The Extreme Effects of Computer & Compact Florescent Light Power Supplies on the Grid Infrastructure, the Buildings and their Occupants.

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The grid was originally designed with a sine wave voltage at 60 Hz with loads that were either resistive (like incandescent lights and heating elements) or inductive (like inductive motors). This meant that the current wave shape was very close to a 60 Hz sine wave also. With inductive motors the current lagged the voltage by a phase angle which meant that the real power delivered to the motor (work done by the motor) was less than the volts times the amps so they came up with a term, Power Factor, which was just the real power divided by the volt amps, PF = W/VA. Now, with the advent of compact florescent lights and computers there are substantial amounts of a different type of load which produces a current that is very different from a 60 Hz sine wave. The term, power factor, is still used to describe these loads put it really doesn't even come close to telling the real story. These electronic loads are so different that they take up to 4.5 times the peak current of resistive and inductive loads and often actually distort the grid voltage by more than 5% THD (total harmonic distortion) creating unwanted harmonics on the voltage of the grid and extreme amounts of harmonics on the current carried through the wiring in buildings and through the entire grid transmission network. Some of these electronics loads actually have more energy in the harmonics than they do in the fundamental meaning their current has over 100% THD. This heavily degrades the efficiency of the entire electrical infrastructure, significantly reduces the infrastructure's total capacity and potentially introduces significant health concerns from the electromagnetic fields produced in the wiring in the buildings.

This paper details a series of tests that can easily be repeated and verified. To encourage others to repeat and extend the tests we have listed all of the equipment used.

Equipment.

Oscilloscope: Tektronix MSO 4034 with FFT. http://www.tek.com/products/oscilloscopes/mso4000/

Volt/Amp/Watt/VA/PF meter: Kill A Watt P4400.
http://www.p3international.com/products/special/P4400/P4400-CE.html

Current Probe: Fluke 80i-110s.
http://us.fluke.com/Fluke/usen/Accessories/Current-Clamps/80i-110s.htm?PID=55352

Sine wave power source: Heart Transverter HT2000 with integrated Volt/Amp/Watt/VA/PF meter and oscilloscope: http://www.transverter.com/products.html

Compact Florescent Lights (4 used): Lights of America 2725 120V~60 Hz 23W 420mA.
http://www.lightsofamerica.com/Products/2725.aspx We have tested many other brands with essentially the same results.

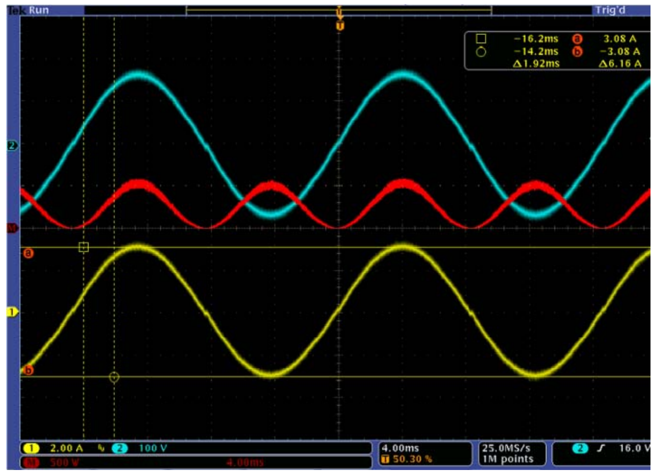
Computer power supplies (2 used) with power resistor loads: Eurostar ATX PX-500
We have tested many other non power factor corrected brands with essentially the same results. This is typical to what is installed in almost all desktop PC's.

Methods.

