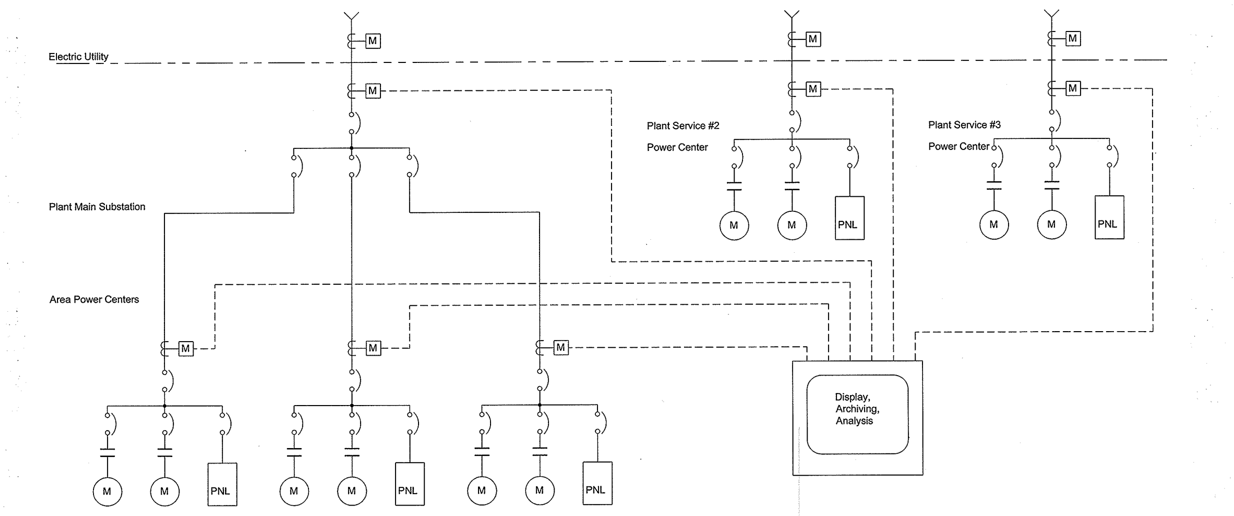
Digital Power Metering and Industrial Data Communication for Meter Systems

Course Content

To successfully apply power metering and interpret the results, one must be intimately familiar with the characteristics of electric energy flow. The electricity characteristics are closely related to the measurement instruments available. The instruments and sensors, in turn, become the limiting factor in the accuracy of the numeric results reported. Even simple meters, today, include a microprocessor. Thus, the results reported include sensor limitations, microprocessor limitations and software limitations. After a measurement is made it must be placed in context for analysis purposes. To create a context, data wiring to a central point, central archiving and display tools improve analysis by several orders of magnitude over a sharp pencil and a clipboard. These principles, some underlying definitions and examples are illustrated and addressed after the system graphic below:



Typical Industrial Power Distribution and Metering System

[Somebody is already complaining that the three meters are located at the Area Power Centers instead of at the main substation. That is certainly a cheaper and valid alternative. But, does it provide maximum benefits to the Owner? The meter at the Area Power Center provides maintenance information to the local supervisor and local maintenance persons. The same information could be accessed at the substation, but probably would not – because of the long walk and somewhat foreign location. If plant data were being archived manually, all the meters at a single location is a benefit. But, with the computerized archiving system in the office, the benefit is much less.]

- Utility service and regulations - Rigid and precise, but different next door.
- Check metering - Essential (author's message).
- Balancing the closure - Check metering demonstrates system accuracy / error, unless you cook the numbers.
- Single-phase circuit - It goes in here and it comes out here.

- Three-phase circuit - It goes in here, here and here. It doesn't come out.
- Volts, peak, average, rms, THD, TDD - It used to be called potential.
- Amps, peak, average, rms, THD, TDD - The flow of electricity.
- Volt-Amp relationships, watts, vars, power factor - Even the real stuff is a little imaginary.
- Measuring Volts, Analog-to-Digital Conversion - Eight-bit conversion means 256 discrete steps or ~.4% accuracy. Twelve-bit is 5096 steps and would be .02% accuracy if it existed. Do you believe 16-bit conversion?
- Electrical Safety - Voltage is sometimes defined as how hard the electricity is trying to get out ... so it can kill you.
- Measuring Amps, Current Transformers, Analog-to-Digital Conversion - Current transformers are problems..
- DANGER, Will Robinson, DANGER - Conventional 5A current transformers are trying to blind or kill you.
- Calculating Volt-amp relationships - Once, there were dedicated analog computation circuits. In a box, the price was $300 each. Today a microprocessor does more, better and costs $10. The box, programming, i/o and display are extra. Maybe it is still $300, net.
- Registers and numeric storage - When you understand this, data communication is easy.
- Waveform storage - Waveforms are sexy but not very meaningful.
- Time-stamped event storage - Only as accurate as the reference clock.
- ModBus communication - Master / Slave. Almost non-proprietary. Certainly supported by many, many vendors.
- Modbus communication wiring and distance extension - What to buy and where to buy it.
- TCP/IP communication - Almost non-proprietary (read the fine print). Supported by many, many vendors, and cheap.
- TCP/IP communication wiring and distance extension - What to buy and where to buy it.
- SMTP - Simple mail transport protocol
- Display, Alarming, Trending, Archiving and Analysis - You get what you pay for.

Each of these concepts and components will be discussed in some detail, followed by discussions of meter installation and project justification.

Utility service and regulations - Each State has a commission charged with regulating the public utilities and protecting the public. They publish a set of regulations and, very rarely, enforce them.

Each Utility has a set of rules for compliance with the utility commission regulations and to provide guide for their employees in providing uniform, high quality service and in protecting the utility from loss of revenue or taking on unnecessary liability.

Each utility area service supervisor has preferences and a well-known, but unpublished list of rules he enforces and rules he prefers be ignored.

Most utilities ignore existing non-compliant installations or try to give them or sell them very cheap to the customer.

These statements set the context for a discussion of check-metering. Understand that the National Electric Code specifies only a single service for a single building. Each State and Utility have rules limiting to a single service. Still, almost every industrial or commercial establishment of any size has several services. The Plant Manager may not know it, but the warehouse erected five years ago has a separate electric meter, and the parking lot lighting comes off a separate meter. He probably knows that the maintenance building, out back, has a separate meter.

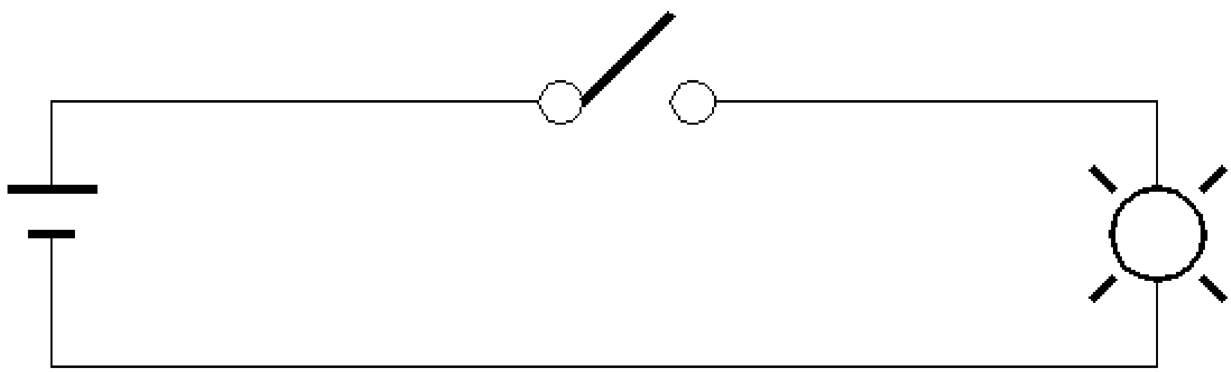
Check metering - Check metering has two great values - billing verification and maintenance data. Utilities are honest, but generally overstrained. A meter installed incorrectly will not be discovered by the Utility until a customer complains. Similarly, the negotiated billing arrangement may incorporate errors that will not be corrected unless the customer does check-calculations.

This is non-trivial. There are Xerox copies of checks for $200,000 hanging on walls to demonstrate the refunds given following resolution of metering disputes. Of course, future billing is less every month.

When a store, office or plant experiences a continuing electrical problem, a key piece of information is whether the source is external or internal. If you can prove the Utility is giving you "bad juice", they will sometimes fix it. A simple volts and amps display gives substantial information. A meter with peak registers tells more; one with individual harmonic measures can identify a bad actor simply by matching problem indications with use record. The meter report very small bad actions that do not quite produce the catastrophic failure. This same result can be produced by portable instruments, but one 30-day rental equals the cost of a permanent installation.

Balancing the closure - Revenue check metering for cost allocation contains an inherent defect - measurement accuracy, which shows up as whole not equaling the sum of the parts. This is corrected by doing the reconciliation before giving the numbers to Accounting. Unless really suspicious, use the Utility measure as correct and proportionately distribute the difference among the in-plant measures. When surveyors do this, they call it "balancing the closure" or "faking it".

