FARS
K6YA
FOOTHILLS AMATEUR RADIO SOCIETY
April 2009 Volume 40, Number 4

March Club Meeting

Date: Friday, April 23, 2009
Time: Socializing at 7 pm, Meeting at 7:30
Place: Covington School, 205 Covington Road, Los Altos
Speaker: Jim Brown, K9YC
Topic: Using High Power Coaxial Chokes to Kill Receive Noise and RFI

Summary: Jim Brown, K9YC, always talks about topics of great interest to Radio Amateurs. This time he will clear up myths and confusions about baluns versus chokes. Do you know the difference? Jim will cover how ham antennas are inherently unbalanced, common-mode and differential-mode current on transmission lines, how to wind chokes, how to measure chokes, and lots of other fun stuff, You may remember Jim's popular talk "RFI and Ham Radio" from FARS December 2007 meeting. Jim's presentation slides can be found at his web site http://www.audiosystemsgroup.com/publish.htm.

About the speaker: Jim Brown grew up in West Virginia and was first licensed in 1955 as WN8FNI, later as W8FNI (General Class) in 1956, and Amateur Extra and First Class Radiotelephone in 1959. He received a BSEE from the University of Cincinnati in 1964, where he was trustee of W8YX, the club station, reactivating it after a long period of down time. UC's engineering was co-op. As part of that program, he worked for WLW, WSAZ, WCAW, and RL Drake, where he tuned up some of their first TR3 transceivers. Jim moved to Chicago in 1964 and became W9NEC. He worked briefly for Motorola, then taught for five years at DeVry. He moved to a new QTH in 1987, and was inactive until 2003 when he erected a few trap dipoles on his city lot, acquired a used OmniV, and put an FT-100 D in his Volvo. In 2003, Jim became K9YC under the Vanity licensing program. His HF operating is primarily CW, but he'll pick up the mike to do contesting. He enjoys VHF tropo, aurora, and Es, and has been playing a bit with PSK31 and RTTY. Jim is a member of the Northern California Contest Club, and the Ridge Runners Radio Club, and trustee of the Ridge Runners Club Station, W6BX. In April 2006, Jim and his wife moved to Santa Cruz. His new QTH is a cottage on 8.5 acres in an old growth redwood forest in the Santa Cruz Mountains. Jim is a semi-retired sound system design consultant, specializing in systems for public places -- theaters, churches, stadiums, arenas, etc. He a Fellow of the Audio Engineering Society (AES), vice-chair of the EMC Working Group of the Standards Committee of the AES and Chair of the Technical Committee on EMC. He is a principal author of four AES Standards on EMC -- AES48, AES54-1, AES54-2, and AES54-3.

The club offers refreshments (great coffee, great cookies). Bring your questions for Dr. Know-It-All and get great answers.

Pre-Meeting Dinner, 6pm at the Beausejour Restaurant, 170 State St., Los Altos. There are Great Early Bird specials.

President's Corner

Membership Meeting. The next regular membership meeting is Friday, April 23rd at 7pm). Our speaker, Jim Brown K9YC, will talk about "**Using High Power Coaxial Chokes to Kill Receive Noise and RFI**." See k6ya.org/meeting meetings for details.

Am-Tech Day. The next Am-Tech Day is scheduled for April 24th. There will be food, radios, and hams. The following Am-Tech Day is scheduled for May 15th. Check the web site (k6ya.org/amtechday/) or the email list (k6ya.org/mail/) for the date and program information.

Electronics Flea Market. The Electronics Flea Market continues on May 8th. Drop by the food booth and support your local ham club. The proceeds from the food booth and the vendor fees benefit your local amateur radio organizations. Check out www.electronicsfleamarket.com for all the details.

MakerFaire. FARS is participating in MakerFaire this year on May 22nd & 23rd demonstrating amateur radio to the public. Michael Pechner, NE6RD is organizing this event and needs volunteers to help out. Contact him if you can help.

Field Day. It's time to begin thinking about Field day 2010. This year's Field Day is scheduled for June 26th and 27th. This is a great opportunity to get on air in a contest without the pressure. Bring your friends and introduce them to Amateur Radio Field Day and a chance to experience Ham radio first hand.

Email Notices. Subscribe to the FARS Announcement list (k6ya.org/mail/) to receive reminders of FARS activities and other news. de Mikel, KN6QI

March Meeting Report

Gary Gordon, K6KV, described a Triplexer that he built for Field Day that permits three stations to operate simultaneously on different bands while sharing a single antenna. Gary helped design and build the triplexer, and WVARA used it at 2009 Field Day. An article describing the triplexer will appear soon in QST.

Gary Gordon, K6KV
March Speaker

Michael, Steve, Herb, Joanna, Keith
Raffle Winners

The first prize, a Samlex America Model 1235M 30Amp DC Switching Power Supply, was taken home by Joanna Dilley, KI6YRU. Keith Remillong, win the 2nd prize, an MFJ-392B Communications Headphones with dual volume control. 3rd prize, a DBJ2 antenna donated by Ed Fong, WB6IQN, was won by Michael Pechner, NE6RD. 4th prize, an ARRL Repeater Directory was won by Steve Stearns, K6OIK. A 2010 Northern California Repeater Directory, 5th prize, was won by Herb Vanderbeek, WY6G. The Wish You Were Here number for Tom Smith, KD6SOJ, was chosen. Unfortunately, Tom was not present to claim the prize.