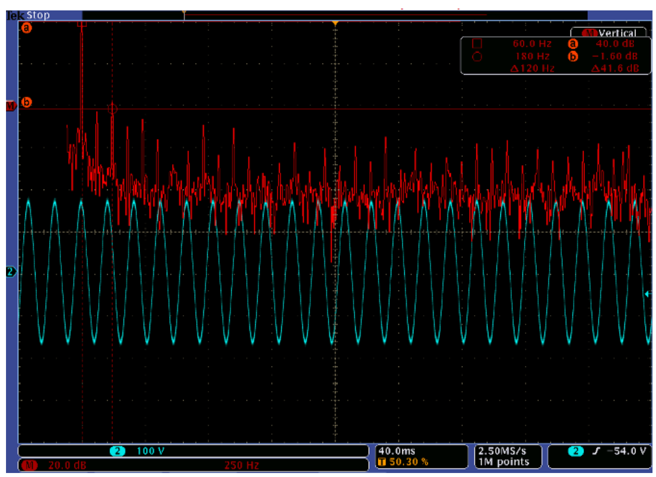
The loads were connected to the Transverter HT2000 via the Kill A Watt meter. The HT2000 could be made to select between its own sine wave power source or the grid. The Fluke probe was clamped around the hot wire going to the load. The voltage at the load was connected to channel 2 of the oscilloscope and the current probe was connected to channel 1. For the wave shape pictures, the math module was used to multiply channel 1 times channel 2 for instantaneous power. For harmonic analysis the FFT was used with Hanning, Horizontal: a=1.065 kHz, b=250 Hz/div. We set the time scale to include 24 wave shapes in order to get descent resolution on the FFT.

TESTS.

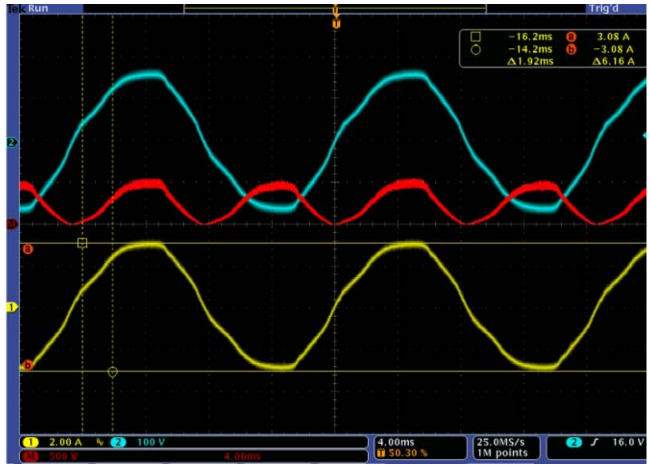
This first picture shows a 251W resistive load with the sine wave from the HT2000. Notice that the current (yellow) has the same shape as the voltage (blue). The voltage has a total harmonic distortion, THD = 1.1%. The red line is the instantaneous power which is just the voltage times the current.



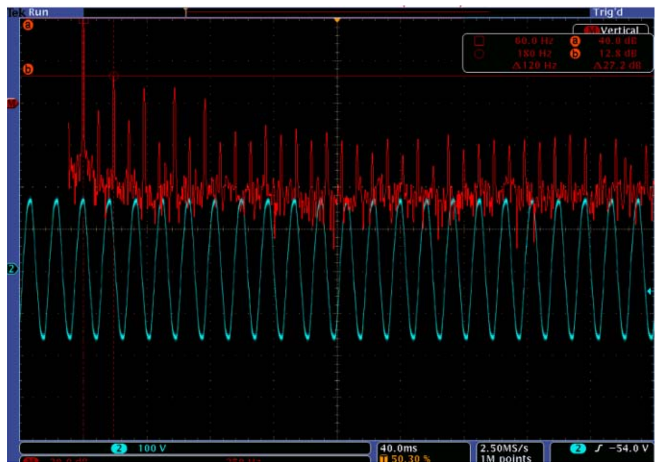
The second picture is graphical display of the harmonics of the voltage. There is a mathematical system call Fourier Analysis that generates any wave shape with a series of wave shapes that are all sine waves with frequencies that are multiples of the fundamental frequency which, in this case, is 60 Hz. On this picture you can see that the first peak is at 60 Hz and is the biggest at 40 dB. You can see that the cursors are lined up at 180 Hz which is the 3rd harmonic and the value is -1.6 dB. This means that the 3rd harmonic is 41.6 dB less than the fundamental. Since the fundamental is 117 volts then the 3rd harmonic is like another sine wave of 180 Hz of 1.0 volt has been added. If you add up the power produced by all of the harmonics you get the total harmonic distortion which, in this case is THD = 1.1%