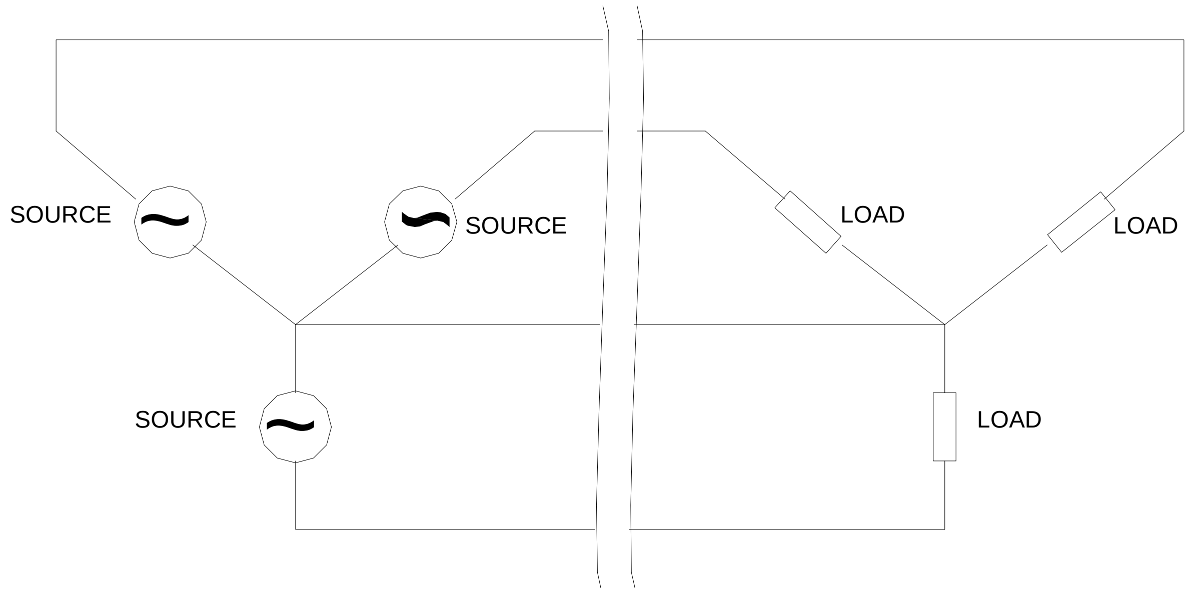
Single-phase circuit - Single-phase circuits are largely intuitive. There is an energy source, battery, wall outlet or Utility connection. There is a wire to the load. There is a return wire back to the source. Nothing mysterious.



Three-phase circuit - Three-phase circuits are not intuitive. There are three sources, usually windings of a transformer. There is a wire to each of three loads. There is a common wire for return back to the source. The mystery is that when the three load currents are equal and well-behaved, there is almost no current back to the source! The trick is that the sources are not quire identical. One is a reference; the second is delayed by 1/3 of a cycle; the third is delayed 2/3 of a cycle. With three near-identical, well-behaved current flows, the returns cancel to zero. The user gets 3x the load capacity with 1-1/2 the copper investment.

This is the reason that industrial power systems are usually three-phase, three-wire. No provision is made for the return conductor. Lighting is connected phase-to-phase and the designer tries to balance the loads on the three phases.

There was a strong implication in the preceding discussion that all loads do not draw well-behaved currents. That was intentional. Present day problem loads are high intensity discharge (HID) lighting, variable speed drives (VFDs) and computers. They can be operated on three-phase, three-wire power, but cause heating of conductors. Welders and frequently starting large motors are also problems. All will be discussed in more detail when we get to the meters which identify the badly behaved currents.



Volts, peak, average, rms, THD, TDD - The source provides the voltage and the load determines how much current flows. If the conductors are good, the voltage at the source is the same as the voltage at the load. You measure voltage with a portable meter by carefully poking an exposed connection of the low side of the source with the black test prod and carefully poking the high side with the red prod. Keep watching the connections and have a helper read the meter.

What does the portable meter report? All meters claim to report rms voltage. RMS is the heating value, or DC equivalent voltage. A premium AC voltmeter takes hundreds of instantaneous voltage readings and calculates the equivalent AC rms to report. A good meter has an analog circuit that accurately provides rms equivalent. A cheap meter uses the basic meter element, which is average sensing, and multiplies it by a constant which is correct for well-behaved voltages. The Utility limit for bad voltages is 4% from good voltages, so, on a good day, the cheap meter works well. It is very wrong for HID lighting, VFD's and computers.

Peak voltage is easy for a premium meter. The microprocessor does a comparison on each instantaneous measurement and stores only the highest. Read the manual carefully. Peak means different things to different people. The most common usage is to compare the time-calculated rms values, not the instantaneous peaks. Thus, a 120V circuit reports 135V peak. In fact, every cycle of a 120V circuit peaks at 120x1.414 = 170V. The slow peak is meaningful for determining stress on equipment and for identifying voltage dip during motor starting. The fast peak is essential for tracing transient problems to the Utility or to problem equipment.

THD and TDD are where misunderstanding and outright lies become prominent. Study IEEE Standard 519 and talk to a power engineer if you want to really understand the topic. In practice, THD is instantaneous sum of harmonic voltages divided by the fundamental voltage. At a VFD you will see 5-25% THD(V). At the utility service you must not see more than 4%.

TDD is the 15 minute average of sum harmonics divided by the fundamental PLUS the harmonics. The long average means that it can only be reported by a portable logger or permanently installed meter. The bigger denominator means that the value is always less than THD. With substantial harmonics, TDD is much lower.

Amps, peak, average, rms, THD, TDD - The source provides the voltage and the load determines how much current flows. A good clean source connected to a well behaved load will produce clean current, except for the transient when the load is turned on and turned off. A dirty source connected to a well behaved load will produce dirty current flow. This is the reason for the Utility limit of 4% THD(V). The Utility must respond to measurements in excess of 4%.

A clean source connected to a badly behaved load will produce dirty current flow. The dirty current flow creates THD(V) by the non-uniform voltage drop across the distribution system and utility transformer. This is why we measure THD(I). Harmonic distortion on the current drawn creates the harmonic distortion on the voltage. It is the harmonic distortion on the voltage that affects the Utility and other users.

This concept connects to the previous discussion of THD(V) as well. If your utility service, on the load side of the utility transformer, is shared by other firms, as in a multi-tenant building or industrial park, THD(V) problems are shared problems. But, the solution is THD(I) reduction at the badly behaved load.

You measure amps by getting a sensing current transformer around the individual conductor of interest. Conductors are most available at connection points, where lethal voltages are present. A substation foreman once bare-handed applied a clamp-on current meter to a 5kV energized conductor 6-in from the lugs. He wasn't sweating. I was. Don't do this.

Modern portable clamp-on ammeters are well designed. They are highly insulated, have guards to limit slipping into busbars, have a reading-hold button, and claim .1% accuracy. Permanent meters require external current transformers. This is the basic limitation of accuracy to the system and deserves detailed discussion later.

As with voltage, the standard for current is rms. Premium meters use sampling and calculation. Good meters use analog conversion. Cheap meters use average sensing with a fixed multiplier on the meter scale. The voltage discussion of peak reading applies, as well.

THD and TDD are critical for current measurement because they measure problems and success in remedies.

General Electric Industrial Systems quotes IEEE-519 Guidelines for max THD(I) as follows:

I(SC) / I(L)	**<11**	**11<h<17**	**17<23**	**23<h<35**	**35<h**	**TDD**
<20	4.0	2.0	1.5	0.6	0.3	**5.0**
20<50	7.0	3.5	2.5	1.0	0.5	**8.0**
50<100	10.0	4.5	4.0	1.5	0.7	**12.0**
100<1000	12.0	5.5	5.0	2.0	1.0	**15.0**
1000<	15.0	7.0	6.0	2.5	1.4	**20.0**

This table relates the stiffness of the supply system to the permitted harmonic currents drawn by the load. If the supply transformer KVA = the load KVA and the transformer impedance is 5%(typical), then I(SC)/I(L) = 20xI(L)/I(L) = 20. This is a soft system. Permitted THD(I) below the 11th harmonic is 4%. (Almost all real-world harmonics are 3rd and 5th.) The purpose of this effort was to understand that 4% is the THD(I) limit for this system.

If the supply transformer KVA = 2.5x the load KVA, then I(SC)/I(L) = 20x2.5xI(L)/I(L) = 50. Then permitted harmonic current below the 11th is 7 or 10%. This is in the direction of a stiff system. 10% is the THD(I) limit for all loads connected and drawing through the service point.

It is possible to examine the physical installation associated with these two cases, but the conclusion is that a unit substation transformer serving mostly VFD loads will require additional harmonic controls if IEEE guidelines are to be met. There is no enforcement consequence except for harmonic voltage at the utility service.

The implication was just made that variable frequency drives draw substantial harmonic currents. In the same GE Industrial Systems publication, it is stated that,

Typical VFD Harmonic Current Content Without using any filtering techniques	
1-20 HP	> 100%
25 – 40 HP	80 – 100%
50 – 150 HP	60 – 80%
200 HP and up	50 – 70%

The total harmonic current is THD(I), not TDD, because TDD cannot exceed 100%, where THD(I) can.

Most vendors include line reactors or DC reactors as filtering techniques and the harmonic currents shown do not reach the supply feeder. Cost can be reduced by deleting the reactors if not specifically required or compliance with IEEE-519 required in the purchase documents. However, line reactors are limited in harmonic mitigation. More powerful methods are fixed harmonic filters computerized matrix harmonic filters, 12-pulse drives and 18-pulse drives with isolation transformers.

Ask your VFD supplier if 20% THD(I) is a reasonable reading at the supply terminals.. If he says, “Impossible!” then you are the only expert in the room.

Well behaved loads lower the THD(I) and THD(V) for the total facility. Beyond that, additional reactors, tuned filters or active filters are required to meet the 4% limit for THD(V).

Volt-Amp relationships, watts, vars, power factor - Volts are applied; the load draws amps. Volts x amps = volt-amps. Usually seen in units of 1000 va, or 1 KVA, this measure is simple, understandable and meaningful. KVA is called apparent power. It works perfectly for well behaved current, but less well for currents that do not match the voltage exactly in waveform and timing. (Remember, the load determines the current.) Transformers are sized in KVA and motors are sized in KVA in Europe. Some power billing contracts charge for KVA.

Timing of the current is off for motors, HID lighting, computers and most loads other than incandescent lights and electric heat. To separate the timing problem, real power is used. Volts x amps x cos(theta) = real power or watts. 1000w equals 1 KW. Cos(theta) is a measure of the delay in starting the current after the voltage. The word for delay in starting is zero-crossing displacment. When there is no delay, cos(theta) = 1 and KVA = KW. Real power corresponds to DC power or heating equivalent or the amount of coal going into the boiler for the utility to generate the power. In many ways it is a better way to measure power and almost all power bills are based upon KW. KW is an instantaneous measure, accurate only for the moment you are looking at the meter. The total energy used in a month is collected by the KW meter as kilowatt-hours, or KWH. This is a simple register function, discussed later.

Cos(theta), the multiplier between KVA and KW, has its own name, power factor. As indicated above, values can range from 1.0, perfect, to 0.0, meaning that the volts and amps have nothing in common. Power factor = .80 is usually assumed when a measured value is not available. Power factor is usually part of utility billing and devices are available to improve power factor independently of the actual load.