CLUB INFORMATION

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Club members and non-members are encouraged to subscribe to the FARS Announcement list by browsing www.fars.k6ya.org/mail, clicking on Subscribe/Unsubscribe and following the instructions under "Subscribing to fars-announce.

You may submit announcements to the FARS Announcement at fars-announce@svpal.org. The list is moderated and messages will be posted as approved by the list moderator.

Contact the FARS board of directors at fars-board@svpal.org

Club meetings are held at 7 PM on the fourth Friday of each month except January (Winter Banquet); and sometimes there are changes for June (for field day) and Nov. & Dec (for holidays).

Annual club membership is $20. Club badges are $9. Visitors are always welcome! Directions in this newsletter. Talk-in: N6NFI (145.23-, 100 Hz) or W6ASH repeater (145.27-, 100 Hz).

FARS *Relay* is the official monthly newsletter of the Foothills Amateur Radio Society. Contributions to the newsletter from members, family, and guests are earnestly solicited! Contributions are subject to editing and/or compression. All readable forms welcome.

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Email: mark.af6do@gmail.com, At FARS meetings.

Upcoming Events

Apr 23	7:00 pm, Club meeting, Covington School
Apr 24	8 am to 9 pm, Am-Tech Day, SLAC NAL
May 1	8 am, VOMARC HamFest, Sonoma
May 6	7:30 PM, Board Mtg at the Los Altos Town Crier
May 8	Electronics Flea Market, hosted by SCCARA
May 15	8 am to 9 pm, Am-Tech Day, SLAC NAL
May 22-23	8 am to 5 pm, Maker Faire
May 28	7:00 pm, Club meeting, Covington School
Thursdays	8:00 pm, FARS net, 145.230(-), 100 Hz PL

See more events, FARS Calendar <http://www.fars.k6ya.org/events/calendar>

April Raffle Prizes

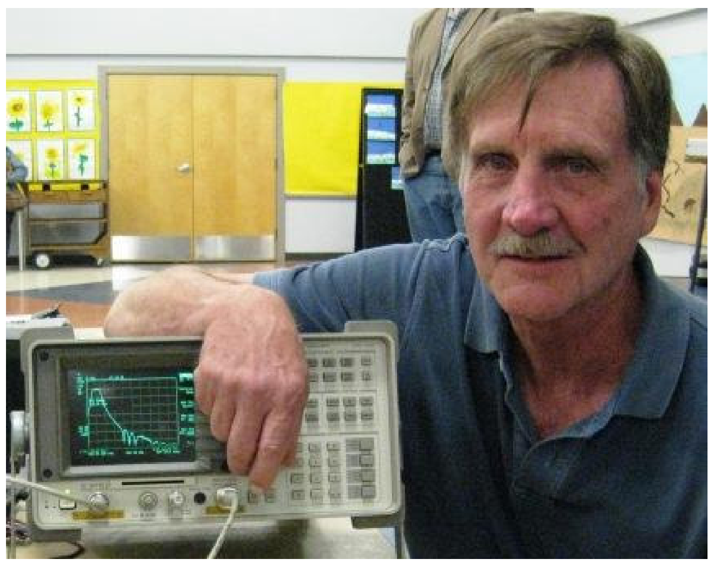
The first prize is the new Icom IC-V80-25 2 meter handheld 5.5Watts with loud RX. 2nd Prize MFJ-281 Cleartone Speaker. 3rd prize Northern California Repeater Directory. 4th prize 2010 ARRL Repeater Directory. FARS will also raffle two tickets to the Maker Faire, donated by Michael Pechner, NE6RD. See pictures at right, from manufacturers.

Field Day Triplexer

Gary Gordon, K6KV, showed the Triplexer that he built that permits three stations to operate simultaneously on different bands while sharing a single antenna. The picture below shows the triplexer as built.

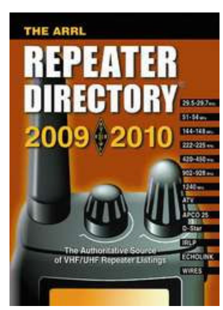
Field Day Triplexer

The frequency response for one band can be seen on the spectrum analyzer screen below. The bands showed good response and good separation.



Spectrum Analyzer with Frequency Response, shown by Gary Gordon, K6KV

April Raffle Prizes



SmartMeters and Electric Power Measurement

Steve Stearns, K6OIK, April 2010

Let's suppose that you are one of many who've returned home only to find a new SmartMeter on your house. Your electric utility provider installed it while you were out. You've read in the news that these new meters may read power differently, resulting in high electric bills. Is this true? Should you complain to your utility or the California Public Utility Commission? This article will review how the new electronic power meters work, and how your electric utility might be charging you more for electric power.

