendix. Depending on the peripherals in use and the TV power, the savings from PFC vary from 0.16 W to 26 W.

The total annual energy savings per unit for PFC is about 6 kWh per year for each TV that meets the CEC's proposed Tier 1 standard. This is the difference in wiring losses for a TV that just meets Tier 1 with PFC compared to a TV that also just meets Tier 1 but does not have PFC. The savings is about 3 kWh per year for each PFC TV that meets the Tier 2 standards. The savings for a Tier 2 TV are lower (than for Tier 1) because the TV draws less current (than a Tier 1 TV) and all the wiring losses are smaller.

The annual energy lost in the wiring without PFC is about 3% of the energy consumed by the TV, for both Tier 1 (3.3%) and Tier 2 (3.0%) TVs. With PFC, the losses are reduced to about 1%, so the savings is about 2% of the TV's energy consumption (2.1% for Tier 1 and 1.7% for Tier 2).

With a projected lifetime of ten years for televisions, a customer would save an average of 60 kWh of electricity over that lifetime for Tier 1 and 30 kWh for Tier 2. Assuming an effective date of January 1, 2011 the amortized Tier 1 PFC energy cost savings equals $7.46. This assumes a discount rate of 3% and established electricity rate projections used by the CEC (CEC 2008). With an effective date of January 1, 2013 the amortized Tier 2 PFC energy cost savings equals $3.73.

The savings will be larger for larger sets, because on average they consume more power and thus have more opportunity for absolute savings. The savings will also be larger if there is any other power-consuming appliance on the same circuit. Also, the trend in peripherals, especially game consoles, is to increase energy consumption. Further, the TVs are often left on considerably more hours than they are actually watched. For all these reasons, these values given are a conservative estimate of the energy savings available.

Cost Effectiveness and Feasibility

In many cases, a switch mode power supply can be redesigned to include PFC without using any additional components. It may require using a different integrated circuit controller, but there is no significant cost difference.

In the worst case, a separate PFC stage may be added to the power supply. ON Semiconductor is one of several manufacturers offering ICs for PFC. Their website lists 30 available chips, with typical costs of $0.50, in small quantities. Some additional components are required, which will be different depending on the power supply design. Without getting into design details, we can estimate that the total cost will be perhaps $1.00 to $2.00. An OEM buying in large quantity would get a lower price, but then add a markup for the consumer. The additional cost to the consumer in this case is estimated to be a similar $1.00 to $2.00.

Thus the incremental cost of PFC to the consumer may be anywhere from zero to $2.00, depending on the power supply design. These costs would only apply to the 40% of TVs that are not already power factor corrected. These costs are less than the value of the energy saved, making the proposed 0.9 minimum power factor standard both feasible and cost-effective.

Appendix

Formulas for calculating energy lost in the distribution wiring.

The energy lost in the wiring for each operating configuration is calculated as:

(1) $$E_{loss} = P_{loss} * t$$

Where t is time and

(2) $$P_{loss} = R * (I_{rms})^2$$

In the before case, the peripherals have a power factor of .50 and the TV has a power factor of .53. The rms current for each is given by:

(3) $$I_{rms_{Per}} = \frac{P_{per}}{115V * PF_{per}}$$

(4) $$I_{rms_{tv_{before}}} = \frac{P_{tv_{before}}}{115V * PF_{tv_{before}}}$$

These two currents will have very nearly the same waveform. When the waveforms are the same, the rms of the sum is the sum of the rms's. Thus a good approximation is:

(5) $$I_{rms_{before}} = I_{rms_{per}} + I_{rms_{tv_{before}}}$$

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These five equations give the energy losses in the before case. This additive approach has already been used implicitly to combine the currents of the various peripherals into a single peripheral current.

The improved case is more complex. Now the waveforms are very different. However, it is still not as difficult as the general case. With a power factor of .98, the TV will now have nearly a sinusoidal wave form. To use this approximation, we first consider the current of the peripherals. We can express the waveform as a Fourier series:

(6) $$I_{per}(t) = \sum_{k=0}^{\infty} A_k \sin(k\omega t) + B_k \cos(k\omega t)$$

Where the sum over k goes from 0 to infinity, ω is the angular frequency, and A_0=0. Now the rms current is given in the frequency domain as:

(7) $$(I_{rms_{per}})^2 = \sum_{k=0}^{\infty}(A_k^{\ 2} + B_k^{\ 2})$$

Since the voltage is a pure sine wave, the active power is given by:

(8) $$P_{per} = A_1 * 115V \quad \text{or} \quad A_1 = \frac{P_{per}}{115V}$$

We can define the (rms) current of all the harmonics by leaving out the A_1 term from equation 7

(9) $$(I_{harm})^2 = \sum_{k=2}^{\infty} A_k^{\ 2} + \sum_{k=0}^{\infty} B_k^{\ 2}$$

This expression actually includes the dc term (B_0) and the out-of-phase fundamental term (B_1), but we will still call it the harmonic current. Now inserting this into equation 7 gives:

(10) $$(I_{rms_{per}})^2 = A_1^{\ 2} + (I_{harm})^2$$

By inserting $I_{rms_{per}}$ from equation 3 and A_1 from equation 8, we get:

(11) $$\left[\frac{P_{per}}{115V * PF_{per}}\right]^2 = \left[\frac{P_{per}}{115\ V}\right]^2 + (I_{harm})^2$$

Using PF_{per} = 0.5, we can solve for I_{harm}

to get:

(12) $$(I_{harm}) = \sqrt{3} * \frac{P_{per}}{115\ V}$$

Now we examine the current of the power factor corrected TV with improved PF. The rms current is given by:

(13) $$I_{rms_{tv improved}} = \frac{P_{tv_{improved}}}{115V * PF_{tv_{improved}}}$$

We assume that this current is very nearly a sine wave, so it will add to the A_1 component of the peripheral current. We assume that the TV makes a negligible contribution to each of the harmonic terms. Similar to equation 7, we now have the rms of the combined currents as:

(14) $$(I_{rms})^2 = (A_1 + I_{tv_{improved}})^2 + \sum_{k=2}^{\infty} A_k{}^2 + \sum_{k=0}^{\infty} B_k{}^2$$

The two sums are just the harmonic current squared, so:

(15) $$(I_{rms})^2 = (A_1 + I_{tv_{improved}})^2 + (I_{harm})^2$$

Using this equation, together with the definitions in equations 8, 12 and 13, we have all the results we need to compute the power and energy losses for the improved case.

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