The computation KW = Volts x Amps x Cos(theta) separates the real power from the apparent power. The mathematics also permit separating the not-real component, imaginary power or volt-amps-reactive, vars. The devices alluded to above, to improve power factor, supply vars or KVARs to the plant and improve the power factor. Power factor correction is not addressed in this course, but measurement of KVARS and calculation of monthly power factor penalties from the Utility are discussed. A substantial monthly penalty suggests that learning about power factor correction might be very valuable.

Historically, the Utility has purchased analog totalizing meters for billing purposes. These analog meters contain a voltage coil and a current coil. The magnetic circuit of the motor created causes it to spin at a rate proportional to the KW of the volts and amps. The number of turns are collected on the totalizer display. Sometimes the instantaneous spin rate is reported as demand KW and the highest demand KW is recorded by a tattle-tale following the KW needle. Analog displays require analog recording by the meter reader and do not lend themselves to automatic reporting. New digital utility revenue meters are cost competitive with analog meters, provide optical reporting in person or telephone or power carrier reporting automatically. The demand in demand-KW simply means the highest value in the billing period. In theory, the Utility must provide capacity for this value and it is often used in the billing calculations. We will examine the monthly demand penalty in the analysis section.

OPTIONAL DISCUSSION, DISPLACEMENT POWER FACTOR VS TRUE POWER FACTOR. The preceding discussion is accurate for 60 Hz volts, 60 Hz amps and no harmonics. It is not accurate for harmonics but works well, nonetheless. When harmonic voltages and currents are present, the zero-crossing time changes from cycle to cycle, or jitters.

An alternate, possibly better, definition of power factor is KW/KVA. KW is always fundamental volts x fundamental amps x cos(theta). KVA can be fundamental volts x fundamental amps or fundamental volts x (fundamental + harmonic amps).

This choice of KVA definition produces two different power factors. The first is displacement power factor, the same as discussed earlier, with the jitter averaged out. The second is called true power factor. The reasoning for the term true is that the number is an accurate measure of utility capacity required to supply the current containing rich harmonics. Displacement power factor is always closer to unity than true power factor. True power factor has a higher KVA, higher denominator and lower quotient.

Digital meters are capable of calculating displacement power factor or true power factor. Older utility tariffs charge for displacement power factor. Check with your utility on the billing method and with the manufacturer on which power factor they use.

Measuring Volts, Analog-to-Digital Conversion - Analog-to-digital (A/D) conversion is the step necessary to convert real world electrical phenomena to numbers for computer computations. The A/D world has developed sophisticated, reliable, inexpensive devices that respond to 0-1 volt. Today, laser-trimmed resistor networks provide high accuracy in dropping 480 VAC, 240VAC or 120 VAC to 1 volt for metering.

Do you want to add a fuse between the power system and the meter voltage sensing terminals? Traditionally fuses are not used on 480 VAC, 240VAC or 120 VAC metering applications. Small wire (#14AWG) is used. It will melt with a solid power fault and not trip off the substation or the plant. It is thought that an unskilled technician working with the fuse holder is more dangerous to himself and to the plant than destroying the wire and losing meter information. Follow the meter manufacturer's installation instructions. See if OSHA or the NEC has published anything requiring external fuses.

A/D converters used to be quirky and require a lot of attention in the meter design and later in meter usage. The technology has advanced to the level that the meter user does not need to worry about temperature coefficients, transients and anti-aliasing filters. The meter user does have to worry about the size of the data word produced by the A/D.

A/D converters are available with 6-bit, 8-bit, 10-bit, 12-bit, maybe 14-bit and probably-not-16-bit accuracy. An 8-bit data word means that the 1 volt input is digitized into 8 bits, or 256 possible combinations. If it is perfect, it reports to one part in 256, or .4%. The final bit or bits may be questionable, but this accuracy exceeds laboratory meters of 30 years ago.

12-bit A/D converters are commonly used in many applications. If we throw away the two least significant bits, we still have 10-bit accuracy, one part in 1024, or .1%. This is revenue billing accuracy and puts us at the limit of accuracy of laser-trimmed resistor networks.

The meaningful conclusion is that a meter utilizing 8-bit conversion is usable, but not a precision instrument. A meter utilizing 12-bit conversion has no limitation in this part of the instrument. Claims of 14-bit or 16-bit conversion stretch credibility. Technology may have advanced, but marketing claims have certainly advanced.

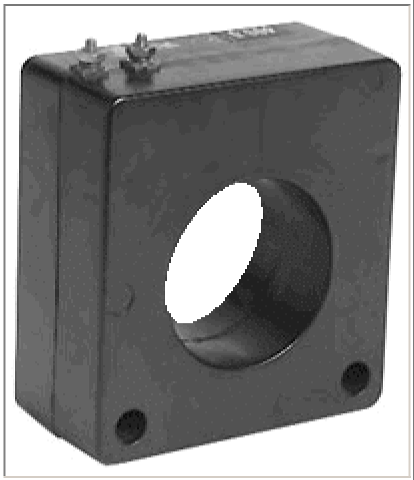
Electrical Safety - The previous section briefly discussed fuses on the meter voltage connection. The overall question of electrical safety was not addressed. PDH Online has a complete course on electrical safety, which can be viewed at no charge. NFPA, NECA and OSHA have extensive manuals on electrical safety.

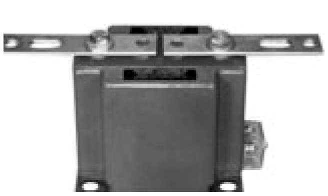
The hazards of voltage measurement, both with portable instruments and installing permanent instruments, are electrocution, arc-flash blindness, lethal burns and the effects of flying droplets of molten copper coming at you.

This course recommends that only a technician trained and experienced in meter work approach energized or de-energized power equipment for metering purposes. An engineer or project manager should stay at least 10 feet back. (This matches proposed OSHA requirements and NFPA 70E.)

Measuring Amps, Current Transformers, Analog-to-Digital Conversion - Laser-trimmed resistor networks solved the step-down problems of voltage measurements. Nothing has solved the current step-down problems. Current transformers are used, with serious well-recognized problems and new, undiscovered problems.

The problem is that interesting electric power currents are in the range of 100 – 1000 amps. A wire with a cross-section of ½-inch to a copper bar with cross-section of ½-inch by 4-inches is needed to carry the current. The traditional response is a current transformer (CT) with a primary of the heavy-copper dimensions and a secondary of reasonable dimensions, #10, 12, or 14 AWG. A variation on the current transformer is to use the existing power conductor or buss as the primary and place a donut-shaped secondary coil around it. Cost is $100-500 per CT. Photos follow of bus and donut current transformers used for utility revenue metering.

Model 191	Model 194	Model 195
		



The best available utility revenue CT's have an accuracy of .1% .2% accuracy is common and complies with ANSI C37.12. This means that their metering will be based, at best, on .1% information. CT accuracy limits mean that your metering will be based, at best, on .1% information. This is the reason that anything more than 12-bit A/D conversion is marketing hype. It is not a benefit to the purchaser.

Less accurate CT's cost $20-100. Claimed accuracies are 3 to 0.3%. Photos follow:

(not voltage limited) (voltage limited to 40 VAC, split-core)

There are a number of technology responses to the physical problems of current transformers. Split-core CT's permit you to open the donut to place it around the power cable. There is some reduction in accuracy from revenue level, but split-core CT's have made portable instruments universal maintenance tools for current measurements. Hall-effect transducers sense current flow not quite magnetically. Laboratory accuracy of .05% is reported, but commercial units are in the 1% range. There is an AC current-to-opto transducer being offered for 345KV circuits, but nothing of this type is readily available for plant or commercial use.

A very, very serious problem with all current transformers is conductor centering in the donut.

Extech Portable Clamp-On Amprobe Portable Clamp-On AEMC Portable Clamp-On

Three good quality portable clamp-on (split-core) ammeters were tested on a single current-carrying conductor, well separated from the return conductors. The conductor was moved within the jaws to identify the maximum and minimum values. The results are as follows:

Verification of Effect of Conductor Centering in Clamp-On Ammeter			
Instrument	**Extech 380932F**	**Amprobe ACD-11**	**AEMC 721**
Measure	8.16 – 8.38	7.9 - 8.0	8.16 – 8.48
Range	0.22	0.1	0.32
Centering Error	1.3%	0.6%	1.9%
Measurement Error	0.7%	4.6%	0.1%

This analysis focuses on current magnitude. Current measurement problems are obvious - if the goal is revenue accuracy. Corresponding invisible problems are phase accuracy in the magnetic circuit and timing errors in the digital circuit.

We have established that the accuracy limit is .1% rating and 1% if donut centering is considered.

DANGER, Will Robinson, DANGER - Electrical hazards should be obvious in connecting meter leads to busses which are energized or soon will be energized. The hazard of placing an insulated donut around an insulated conductor and connecting the small leads carries substantial concealed hazard.

A conventional 100:5 current transformer will create a high-voltage arc if the secondary circuit is opened under load. Shock and arc-flash are hazards all out of proportion to the apparent wire size and load. The CT shorting block on switchgear can cost more than the CT. This is the impetus for development of voltage-limited CTs, Hall-effect sensors and standards other than the 5A secondary.

Again, this course recommends that only a technician trained and experienced in meter work approach energized or de-energized power equipment for metering purposes. CT's should be hard-wired with quality crimp lugs on screw terminals or use retention terminals. Crimps should be tested for pull-out. Torque the screws to values per the manufacturer's instructions.

Calculating Volt-amp relationships - Computational methods within meters are not generally revealed or discussed. There may be published IEEE or EPRI conference proceedings which contain this information, but they do not show up on an internet search and are not readily available to assist buyers.

Do advertising claims of .01% accuracy speak truth? No. The CTs have .2% accuracy. An honest claim might be ".01% + sensor accuracy".

With reasonable power factor (greater than 70%) and reasonable harmonics (less than 4% volts and 10% amps), most commercial KW, KWH, KVA, pf, THD(V), THD(I) and harmonics meters can be expected to give meaningful results - probably approaching 0.1% accuracy.