As you probably read in the news, Los Angeles attorney Michael L. Kelly of Kirtland & Packard LLP is suing electric utilities in California because the new SmartMeters report greater energy usage than the old meters they replaced. Watt-hour meters were electromechanical in the century after their development by Thomson, Duncan, General Electric, Tesla, Sangamo, Westinghouse, and others. Today, four companies make watt-hour meters: Landis+Gyr (formerly Siemens, Duncan), GE, Itron (formerly Schlumberger, Sangamo), and Elster (formerly ABB, Westinghouse). All four companies have historic roots dating to the 19th century, and all manufacture electronic watt-hour meters today. Elster is the last company to offer an electromechanical model.

First we will review some basics from AC circuit theory to understand what power means before tackling the question of how it is metered. Power is the rate at which energy is delivered. The unit of electric power is the watt (W). Mechanical engineers often use the horsepower as the unit of power. One horsepower is approximately 746 watts. The unit of electric energy is the joule (J), which is one watt-second. Electric utilities measure energy with a bigger unit, the kilowatt-hour (kWh). One kWh is 3.6 Mega joules (MJ).

Imagine a circuit consisting of a voltage or current source connected to a load. The power delivered to the load at each instant of time is the product of the voltage across the load times the current flowing through the load. If the source waveform is periodic in time, then the instantaneous power can be averaged over one cycle to obtain real average power. In the electric power industry, it is called "active" power to contrast with "reactive" power. Real average (or active) power is the basis for metering and billing. When the source is sinusoidal and the load is linear the real average power delivered to the load is given by well known formulas

$$P = \frac{1}{2}\mathrm{Re}\left\{ VI^* \right\} = V_{rms} I_{rms} \cos\theta = P_{apparent} \times \text{Power Factor}$$

where V and I are complex phasors representing sinusoidal voltage and current, the superscript asterisk represents complex conjugate, Re{} denotes the real part of a complex number, V_{rms} and I_{rms} are the rms voltage and current, $P_{apparent}$ is the product $V_{rms}I_{rms}$ in volt-amps and is called "apparent power," and $\cos\theta$ is the cosine of the phase angle between V and I and is called "power factor." It is important to remember that these AC power formulas apply only when the source is sinusoidal and the load is linear.

More generally, if the load is nonlinear and its voltage and current waveforms are general periodic functions of time, then real average power is given by

$$P = \frac{1}{T}\int_0^T v(t)i(t)dt = \frac{1}{2}\sum_{n=1}^{\infty} \mathrm{Re}\left\{ V_n I_n^* \right\} = \sum_{n=1}^{\infty} P_n \le V_{rms} I_{rms} = P_{apparent}$$

The formula on the left states that the average power is the average of the instantaneous power averaged over one period of the voltage and current waveforms. The formulas in the middle state that the power is the sum of the powers of the harmonics. The inequality on the right is a statement of the Cauchy-Schwarz inequality, namely that the real average power cannot exceed the product of the rms load voltage times the rms load current. This product is called "apparent power," the same as in the sinusoidal case. Electric power metering is based on the integral on the left. The other expressions will help us understand the issues with SmartMeters.

Electromechanical watt-hour meters are induction motors. They have two coils for sensing voltage and current respectively. The voltage sensing coil induces a radial current in the rotor, which is a thin conducting disk, usually aluminum. Early disks were suspended on jewel bearings; later disks floated on magnetic suspension. The current sensing coil creates a magnetic field perpendicular to the disk that creates a force on the current in the disk according to the magnetic force law

$$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}$$

This force, in turn, creates a torque on the disk. A magnetic brake plus bearing friction supply drag forces that hold the disk's speed in check, preventing unlimited acceleration. The speed of rotation is proportional to a moving average of the instantaneous product of the currents in the voltage and current sensing coils. The disk is connected by gears to a register of dials that count its turns. Figure 1 shows a common arrangement.

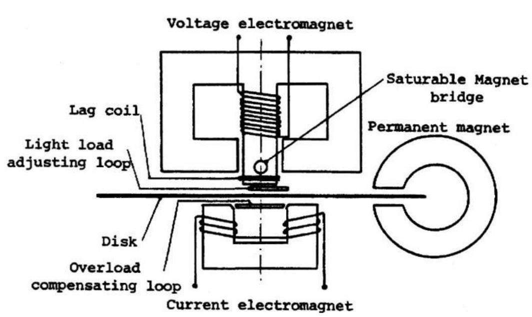


Figure 1. Electromechanical meter [Baghzouz].

The new meters are electronic rather than electromechanical motors. The voltage and current waveforms are sensed, either through isolation transformers or other coupling means, and digitized by A/D converters that sample the voltage and current waveforms at a high rate. Once digitized, a DSP processor multiplies the samples digitally to obtain instantaneous power. The products are summed to obtain real or active power. This method of power measurement includes the power in hamonics that are within the passbands of the transformers and anti-aliasing filters.