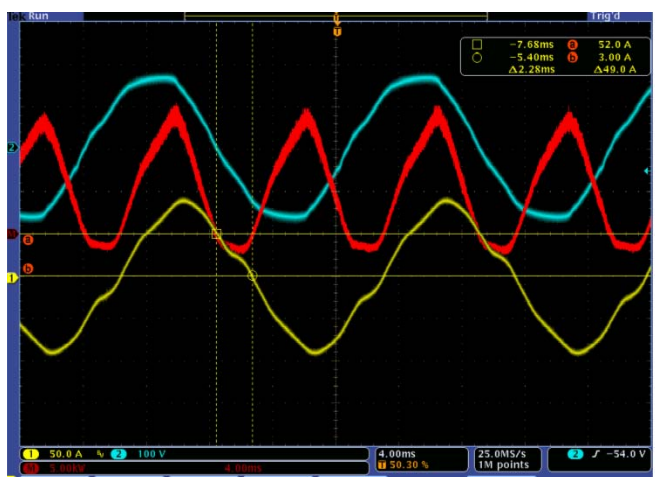
This third picture is of the same 250W resistive load but powered by the grid. In this case the grid is a large hydro-plant which most certainly creates a pure sine wave. There are enough electronic loads in this grid sector so that they have distorted the grid's wave shape for all customers.



The fourth picture is the FFT of the harmonics for the grid wave shape that has been distorted. You can see the 3rd harmonic at 180 Hz has a value of 12.8 dB which means it is 40 – 12.8 = 27.2 dB less than the fundamental. This is like an extra sine wave at 180 Hz of 5.2 volts being added which is much more significant than the 1.0 volt wave in the second picture. This grid voltage has a THD = 5.6%.

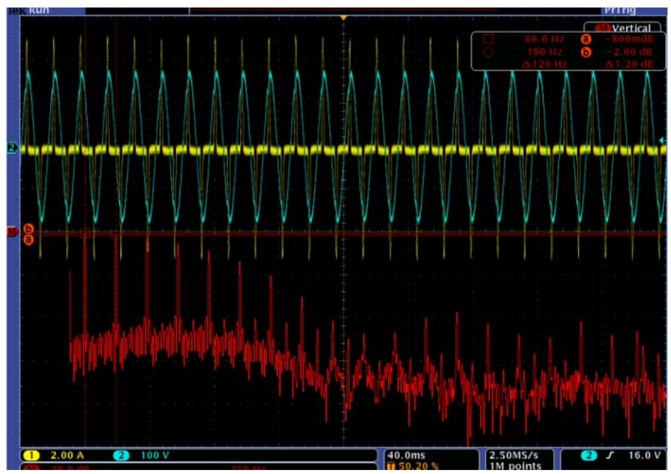


This fifth picture is for an inductive motor pump. Notice how the current (yellow) lags the voltage by 2.28 ms which is 49°. Notice that the power (red) actually goes negative for a short time. For that short time the motor is actually putting some power back into the grid. If the phase angle was 90° then there would be no real power transferred to the load and the power factor would be = 0. The current wave shape is basically a sine wave but is distorted by the grids voltage wave shape and the capacitor on the extra winding on the pump motor.