When power factor is less than 70%, reasonable computational assumptions start to fail. When THD exceeds 10%, then frequency response becomes part of the computation accuracy and CT phase error and timing skew in the A/D cause deteriorated accuracy. The meter will tell you that you have a problem, but may be substantially off in the direction it points its finger.

Registers and numeric storage - Digital computers produce numeric results. In computer jargon, the results are stored in registers, which can be accessed by name or published register number.

The computer can perform additional work on the values contained in the registers. KWH is updated frequently by using the present value of KW and multiplying by elapsed time since last update. Similarly, the computer can compare present VOLTS register with the stored VOLTS MAX. If the present value is higher, the computer replaces the VOLTS MAX value.

The significance of registers is that they perform the transfer function between the meter and the central display, archiving, analysis workstation. The workstation periodically requests the values from the meter registers and places it in display registers on the workstation and in sequential files in the workstation storage system.

<u>Waveform storage</u> - Waveforms take a lot of storage space. Three phases of voltage, three phases of current mean that 6 x 60 = 360 waves must be stored each second. For 30th harmonic resolution, a minimum of 60 samples are required of each wave. 30 x 360 = 10,800 points must be stored each second. A motor start takes 15-seconds. 15 x 10,800 = 162,000 data points for a single motor start.

When memory and hard disk space were expensive, very sophisticated software was developed to intelligently select the phases and seconds to be stored. For the most part, new meters and loggers do not utilize the cheap memory and hard disk storage and do utilize sophisticated, programmable storage.

Another approach to reducing the storage requirements for waveforms is to compress the information - like a .zip file for AutoCAD or WORD files. This works, with loss of information and the addition of a proprietary format that cannot be read by other analysis programs.

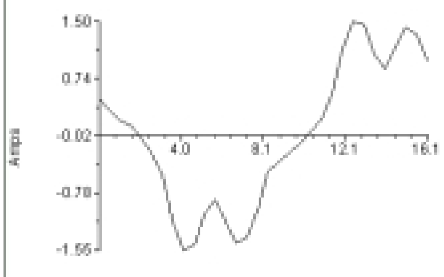
Waveform storage costs a lot and locks you into a single vendor. What value is provided by waveforms? The final discussion of data analysis will introduce a no-charge EXCEL routine to change a months data into a waterfall plot. It will be argued at that point that the waterfall plot permits intuitive analysis and identification of patterns.

Back to the question of value in waveforms. Sample printout results from a premium power logger are offered for your review.

Event: 1 Of 1736 Event Triggered by Time
Duration: 2 Cycles Event Trigger Cycle 1

Time: 02/24/2003 09:45:00.01
Input: PH C Amps
Cycle: 1

Harm	% Of Fund	Amps	Angle	Harm	% Of Fund	Amps	Angle
Fund	100.00	0.9	0°	2	0.37	0.0	314°
3	5.40	0.1	263°	4	0.52	0.0	77°
5	22.80	0.2	192°	6	0.29	0.0	330°
7	10.24	0.1	19°	8	0.57	0.0	75°
9	0.69	0.0	292°	10	0.57	0.0	70°
11	0.87	0.0	62°	12	0.14	0.0	21°
13	1.80	0.0	197°	14	0.27	0.0	347°
15	0.93	0.0	250°				



Cycle Waveform

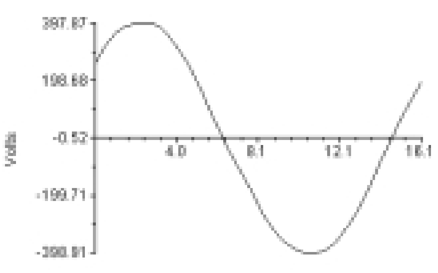
Total Harmonic Distortion	25.70 %
Odd Contribution	25.67 %
Even Contribution	1.11 %
RMS Of Fundamental	0.93 A
RMS Of Fund + Harm	0.96 A
K Factor	2.75

AEP Chart February 24, 2003 26% THD(I) at Service Entrance

Event: 1 Of 1736 Event Triggered by Time
Duration: 2 Cycles Event Trigger Cycle 1

Time: 02/24/2003 09:45:00.01
Input: PH A Volts
Cycle: 1

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	284.7	0°	2	0.03	0.1	268°
3	1.64	4.7	108°	4	0.07	0.2	43°
5	1.22	3.5	148°	6	0.13	0.4	359°
7	0.76	2.2	66°	8	0.26	0.7	298°
9	0.50	1.6	145°	10	0.10	0.3	146°
11	0.21	0.6	253°	12	0.12	0.3	280°
13	0.27	0.8	290°	14	0.04	0.1	259°
15	0.11	0.3	272°				



Cycle Waveform

Total Harmonic Distortion	2.30 %
Odd Contribution	2.28 %
Even Contribution	0.34 %
RMS Of Fundamental	284.71 V
RMS Of Fund + Harm	284.78 V

AEP Chart Event Record, February 24, 2003
Harmonic Voltage Distortion at Service Entrance, 2.3% vs 4% limit

Time-stamped event storage - The waveform storage discussion mentioned sophisticated event identification software. As mentioned previously, selection of triggering thresholds is critical. Too tight, and nothing is recorded. Too loose, and the machine tries to record almost continuously and you discover how it handles a storage overflow problem.

Typically, voltage transients, voltage surges, voltage sags, high voltage and low voltage are recorded, as defined by IEEE Red Book. Current thresholds can be selected, but analysis of the currents associated with voltage events usually tells the full story of the current variations. Using these setup configuration values, the results are meaningful in standard context to an reader of the data.

The recorded magnitude of transients is not well defined. Transients are very short duration voltage excursions, from utility switching, VFD line notching or other sources which attempt an instantaneous change between very low and very high voltages. The voltage sampling circuit in the meter has a fixed duration open window during which it records magnitude, followed by a much longer closed window when the A/d is processing internally or measuring other values. What does the A/D record for the rapidly rising or falling value during the open window? We can be pretty sure it records nothing during the closed window. This shared-A/D problem can be somewhat eliminated by including three dedicated peak-holding A/D circuits in the meter. If this is important, it must be specified or identified in the manufacturer's literature.

A single value of the time/date of the monthly billing KW demand is essential. Multiple near-peaks can be recorded as events, or extracted from the KW trend data on the archiving workstation. It is not terribly onerous to ask the meter to record a full month of 15-minute demand KW values. (Time +magnitude) x 4/hr x 24 hr/da x 30da/mo = 5760 data points per month. This permits data analysis by downloading the meter without buying the data communications system or central workstation.

A valuable discussion at this point is comparison of the utility's revenue meter with the Owner's check meter. On most billing arrangements, KWH energy usage for the month is the big cost and maximum 15-minute demand KW is the second most significant cost. For small customers, the billing arrangement is selection of the appropriate schedule from the small number approved by the state utilities commission.

Demand is almost always 15-minute or 30-minute and either fixed start interval or sliding interval. 15-minute demand is the most sensitive (and expensive to the user). The demand start interval is associated with a reset pulse, which is usually available from the utility free or at very low cost. This permits the check meter to most closely match the revenue meter results. Sliding interval keeps a running value of demand and stores the highest value of the month, exactly like the VOLT MAX register in the analytical meter. Accuracy of the check meter sliding demand value is easy to determine. The utility should identify the billing demand time/date. If the check meter and the revenue meter don't match, some work is indicated.

A very serious problem with time-stamped events is the time reference. When catastrophic electrical events occur, there is an initiating event, followed by a series of consequential events, usually the operation of protective devices. Identifying the initiating event is of critical importance. Verifying the proper operation of protective devices is also important. Each of these tasks are performed by comparing a string of events which occur in a period of less than a second. A three-cycle power circuit breaker takes 3 x 1/60 = 50 milliseconds to operate. Depending upon the fault magnitude, the protective device should respond in 5 mS.

It is not hard to get the meter to record events in milliseconds. It is very hard to get two meters synchronized, unless they were design to use an external standard, as GPS or NBS. (Some high-end meters now use GPS.)

Another concealed form of time reference instability is time-stamping events at the archiving workstation. Ethernet communications are non-deterministic. That is, CSMA/CD (carrier sense multiple access / collision detection) assumes that the communication channel will be busy and automatically waits a random period before retransmitting. This insertion of a random wait because another station is reporting an event means that the receiver has litter idea of the actual sequence of events from the messages it receives.

ModBus communications are master/slave. The master station initiates all communications and the slave reports what it knows. The sequence of events received will be the order of polling, not the order of occurrence.