The definition of reactive power and the explanation of its measurement is more complicated. Landis+Gyr documents make it clear that the FOCUS AX meter is designed to measure and report the components of complex power – real and reactive, inductive and capacitive, current leading or lagging, positive or negative. This is easy to do when the voltage and current waveforms are sinusoids with only a relative phase shift between them. In this situation, power factor and reactive power are determined by measuring the phase shift between current and voltage. However, when waveforms are not sinusoidal, the situation is more complicated.

We can make general definitions of real and reactive power that include harmonic power

$$P = P_{real} = \frac{1}{2}\mathrm{Re}\left\{\sum_{n=1}^{\infty} V_n I_n^*\right\} = \frac{1}{2}\sum_{n=1}^{\infty}\mathrm{Re}\left\{V_n I_n^*\right\} = \sum_{n=1}^{\infty} P_n$$

$$Q = P_{reactive} = \frac{1}{2}\mathrm{Im}\left\{\sum_{n=1}^{\infty} V_n I_n^*\right\} = \frac{1}{2}\sum_{n=1}^{\infty}\mathrm{Im}\left\{V_n I_n^*\right\} = \sum_{n=1}^{\infty} Q_n$$

where the symbols P and Q denote active and reactive power respectively, i.e. the real and imaginary parts of the complex power $P + jQ$. In order to compute power according to these definitions, Fourier analysis must be performed on the voltage and current waveforms. An electronic meter can compute reactive power by the definition above if it has an FFT, which some meters do, but there are simpler ways to determine reactive power Q in single-phase power systems. First, notice that complex power has squared magnitude given by

$$P^2 + Q^2 = \left(V_{rms} \times I_{rms}\right)^2 = P_{apparent}^2$$

from which we obtain the magnitude of Q but not its sign

$$|Q| = \sqrt{\left(V_{rms} I_{rms}\right)^2 - P^2}$$

The units of reactive power are "volt-amperes reactive" or Vars, and can be positive or negative. Linear inductive loads have positive reactive power, and capacitive loads have negative reactive power. Nonlinear loads also have positive or negative reactive power. If the direction of metered power flow reverses, the algebraic signs of all power components are reversed. These conventions, taken from an L+G document, are shown in Figure 2. It is clear that Landis+Gyr meters measure P and Q as algebraically signed quantities.

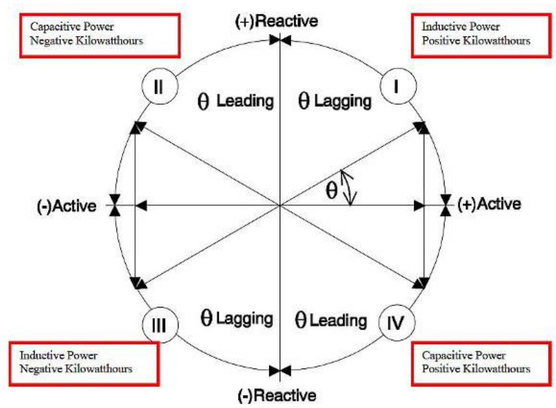


Figure 2. Landis+Gyr conventions for the real and reactive power.

Can a meter determine the sign of the reactive power Q without an FFT? A clue comes from the sinusoidal case that started this discussion.

$$Q = \frac{1}{2}\mathrm{Im}\left\{VI^*\right\} = \frac{1}{2}\mathrm{Re}\left\{-jV \times I^*\right\} = \frac{1}{2}\mathrm{Re}\left\{Ve^{\frac{-j\pi}{2}} \times I^*\right\} = \frac{1}{T}\int_0^T v_{delayed}(t)i(t)dt$$

We see that reactive power can be calculated by multiplying current and voltage time waveforms provided the voltage waveform is first delayed a quarter cycle before multiplying it by the current. Similarly for general loads, reactive power Q is found by multiplying the current waveform times a modified voltage waveform and averaging over a cycle.

$$Q = \sum_{n=1}^{\infty} Q_n = \frac{1}{2}\sum_{n=1}^{\infty}\mathrm{Im}\left\{V_n I_n^*\right\} = \frac{1}{2}\sum_{n=1}^{\infty}\mathrm{Re}\left\{-jV_n I_n^*\right\} = \frac{1}{2}\mathrm{Re}\left\{\sum_{n=1}^{\infty} V_n e^{\frac{-j\pi}{2}} I_n^*\right\} = \frac{1}{T}\int_0^T v_{\mathrm{mod}}(t)i(t)dt$$

The modified voltage waveform is obtained by delaying all of the voltage harmonics by a quarter cycle. This is easily done by passing the voltage waveform through a Hilbert transform filter. Such filters are readily implemented in DSP as finite impulse response (FIR) or infinite impulse response (IIR) filters. Landis+Gyr meters use FIRs based on a patent by Jurisch and Kramer. The preferred approach today is to use IIR filters, which require fewer multiplications than FIR filters for equal accuracy. More expensive electronic meters use chips such as the Cirrus Logic CS5463, which is a mixed-signal (analog and digital) chip that has an onboard FFT and a sigma-delta analog-to-digital converter that's clocked at more than 500 kHz.