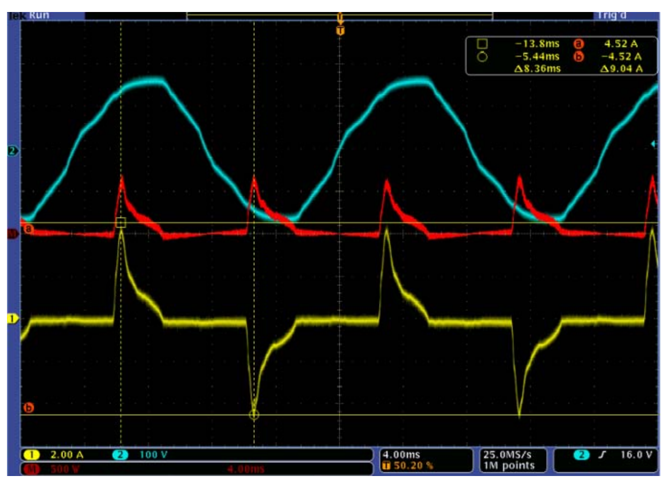


This sixth picture is of 92W of compact florescent lights. Notice how the current (yellow) is in sharp spikes. Although this is drawing only 92 watts it is taking 171 volt amps giving it a power factor = .53 which means that you only have 53% utilization of the electrical infrastructure. Even circuit breakers which would power 1,000 watts of resistive loads would only power 530 watts of these loads. Even though the current = 1.48 Arms (amps rms) it has a peak current = 5.08 amps.

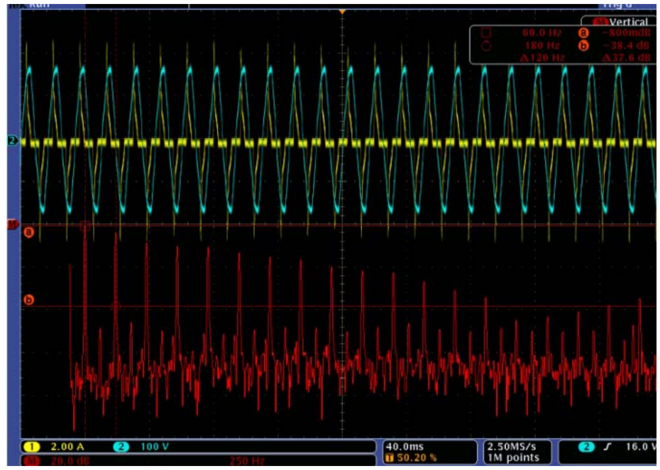
This seventh picture is the FFT (Fast Fourier Transform) of the harmonics of the current of the previous picture. You can see that the 3rd harmonic (second red line peak) is almost as big as the fundamental (first red line peak). In fact, there is more power in the harmonics than there is in the fundamental giving it a THD = 141%. When the grid was designed they never imagined there would be significant loads like this.



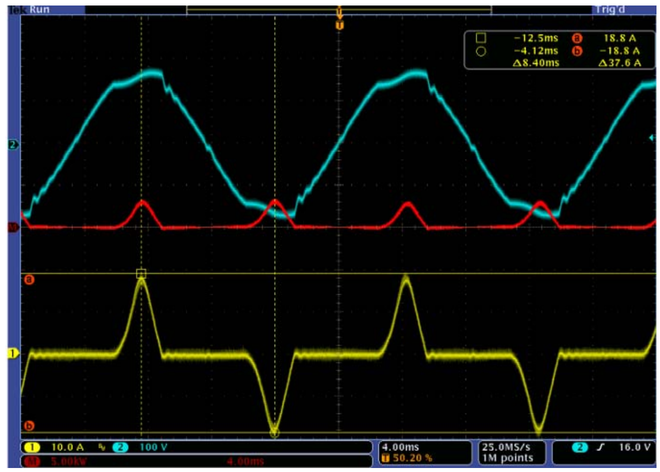
This eighth picture is of 90W of compact florescent lights powered by the distorted voltage wave shape of the grid. It might not look like the grid's voltage wave shape was that different but it causes a significant change in the current wave shape. This actually causes it to produce 2 watts less light. This has a power factor = .62. Even though the current = 1.21 Arms it has a peak current = 4.52 amps.