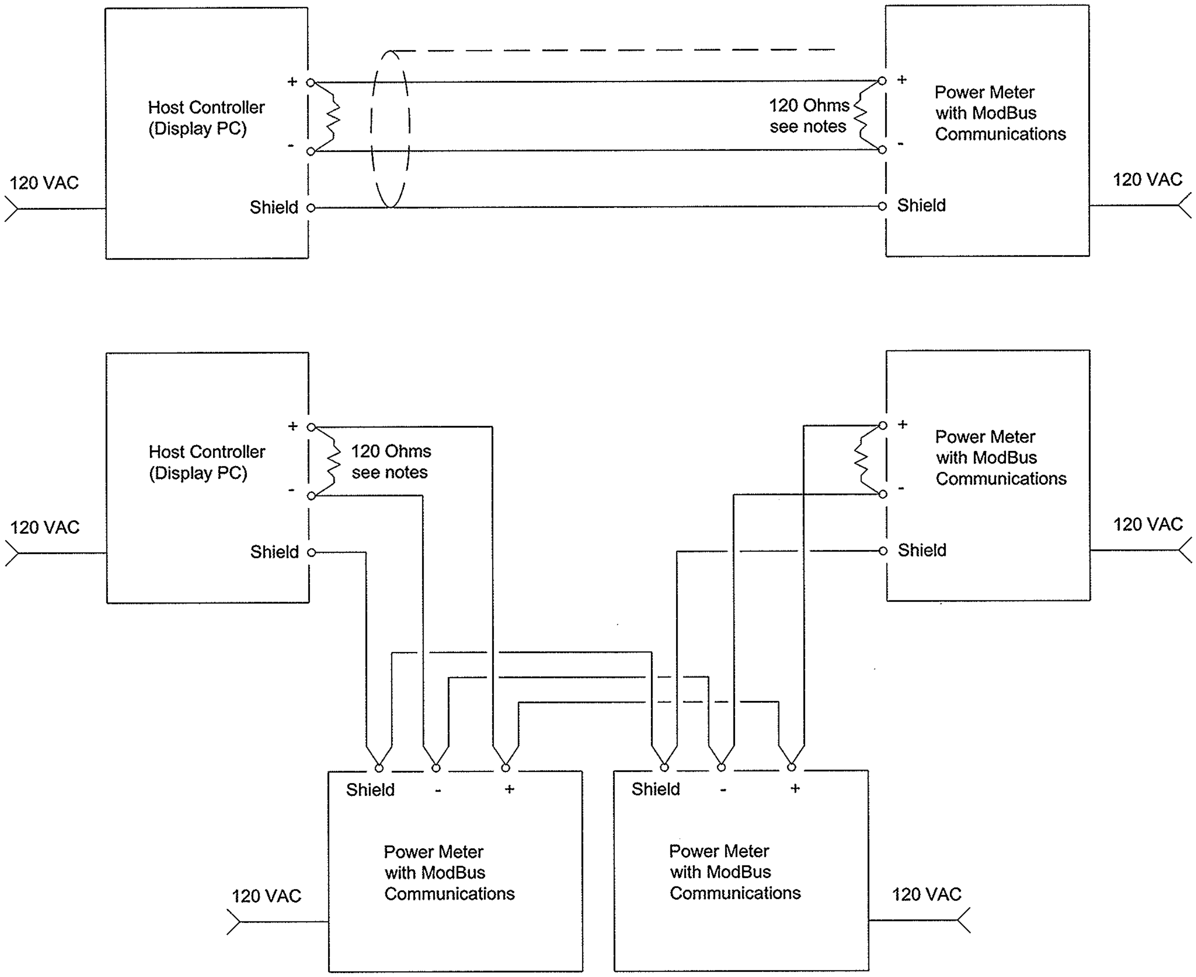
This discussion is not meant to imply that sequence of events reporting on a general purpose metering system is worthless, only that in order to get high resolution data, high resolution devices must be selected.

ModBus communication - ModBus is an early proprietary communications protocol for programmable logic controllers. It has entered the public domain and is widely available for field devices and central devices. Most meter manufacturers offer ModBus communications for free or at very low cost.

ModBus is intended to interface the field device with a control device, as a plc, or with a human machine interface (HMI) such as WonderWare, Intellution Fix or National Instruments LabView. HMI programming has become near-painless configuration, usually done by clicking on a desired display type, dragging to the desired location on the screen and right-clicking to set the field instrument and register to be displayed. The MHI requests the data and updates the display.

A commercial HMI product contains archiving modules, trending modules and analysis modules of various levels of sophistication. It also contains OLE links to transfer the archived data to external analysis programs, such as EXCEL.

Modbus communication wiring and distance extension - For us, today, ModBus means 9600 BPS multi-drop RS-485 wiring with ModBus RTU communications protocol. RS-485 is a fairly old wiring method, with 4000-ft maximum distance. Being old, there are a wealth of competitive interface products available and extensive technical support available. The basic form is jacketed two conductors plus shield (Belden 9463, 2-#20 stranded, foil polyester shield). The shield can be dropped and the communications work very well in industrial environments as jacketed two conductors plus ground (West Penn 232, 3-#20 stranded, jacketed). (No one will tell you that the unshielded version works.) Instructions for installation of RS-485 vary extensively Sometimes the shield must be terminated at both ends, sometimes one end, cut carried through the run. Follow the instructions for the meter you select, so that the tech support people there will talk to you. Below is a reasonable connection diagram:



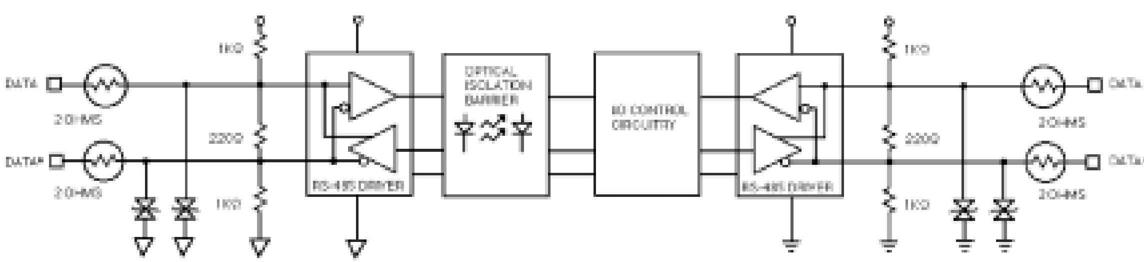
ModBus / RS-485 Field Wiring

Notes: 1. For long-distance communication, or if noise from an external source interfers with the signal, install 120-ohm, 1/2-watt resistors across terminals of both end devices.

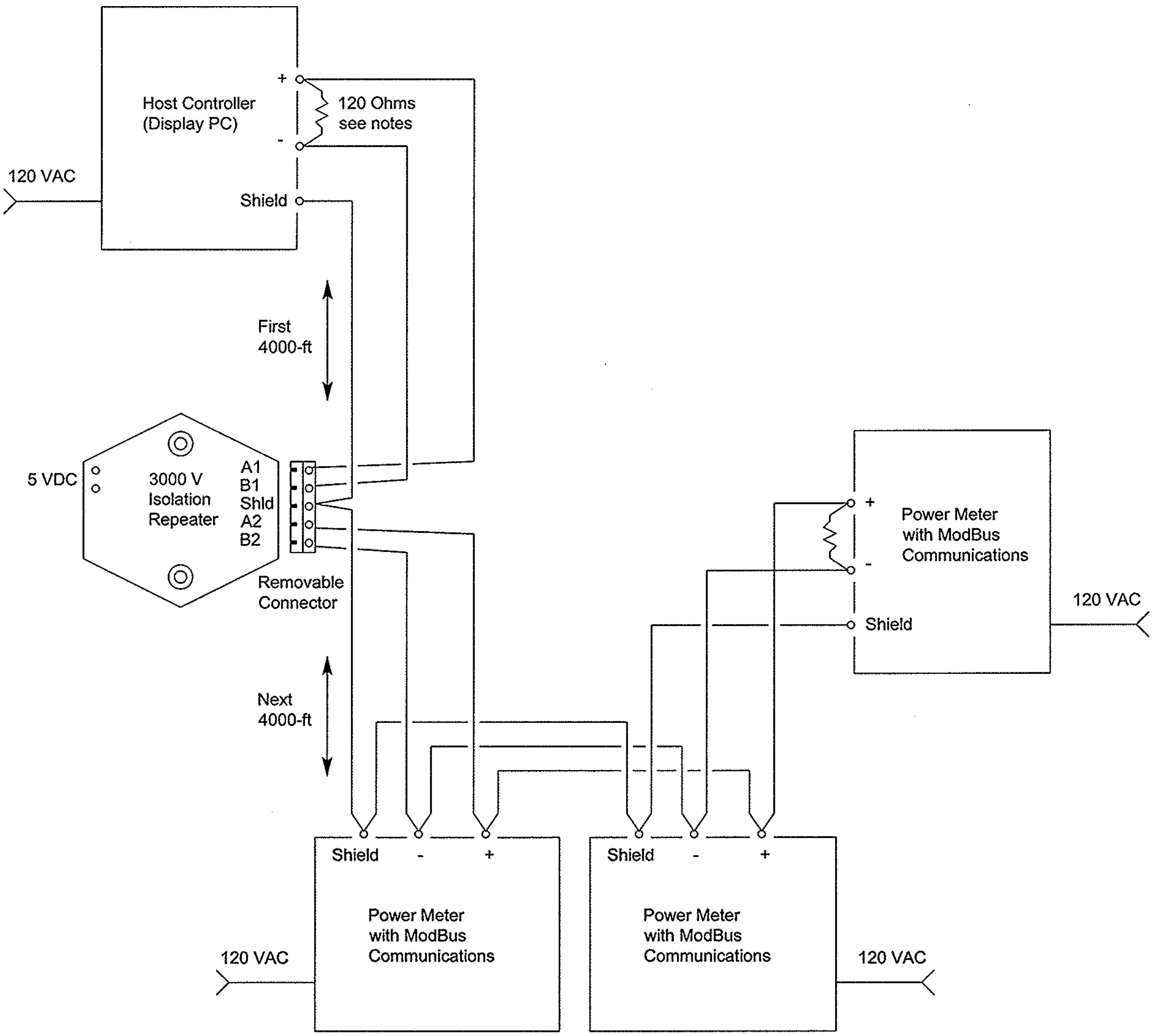
2. Terminating resistor may be internal to device, with switch to USE or NOT USE.

3. Multi-port PCI cards for the display workstation are available. Check with software vendor for support before purchasing.

The 4,000-ft limit for ModBus / RS-485 has many work-arounds for campus installations or large integrated facilities. The easiest is the repeater. For ~$150, it isolates the host side of the circuit from the field side of the circuit and regenerates the signal for another 4,000-ft run. Johnson Controls uses RS-485 for their MetaSys N2 bus and can provide or supervise field installation and start-up.



This is the DataForth SCM9B-D192. It can be used as follows:



ModBus / RS-485 Field Wiring with Repeater

Notes: 1. For long-distance communication, or if noise from an external source interfers with the signal, install 120-ohm, 1/2-watt resistors across terminals of both end devices.

2. Terminating resistor may be internal to device, with switch to USE or NOT USE.

3. Multi-port PCI cards for the display workstation are available. Check with software vendor for support before purchasing.

A second work-around for distance is translation to fiber optic. Individual modules cost ~$100 and support very long distances without modifying the ModBus data packets.