Unlike an electromechanical meter, the display of an L+G electronic meter does not run backwards when the consumer supplies power to the grid. Rather, the meter records energy flow by accumulating complex power in four separate accumulators that correspond to the quadrants shown in Figure 2. This enables the utility provider to choose whether to credit a customer for power supplied to the grid, i.e. negative active power. Electromechanical meters did not give the utility a choice in this matter. Residential customers are by law billed only for real, active power.

"Smart" electric meters are made by adding a wireless digital communications module to an electronic watt-hour meter. PG&E buys its SmartMeters from GE and Landis+Gyr. Residential customers are getting the GE I-210+ or the Landis+Gyr single-phase FOCUS AX series meters. If you compare the readings of an old electromechanical meter with those of a new SmartMeter, you will find that both meters agree (within meter tolerance) on power consumed if the load is linear-real, e.g. a resistor. They also agree when the load impedance is linear-reactive $Z = R + jX$, e.g. motors and fluorescent lamps with magnetic ballasts. But they won't agree when the load is nonlinear, e.g. switching power supplies, light dimmers, fluorescent lamps with electronic ballast, CFLs, plug-in wall wart power supplies, and nearly all consumer electronics. The new meters measure instantaneous power in a much wider measurement bandwidth, ten times greater than the old meters – 3 kHz to 5 kHz or more, instead of 300 to 500 Hz for electromechanical meters. The new meters measure, and the consumer gets billed for, harmonic power that the old meters did not sense. The greater bandwidth and digital multiplication measurement technique mean that high-order harmonics now contribute to the power measurement, 50 to 100 harmonics instead of 5 to 10. The new electronic meters are able to sense and respond to aspects of the voltage and current waveforms to which the old electromechanical meters were blind.

The measurement discrepancy does not lie in the "smart" part of the SmartMeter, which is just Part 15 low-power digital packet communication links – 400-mW, 900-MHz ISM band to the house and 100-mW, 2.4-GHz ZigBee to the utility – nor does it lie in the utility's data collection methods. Rather, it lies in the working guts, the electronic power measuring part of the meter. By measuring power using a different bandwidth, the new meters have indirectly redefined the electrical watt, or at least the billable watt. While the utility will claim that they are not billing consumers for reactive power, they are actually doing something else, billing for higher-order harmonic power – and unequally among different meter models. Moreover, depending on the internal algorithms for quadrant accumulation of power, it is shown below that the metering and billing algorithms can actually create phantom power that the consumer gets billed for.

The fact that electric utilities are installing different models of meters made by different manufacturers is problematic. There are no standards for meter bandwidth or waveform crest factor specified in the Canadian or ANSI standards for electric meter accuracy. Those standards do not consider the issues discussed here. Consequently, SmartMeters made by different manufacturers, such as GE and Landis+Gyr, can differ widely on such basic circuit parameters. Customers whose loads are linear (e.g. incandescent lamps and motors) will be billed equally, but, customers whose loads, are nonlinear (e.g. modern electronic devices) may be billed differently for the same power consumption. Without bandwidth and crest factor standards, the only remedy is that billing rates cannot be both universal and fair but should be tailored and specific to each model of meter.

Some people may reason that because the strength of harmonics ultimately fall off with frequency, it follows that high-order harmonics have a negligible contribution to total power. Such reasoning is incorrect. The infinite series

$$\sum_{n=1}^{\infty} \frac{1}{n} ,$$

which is called ironically a "harmonic" series, has terms that decrease as n increases. Yet this series sums to infinity, thereby proving that many vanishingly small things can indeed add up to a very big thing, infinity. Merely getting weaker is insufficient for high-order harmonics to contribute negligibly to total power. A stronger condition is needed.

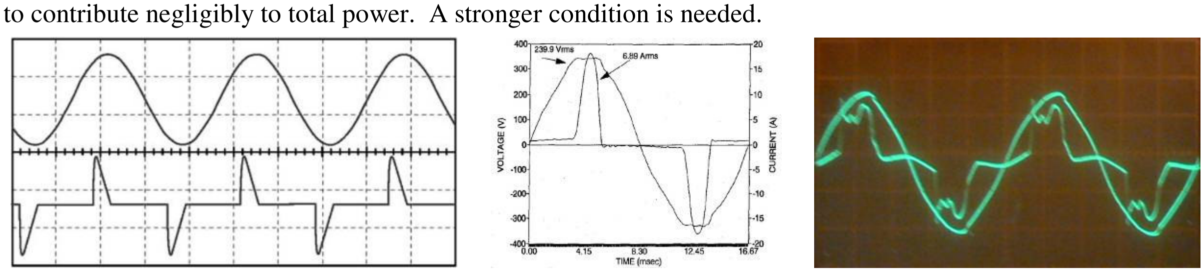


Figure 3. Voltage and current waveforms: (a) ideal switched-mode power supply; (b) measured heat pump [Domijan]; (c) measured CFL [Korsak].