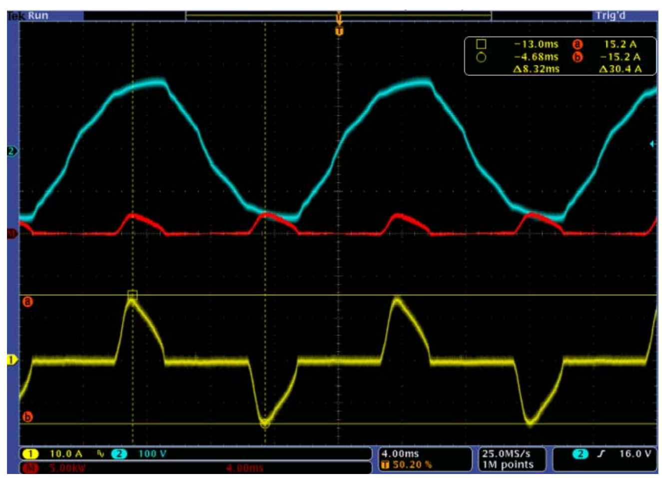
This ninth picture is the FFT (Fast Fourier Transform) of the harmonics of the current of the previous picture. Again, there is more power in the harmonics than there is in the fundamental giving it a THD = 101%. Every harmonic through the 9th has over 10% of the power of the fundamental.



This tenth picture is of 505W of computer power supplies which represents 3 or 4 desktop PC's. This looks similar to the CFL's but not quite as bad. Although this is drawing only 505 watts it is taking 756 volt amps giving it a power factor = .66. Even though the current = 6.48 Arms it has a peak current = 18.8 amps. The harmonic content gives a THD = 97% meaning there is almost as much power in the harmonics as in the fundamental.



This eleventh picture is of the same computer power supplies but run off the distorted voltage wave shape of the grid. The peak current is not as high and the power factor is a little better but notice how steep the leading edge of the current is. This has a power factor = .72 and a peak current = 15.2 amps.



Infrastructure Effects. Even with these electronic loads, the same relationship between power factor and infrastructure utilization holds. This means that if you have a generator, transformer, breaker panel or network of wires and is rated at 10 kW, then it will only support a load of 6 kW if it has a power factor = .6.

Transmission Effects. The transmission wires, the wires in the transformers and even the wires in the coils in the generators all have resistance. Add this all up to a resistance = R. The instantaneous distributed power loss will be I^2R where I is the current. If the power factor = 1, then the RMS current is just the power divided by the RMS voltage, Irms = P / Vrms. This creates a transmission loss = $(Irms)^2*R$. However, when the power factor is less than 1 then the rms current is raised. We'll call this new current IPrms and the new transmission loss = $(IPrms)^2 * R$. The definition of power factor is power/voltamps or PF = P / (Vrms * IPrms). Since the voltage remains reasonably close to a sine wave, PF = (Vrms * Irms) / (Vrms * IPrms) = Irms / IPrms. This means that Irms = PF * IPrms. To find the ratio of the power loss with the low power factor load to the power loss of a PF = 1 load you just divide the two power losses. RATIO = $((IPrms)^2 * R) / ((Irms)^2 * R) = (IPrms)^2 / (PF * IPrms)^2 = 1 / PF^2$. To find the increase in transmission loss because of the power factor just subtract 1 for TLincrease = $(1 / PF^2) -1$. This is dramatic. For the 92W CFL load we had a power factor = .53 meaning the transmission loss is increased by 256%. Most grid situations have a total transmission loss in between 6% and 12% so this means there will be an additional loss of between 15% and 31%. If, for example, the power came from burning coal they would have to burn between 15% and 31% more coal. With the CFL load powered by the distorted grid voltage the transmission loss is increased by 160%. With the computer load the transmission loss is increased by 130% and with the computer load run off the distorted grid voltage the transmission loss is increased by 93%. This is extreme and this added cost is mostly being absorbed by the grid companies. This added transmission loss is in the form of heat dissipated by the wires and can be significant when the wires are confined and closely packed like in a transformer or in the windings of a generator. The grid companies mostly bill by the kWh and so end up absorbing this extra losses.