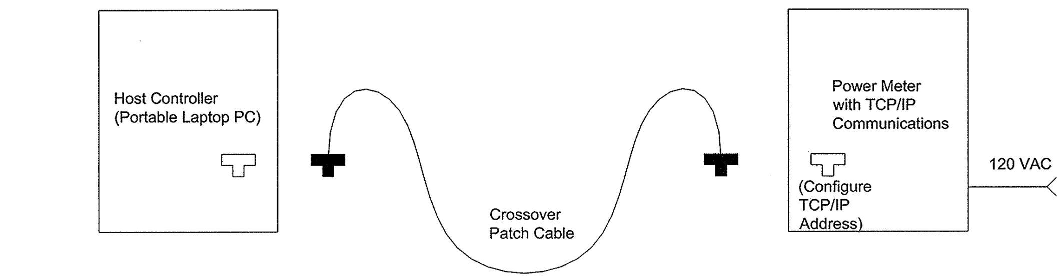
Another work-around, not recommended here, is the gateway. This $500 - $10,000 device decodes the ModBus data packet and re-encodes it in another protocol, such as TCP/IP. The results are very satisfactory, but starting with a TCP/IP power meter is usually no cost increment over ModBus.

TCP/IP communication - For us, today, TCP/IP means unshielded 4-pair Cat 5 copper unshielded twisted-pair (UTP)cable with a 300-ft maximum distance and a $20 10-megabit hub to attach more devices. This form of local area network (LAN) wiring is extremely popular with a wealth of competitive interface products available and extensive technical support available.

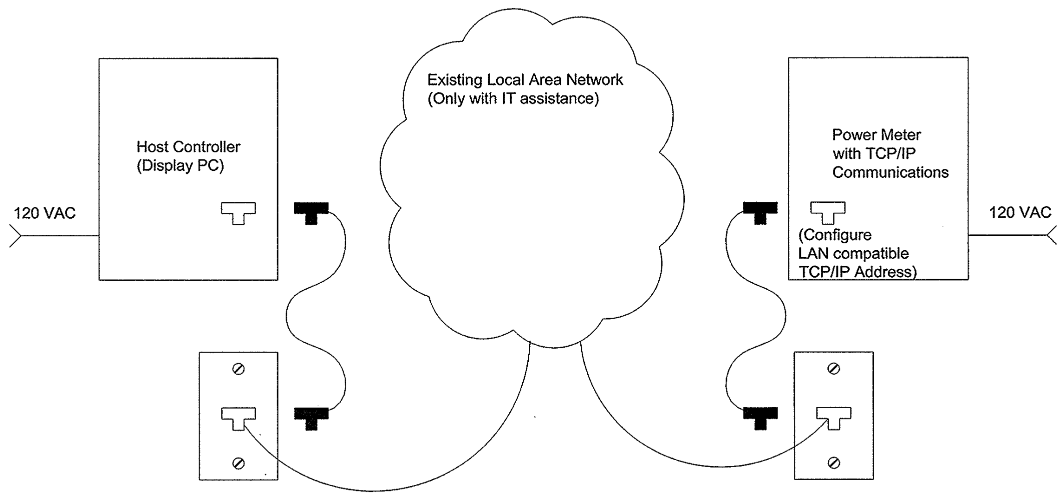
There is much confusion on what TCP/IP means and how local area networks work. The underlying principle is that a system is installed which handles information packets by reading the destination and size and paying no attention to the contents. You type <Alt> F S and MicroSoft WORD establishes a path to your server and saves your word processing, then closes the path. It may go through, hubs, routers, data switches, a T1 link and a satellite link. Similarly MicroSoft EXCEL can create a path to each meter, download data and close the path.

The 300-ft limit appears to be onerous, but that only means that the existing Information Technology (IT) group must have a data port within that radius. There is always the option of buying a ~$100 converter and running your own fiber optic back to the display workstation. However, installed LAN's are almost universal and can be shared for low bandwidth meter communications. The alternative of a dedicated fiber optic run is very economical for a two-strand cable, but considerably more expensive for the a 12-strand cable which will support the long-term IT plan.

Cat 5 cable can be run by in-house staff or a contractor who has a continuing relationship with the firm. Cost is amazingly low. I consistently had twelve drops in a six-story building installed and terminated for $800 per building (multiple very similar buildings). Below is a reasonable connection diagram:



TCP/IP download Field Wiring



TCP/IP (LAN) Field Wiring

TCP/IP communication wiring and distance extension - TCP/IP appears to be the communications method available today which will have the longest life. For this reason, a little more emphasis will be placed upon details of TCP/IP communication wiring.

We saw that ModBus field equipment can be daisy-chained to existing equipment or to an existing communications cable. TCP/IP started out this way, then called EtherNet. Within a short time, dedicated cables and isolating hubs took over. Part of the reason was cost, but a more powerful reason was ease of maintenance.

In a daisy-chain configuration, when a fault occurs, the system goes dead. Individually removing devices or cable segments is the troubleshooting method. When a star configuration has problems, it is usually only one device, while the remainder remain intact. Almost all hubs have activity lights, which indicate functioning of each port, including the rare jabber-mode failure.

ModBus uses screw-terminal connections. Early Ethernet used vampire taps and military screw-down plugs, later, quarter-turn bayonet plugs. UTP uses RJ-45 modular plugs which are much, much faster to terminate and are finally attached with a push and a click.

The only confusing part of UPT / RJ-45 connections is polarity. For the most part, users never encounter this. All outputs are configured to line up with their associated inputs. A straight-through wired cable is used.

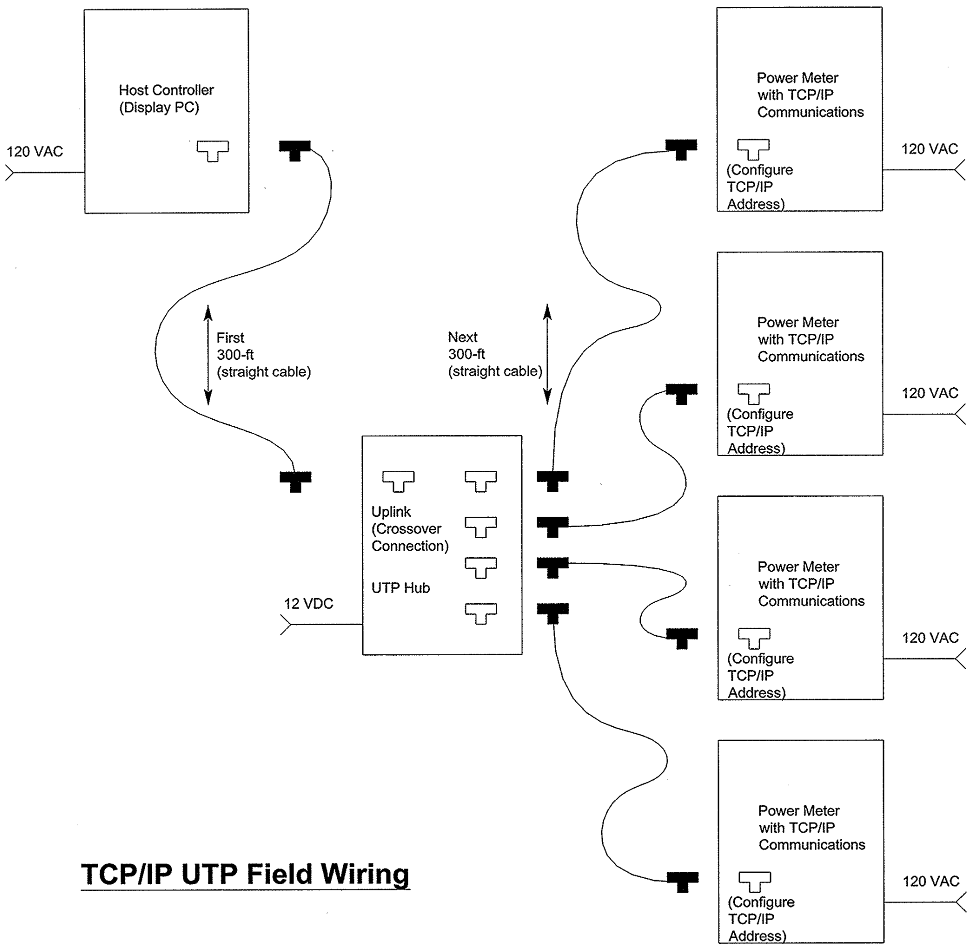
The exception is when two clients are connected together, without an intermediate server. Both clients talk on the same wire. Both listen on the same wire. A crossover cable is needed to permit electrical communication. A pre-wired crossover cable, as implied, has the transmit and receive positions swapped on one end. It costs the same as a pre-wired straight cable.

Fiber optic will not be discussed here. As indicated below, the field meter is UTP copper and the display PC is UTP copper. The media conversion and media should be transparent. Many competitive firms will help you choose compatible converters and media. Expect to pay ~$100 for a converter, ~$200 for a 4-port hub with fiber uplink and 20-cents per foot for multi-mode zip fiber. Better everything costs more.