Figure 3(a) on the left shows what the voltage and current waveforms of a switched-mode power supply might look like ideally. The voltage waveform is a pure sinusoid, but the current waveform is not. Power harmonics are created only if the voltage and current waveforms both have harmonics of the same order. So in this case, no harmonic power is created. However, this ideal case is only of academic interest because the power grid at the meter has a Thevenin source impedance that isn't zero. Small yes, zero no! Consequently, if a nonlinear load creates current harmonics, voltage harmonics are also created automatically by loading. The effect of current loading on voltage is shown in shown in Figure 3(b). The voltage waveform at the meter is no longer a sinusoid. Figure 3(c) shows similar waveforms for a compact fluorescent lamp (CFL), measured by A. Korsak, KR6DD. Again, the voltage waveform is visibly distorted and is not a pure sinusoid.

An important point is that power harmonics are only created when current and voltage harmonics are both present simultaneously at the meter. A consumer's load directly causes only current harmonics. A utility's grid design determines its Thevenin source impedance and voltage purity at the consumer's meter. In this sense, a utility that skimps on infrastructure design causes power harmonics. As we will soon see, power harmonics, once created, can lead to phantom power that can affect the consumer's bill.

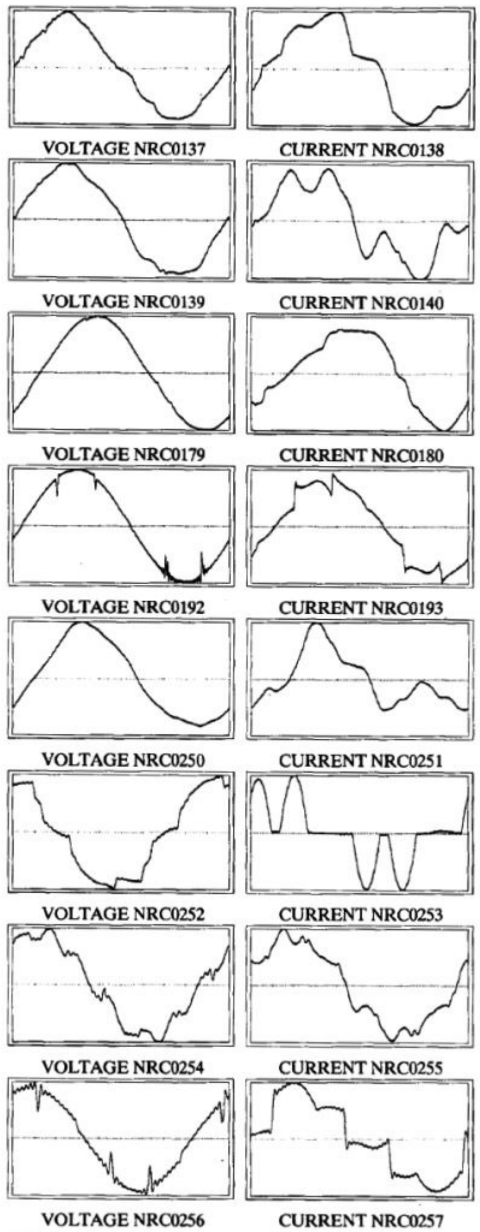


Figure 4. Measured voltage and current waveforms [Filipski].

Figure 4 shows more measured waveforms for eight different kinds of loads. Note how distorted AC voltage and current waveforms can be. In general, if the current is not sinusoidal, then the voltage isn't either. The idea of clean sinusoidal AC power is a myth taught in school.

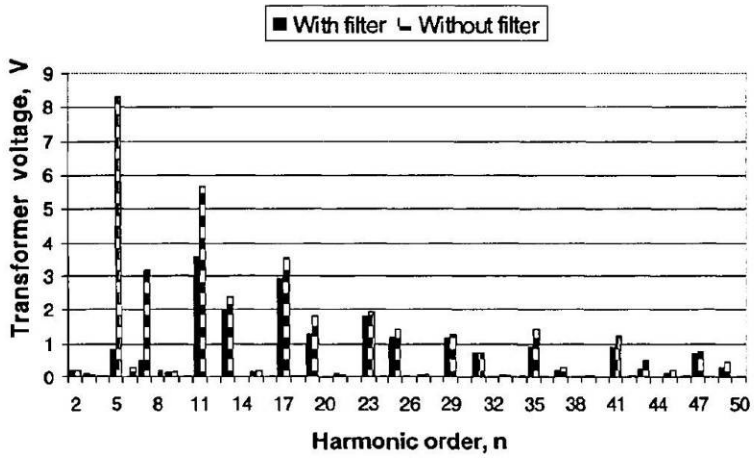


Figure 5. Voltage harmonics, [Lundquist].

The reader may ask how strong can the harmonics of a distorted voltage waveform be? Figure 5 gives some idea of the answer. The vertical axis is linear volts. The amplitudes of the harmonics are significant out as far out as the graph goes, to the 50^{th} harmonic or 3 kHz. Odd harmonics are generally stronger than even harmonics. Harmonics do not decrease monotonically with harmonic order. For example, notice that the 5^{th} and the 11^{th} are stronger than their neighbors. Far out, however, the voltage harmonic amplitudes do roll off roughly as $1/n$. Current harmonics generally roll off more slowly than voltage harmonics. It follows that the infinite series

$$P_{complex} = \frac{1}{2}\sum_{n=1}^{\infty} V_n I_n^*$$

may converge slowly. Harmonics can, in fact, account for a significant fraction of total power. It should also be mentioned that the bandwidth of some electronic meters is greater than the 3 kHz used in Figure 5. The new meters are capable of sensing some 50 to 100 or more harmonics depending on model.