Health Effects. There is a growing concern with the health effects from the electromagnetic fields generated by the wiring, both in the buildings, and from the transmission wires of the grid itself. Imagine two wires separated by some distance. When a DC current is flowing through one wire it does not create any voltage effect on the second wire. However, when the current is changing, it induces an EMF or voltage on the second wire proportional to the rate of change of the current (referred to as dI/dt). This is what makes a transformer work. Even if the wires are separated by fairly large distances of air (or even a vacuum) this effect still holds true, like in the case of RFID devices that are powered by the external transmitter. Another example is a radio transmitter antenna as the first wire and the radio receiver antenna as the second wire. In this biological effect case the first wire is the wires going through the grid and through the house wiring to power the load. The second wire is conduction paths through the delicate chemistry of parts of living organisms (people). Whatever effect there is will be proportional to dI/dt. To scale this effect for different size loads we come up with a new term I/S/W which is the rate of change per watt in amps per second per watt. Look at this table.

Load	**I/S/W**	**Ratio from Resistive**	**Ratio^2**
Resistive PF = 1	5.0	1.0	1
CFL PF = .53	79.7	15.8	251
CFL PF = .62 from distorted grid voltage	141.4	**28.1**	**790**
Computers PF = .66	32.9	6.5	43
Computers PF = .72 from distorted grid voltage	38.3	**7.6**	**58**

We do not attempt to establish what these medical effects are here but you can see that these weird current wave shapes are multiplying these effects by as much as 28 times. Also, it is interesting to note that in both instances where we used the distorted grid voltage with the same load that it significantly increased this effect. This is relevant with a mechanism that needs some threshold voltage imposed upon it to trigger some change or event. However, if the effect is from power dissipated in actual current flowing (maybe that promotes some microscopic chemical reaction) then this will be proportional to the square of the imposed voltage. Look at the $Ratio^2$ column. This gets really dramatic with the effect being between 43 and 790 times stronger than with a simple PF = 1 load.

Solutions.

Power factor corrected devices. It is possible to make the power supplies of the CFL lights and the computers with power factor corrected power supplies. There are numerous integrated circuits designed for this and power factor corrected computer power supplies are available on the market. However, these require more electronics and drive the cost up and in today's cost driven world it means that essentially no one uses these. Nothing short of strict legislation will cause this change.

Electronic power factor correctors at the breaker panel. There exist products that can introduce currents that compensate for these load currents so that what the grid sees is a PF = 1 current like from a resistive load. The Transverter HT2000 is an example of this. This will probably not happen on a large scale because of the added expense unless it is embedded into equipment that needs to be installed anyway, like UPS systems. These systems are generally installed next to the breaker panel and solve the infrastructure and transmission loss issues with the grid but do not address the losses and health effects from the wiring from the breaker panel to the load.

DC sub-grids. Actually, the CFL and computer power supplies would be cheaper and more efficient if they were run off of a DC grid. The entire Telecom industry already does this with a 48 VDC grid. This removes the problem completely on all levels. However, it requires cooperation with the manufacturers creating new models of devices that run of DC and a new set of wiring would need to be installed in the buildings. This would never completely replace the AC grid because of the enormous amount of inductive motors and transformers that are already installed and work quite well. To implement this you would need an AC to DC converter and it would, of course, have to be power factor corrected or there would be no sense in implementing the DC grid. These AC – DC converters are additional equipment that would have to be purchased but that cost could be offset by the reduced cost of all the devices that are now DC instead of AC and so are cheaper to build. This converter cost can also be absorbed if it is embedded in equipment that is already needed, such as UPS systems, like is done in the Transverter HT2000. Obviously, it would take a while for the DC sub-grid to catch on but is definitely the way of the future and should be seriously considered for all new construction. It has already been implemented in some data centers.

It is amazing that a situation as extreme as this has evolved without anyone really drawing much attention to it. You would think that total grid transmission losses being increased by as much as 256% and health effects being multiplied by as much as 790 times would have caught someone's attention.