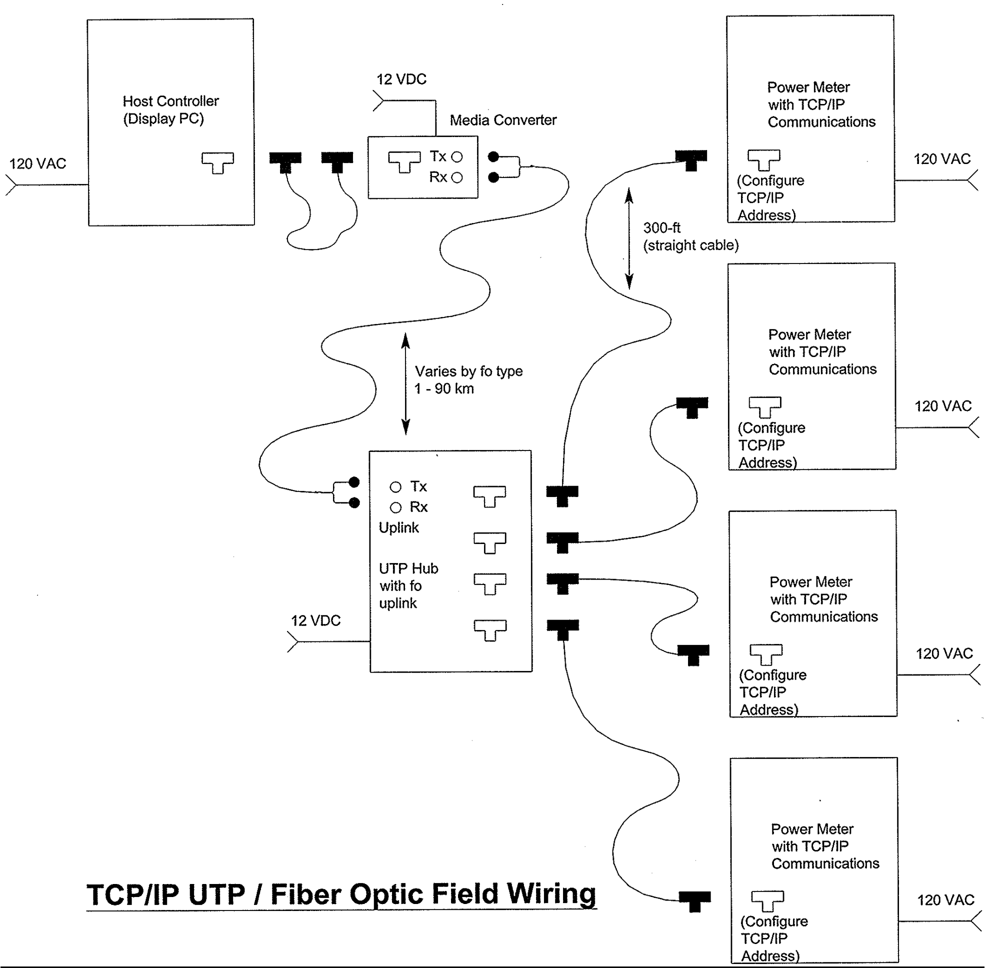
A final digression regards data rate. For many years, ModBus has operated at 9600 bits per second (BPS). It works well. A new installation to this specification will have a long, productive life. Higher data rates are commercially available, at little premium in cost. The isolated ModBus repeater is spec'd to 115,000 BPS. The problem is that data errors increase sharply as data rate increases. It is unlikely that any benefit will be noticed at the increased rate, but exposure to failure has risen substantially.

This discussion was directed to 10 megabit UPT TCP/IP. The communications are reliable and the equipment and media are very inexpensive. Actual throughput will be about 150 KBPS, but this so far exceeds the 9600 BPS meter that it appears heaven has been reached. A single 10 megabit channel can easily carry a large substation of power meters and four webcams pointed at the parking lot. However, it will not support download of pirated movies and music along with power data and security.

The following graphics illustrate copper and fiber optic connections:



TCP/IP UTP Field Wiring



TCP/IP UTP / Fiber Optic Field Wiring

SMTP - Technically, Simple Mail Transfer Protocol (SMTP) means that the meter acts as a server and any browser on the LAN can be a client. If your LAN has remote access, then anywhere in the world can view the power flow from the meter. This is how most webcams work. There is no downside.

However, it is a bad idea. In the first place, unless you open multiple browser windows, you can view only one meter. Checking the system means stepping through the meters using the browser, remembering the normal values and looking at the present values.

Observing trends means using a pencil and finding the same piece of paper each time you step through the meters. Cut-and-paste works with the browser, but it is more time-consuming and not pleasant.

A good solution is expensive proprietary power metering software available from the meter manufacturer. These packages handle polling and communications between the display workstation and the meters very easily (though you still have to set the TCP/IP addresses and select the registers to be displayed). Spend enough time talking to your meter vendor so that you hear each of the benefits he is offering in his proprietary package. Remember, however, that you are forever locked in to his hardware and his gateways to competitive equipment, if he offers such gateways.

The better idea is an expensive human machine interface (HMI) which has been optimized for display, alarming, trending and archiving. It will meet your needs with just a little more effort on your part. You must set the polling interval, TCP/IP addresses and select the registers to be displayed and lay out your display screens. This work is fun for high school interns or college co-ops.

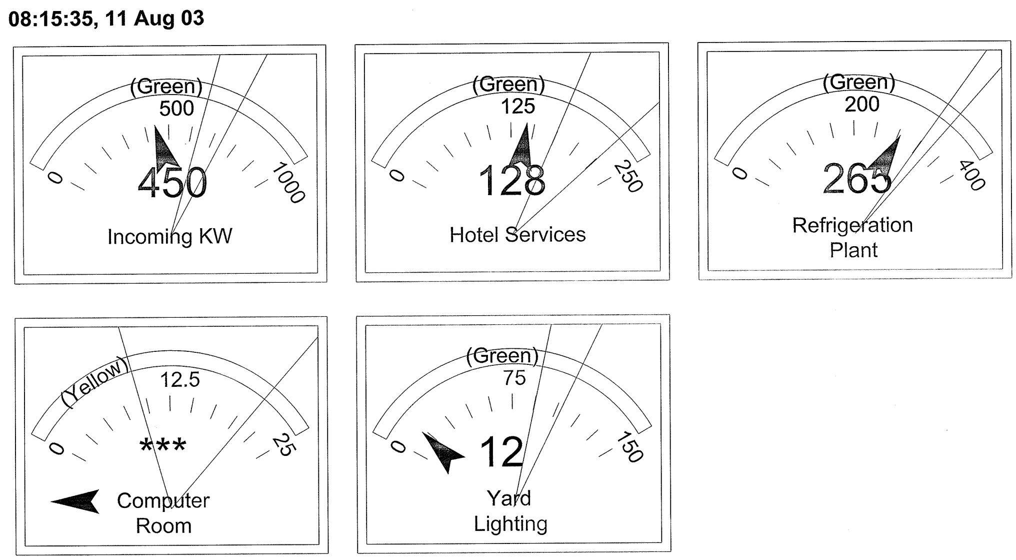
You will find that analysis software offered with the proprietary power meter software is disappointing. You will find that analysis software available for the HMI ranges from simple-to-use and impressive to tools suitable for PhD researchers. A very limited discussion of analysis software follows.

Display, Alarms, Trending, Archiving and Analysis - The problem with power meter data is that it is supposed to change during the day, between days and between weeks. The present value is only meaningful in reference to the equipment limits and the normal value for this time of day and level of operation of the facility.

Nonetheless, a simple tabular display is valuable and lays groundwork for alarms, which may not be available in the present software package. A simulated tabular display follows. Normally, <Ctl> P causes the present screen to print on the system printer.

			08:15:35, 11 Aug 03	
Meter	**Present Value**	**Normal Value**	**Equipment Limit**	**In Alarm**
Incoming	450KW	620KW	733KW	
Hotel Services	128KW	150KW	200KW	
Refrigeration Plant	265KW	300KW	325KW	
Computer Room	Meter out of service	10KW	20KW	***
Yard Lighting	12KW	80KW	100KW	

A simulated graphic display follows. Data is automatically being logged and archived, so the screen print has no value. A tabular report can be printed at any time.



Simulated HMI KW Display

The primary goal of check metering is verification of the monthly utility bill. For both technical and political reasons, the computations between measured electric parameters and net dollars due are complicated. Most accountants can figure it out and perform replication monthly. Most engineers can figure it out and perform replication monthly. Utilities do make mistakes. Utility meters do malfunction and fail in ways penalizing the customer.

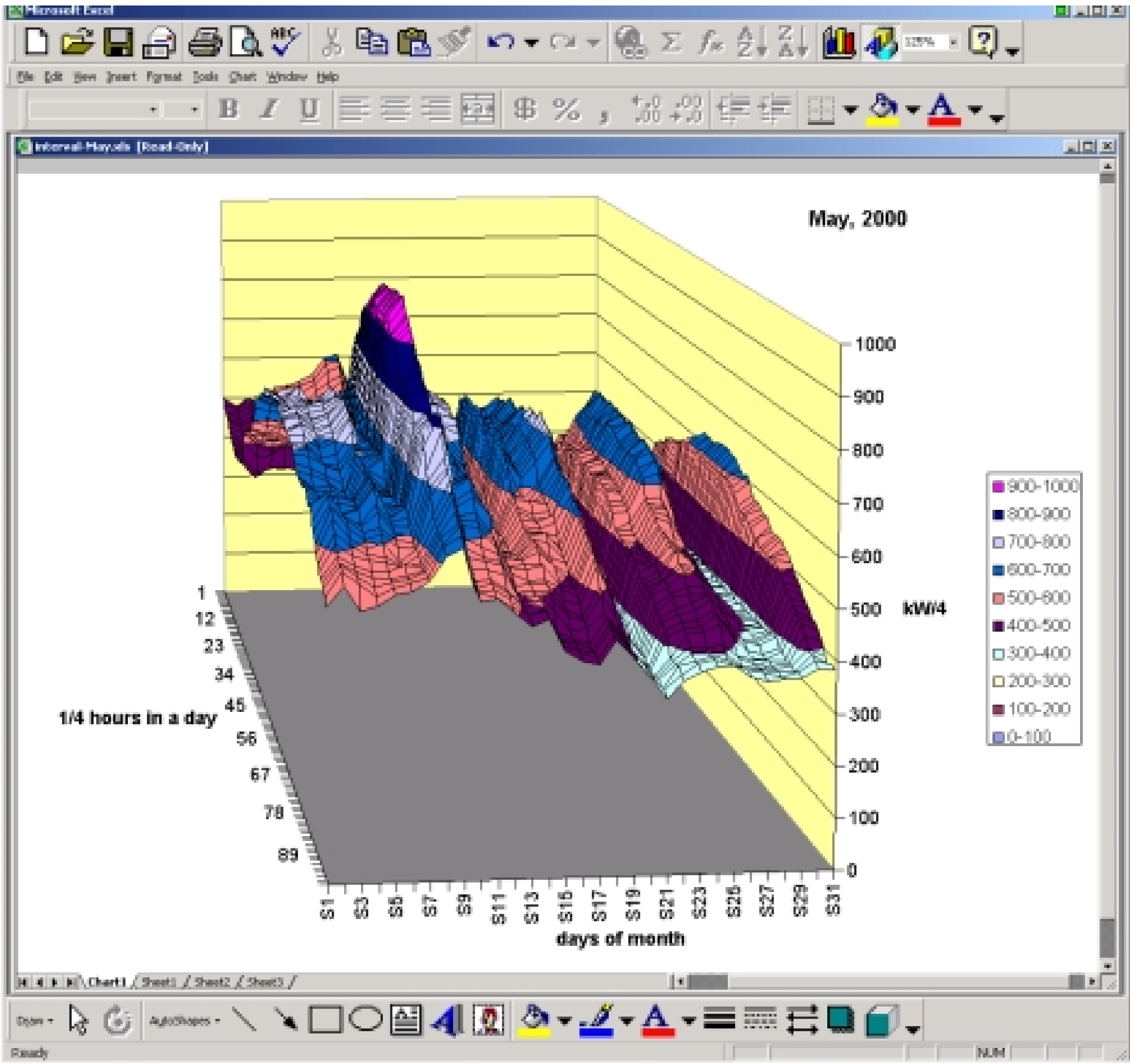
With a little persistence, a utility representative can be persuaded to help with sample calculations until the procedure is reliable. Use old bills.