Troubling Questions

The discussion above leads us to some troubling questions, none of which has been satisfactorily researched or answered. The first question is how much can the meter readings differ between different watt-hour meters due to bandwidth differences alone. A mathematician would answer simply that if one meter's bandwidth includes M harmonics and another meter's bandwidth includes N, where $N > M$, and if both voltage and current are allowed to have arbitrary waveforms, then waveforms exist for which the second meter reports arbitrarily more power than the first meter does. One merely has to design the load to concentrate all dissipated power in the $N – M$ highest harmonics. In this way, the first meter measures zero, while the second meter measures all of the load's power. An engineer would modify the question: For the current waveforms created by actual nonlinear loads that people have in their homes, by how much do the readings of different meters differ? This question can only be answered by surveys and laboratory measurements.

A specific question is: Do CFLs really save energy? As near as I can determine, the only evidence that CFLs save energy came from measurements made using old watt-hour meters, which had smaller measurement bandwidth and were blind to power in the higher-order harmonics of the voltage and current waveforms. Did any competent laboratory such as the National Institute of Standards and Technology (NIST) ever measure the real power consumed by CFLs? Such measurements require specialized equipment for making power measurements. The measurements should be made in a shielded EMI chamber to eliminate stray RF pickup. Laboratory equipment would digitize the voltage and current waveforms of a load separately in a wide bandwidth, and compute the integrated product. It seems unlikely that such accurate measurements were ever made. The claims for the greater efficiency of CFLs were made years before people questioned watt-hour meter physics and performance. The Canadian and ANSI standards for electrical metering don't appear to include such tests among their test protocols. Any competent technician can measure current and voltage waveforms. A simple test setup for measuring CFL current and voltage waveforms with an oscilloscope is shown in Figure 6. However, making accurate power measurements when current waveforms are impulsive with harmonics in the ULF and VLF radio bands requires professional laboratory facilities.

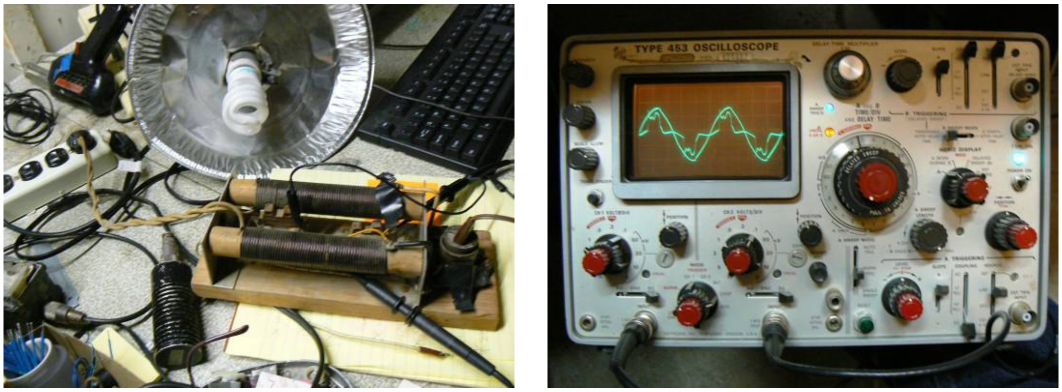


Figure 6. (a) Setup for testing CFLs; (b) measured waveforms [Korsak].

Concerning the accuracy of electronic power meters, one electric utility's engineers and consulting engineers (Florida Power) have stated in print: "Highly distorted waveforms (like those in Figure 3) often have a very high crest factor. Electronic meters have some limit to the maximum current magnitude they can interpret correctly because either they reach the upper limit of an A/D converter or somewhere in the electronic circuit an amplifier is driven to its limit; thus some signal truncation may occur under specific circumstances."

Now "truncation," the correct term is "limiting," would normally be to the customer's advantage if voltage and current samples were simply multiplied and accumulated. However, from the discussion surrounding Figure 2, we saw that electronic meters can use four quadrant accumulators. If a meter uses an FFT, like Cirrus Logic's CS5463 chip, instead of a Hilbert transform filter, then different algorithms for putting the FFT outputs into the quadrant accumulators can give greatly differing results. To see what can happen, consider the array of numbers.

$$\begin{array}{cccc} 1 & -2 & 3 & -4 \\ 5 & -6 & 7 & -8 \\ 9 & -10 & 11 & -12 \\ 13 & -14 & 15 & -16 \end{array}$$

We are going to add the numbers, tallying positive and negative sums separately. Consider three methods for doing this.

Method 1: First add all 16 numbers to get -8. Since the sum is negative, we put -8 in the negative accumulator and put zero in the positive accumulator. We write the result as (-8, 0).

Method 2: Sum each row by itself. Then put the negative row sums in the negative accumulator, and put the positive row sums in the positive accumulator. Since every row sum is -2, we again obtain (-8, 0).

Method 3: Sum each column by itself. Put negative column sums in the negative accumulator, and put positive column sums in the positive accumulator. Since column sums are 28, -32, 36, -40, we obtain (-72, 64).

Now suppose the first row corresponds to power in the first four harmonics determined from FFT no. 1. The second row corresponds to FFT no. 2, and so on through FFT no. 4. Suppose that positive numbers represent "active" power delivered from the grid to the customer, and negative numbers represent negative active power delivered from the customer to the grid.

Next consider two different billing policies. Under Policy A, the utility bills for the net active power, i.e. the difference between the accumulators – the value in the positive accumulator minus the value in the negative accumulator. Under this policy, all three methods of tallying harmonic power result in a credit to the customer of 8 units. Now consider the effect of Policy B under which the utility bills for positive active power with no credit for negative active power. Under Policy B, Methods 1 and 2 result in a zero bill, but Method 3 results in a bill for 64 units. We see, therefore, that the customer's bill ranges from a credit of 8 to a debit of 64 depending on meter accumulation algorithm and billing policy. Odd, true. But this story has a more bizarre twist.

As shown in the example above, each harmonic represents positive or negative active power by itself. It all depends on the relative phase between a voltage harmonic and its corresponding current harmonic at the point of measurement. However, nonlinearities inside the meter, such as limiting, affect these phase relationships. So while net power is unchanged, the directions of active power flow of individual harmonics can be modified and even reversed by nonlinearities in the meter itself. A customer might use 1 kWh, but the meter might report it as 3 kWh positive active and 2 kWh negative active, and the utility using Policy B would bill the customer for the 3 kWh and ignore the 2 kWh. In this example, the meter creates and adds phantom power in equal amounts to the customer's positive active and negative active accumulators. Normally such phantom power in both accumulators is cancelled when the accumulators are subtracted. However, under Policy B, this subtraction does not occur, and the customer is billed for the positive active phantom power in addition to his real power consumed. This is not fair. But it is altogether more unfair when it is the meter's own nonlinearity (e.g. limiting) that created the phantom power in the first place.

That nonlinearities in an electrical circuit can modify the phases of current and voltage harmonics is familiar to analog RF circuit design engineers. In fact, the mathematical technique of "harmonic balance" analysis, used in professional circuit design programs made by Agilent, Ansoft, and Applied Wave Research, was developed precisely to analyze such effects. The interested reader is referred to the engineering literature (cf. Gilbert and Steer) for explanation of the harmonic balance method in circuit analysis and design.

What to Expect?

We expect that as utilities roll out SmartMeters throughout the state, a strange irony will emerge: Those customers who did the most to save energy will see their bills increase the most, while late adopters who still use Edison's incandescent lamps, have no wall warts or consumer electronics, will see little or no increase in their electricity bills. A small increase of a percent or two may sometimes occur when the original electromechanical meter ran "slow" due to increased friction from age. However, the increase due to increasing the meter's measurement bandwidth by a factor of ten or more is much greater than a few percent. Given that the California Public Utilities Commission (CPUC) has allowed the electric utilities to change the definition of the billable watt by changing the measurement bandwidth, it seems reasonable and fair that consumers demand the CPUC to create new electric rates to go with the new meters and refund the difference to consumers who were overcharged by a mismatched application of old-meter billing rates to SmartMeter readings.

Furthermore, because meter nonlinearities can modify harmonic phase relationships to potentially create phantom power (equal amounts of fictitious positive and negative active power), it is reasonable and fair that consumers demand the CPUC to prohibit utilities from billing residential customers for anything except "net" active power. This means credit must be given for negative active power (power delivered to the grid by the consumer) as reported by electronic meters. Until it is proven that electronic meters cannot create phantom active power by altering harmonic phase relations, utilities should be prohibited from using billing policies like Policy B and should be required to bill customers for "net" or "positive-minus-negative" active power, which removes any phantom power from the customer's bill.

Acknowledgment

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http://watt-hourmeters.com/history.html

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Steve Stearns, K6OIK, started in ham radio while in high school at the height of the Heathkit era. He holds FCC Amateur Extra and a commercial General Radio Operator license with Radar endorsement. He previously held Novice, Technician, and 1st Class Radiotelephone licenses. He studied electrical engineering at California State University Fullerton, the University of Southern California, and Stanford, specializing in electromagnetics, communication engineering and signal processing. Steve is currently Senior Staff Engineer at Northrop Grumman's Electromagnetic Systems Laboratory in San Jose, California, where he leads advanced technology projects in advanced signal processing algorithms, active non-Foster circuit design, exotic antennas, and electromagnetic wave phenomena. Steve is vice-president of the Foothills Amateur Radio Society, and served previously as assistant director of ARRL Pacific Division. He has over 50 professional publications and nine patents. Steve has received numerous awards for professional and community volunteer activities.

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