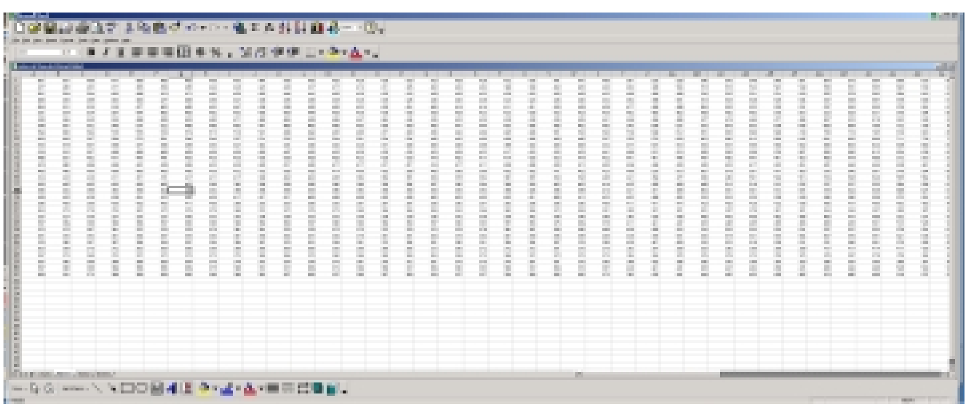
Within the electric bill is an energy charge for KWH and a facilities charge for KW. It is extremely valuable to do a sensitivity analysis - what effect does 1% change in KWH have on the bill? What effect does a 1% change in KW have on the bill? KWH can be reduced by turning something off for 24 hr/da, 30da/mo, like lights or electric heat. KW can be reduced by starting a large machine 15-minutes after the monthly billing peak.

This peak-shifting has been explored in detail for 30-years. There are three tasks, identifying the monthly peak(s), identifying the large discretionary loads, and, convincing the operator that saving the firm $1,000 is worth his attention.

The check metering installation should identify the monthly KW peak and any near-peaks. A limited amount of experience in analyzing plant data suggests the peak is often just after shift change or at 2PM every production day. The peak can be found by loading the data in an EXCEL spreadsheet and sorting it (please get a software package that includes OLE to share data with EXCEL without retyping). Another EXCEL tool is graphing. A conventional line plot will show peaks, but a waterfall plot will show the pattern of peaks on a daily and weekly basis. The waterfall plot is also valuable in identifying peculiarities in the load pattern - opportunities for investigation and maintenance or billing reduction.

The EXCEL waterfall plot is shown below, along with the construction procedure:





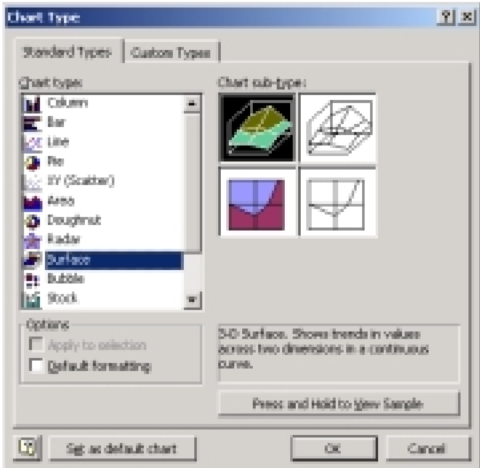


Chart Type
Standard Types
Custom Types
Chart type:
Chart sub-type:
Column
Bar
Line
Pie
XY (Scatter)
Area
Doughnut
Radar
Surface
Bubble
Stock
Options
Apply to selection
Default formatting
Press and Hold to View Sample
Set as default chart
OK
Cancel

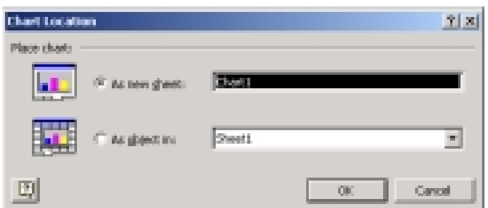
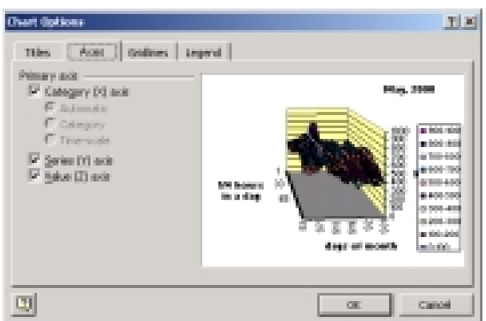
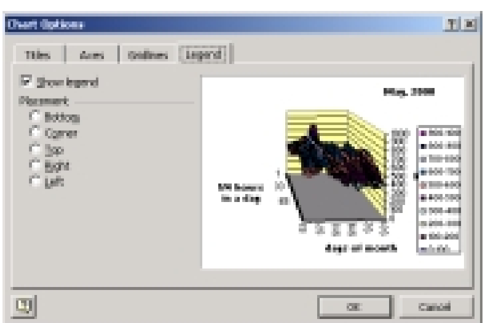
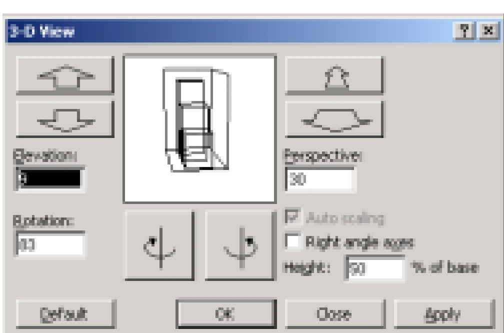
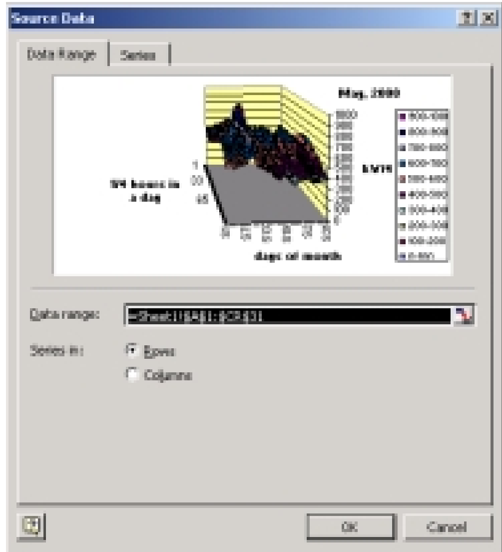


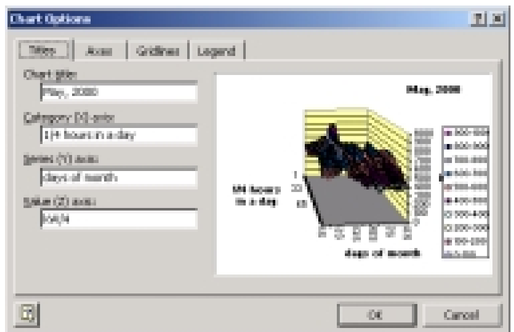
Chart Location
Place chart:
As new sheet:
Chart1
As object in:
Sheet1
OK
Cancel

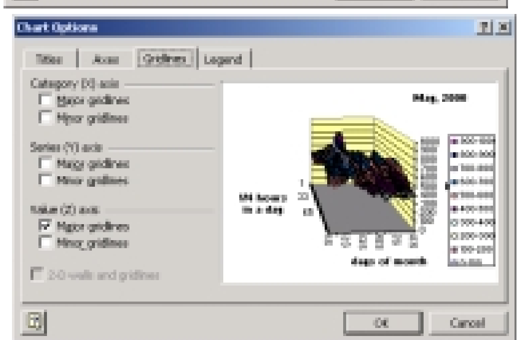


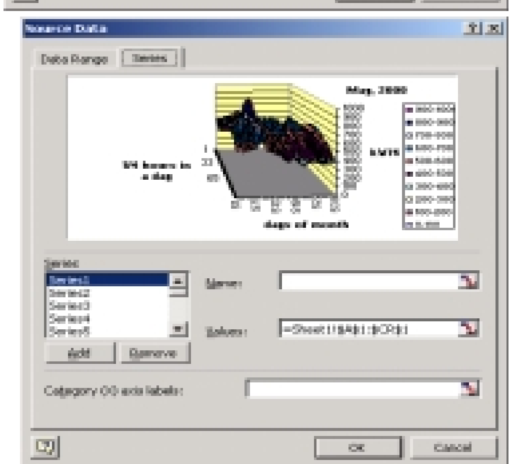



3-D View
Elevation:
Rotation:
83
Perspective:
30
Auto scaling
Right angle axes
Height:
50
% of base
Default
OK
Close
Apply


Source Data
Data Range
Series
May, 2000
days of month
Data range:
Series in:
Rows
Columns
OK
Cancel







From: Energywiz@aol.com
Sent: Thursday, February 07, 2002 8:44 AM
To: ThosMason@yahoo.com

Subject: Interval Meter Data Sample
Attached is the Excel file used to create the 3-D chart discussed in my ES column. It already contains the 3-D graph, so feel free to take it for a spin!

Note that, in the data cells, I have already stripped off the dates and times. Normally, one would typically see the day and date in the far left hand column and the military time (e.g., 13:45-14:00) across the top row. They have been removed in this sample to avoid any confusion regarding what cells are to be highlighted when developing the graph. In this example, the first row is May 1 and the first column is 12:00 - 12:15 AM.

You may also wish to visit our customer information web site at:

http://www.energybuyer.org

for other useful tips on energy procurement and use.

Best wishes,

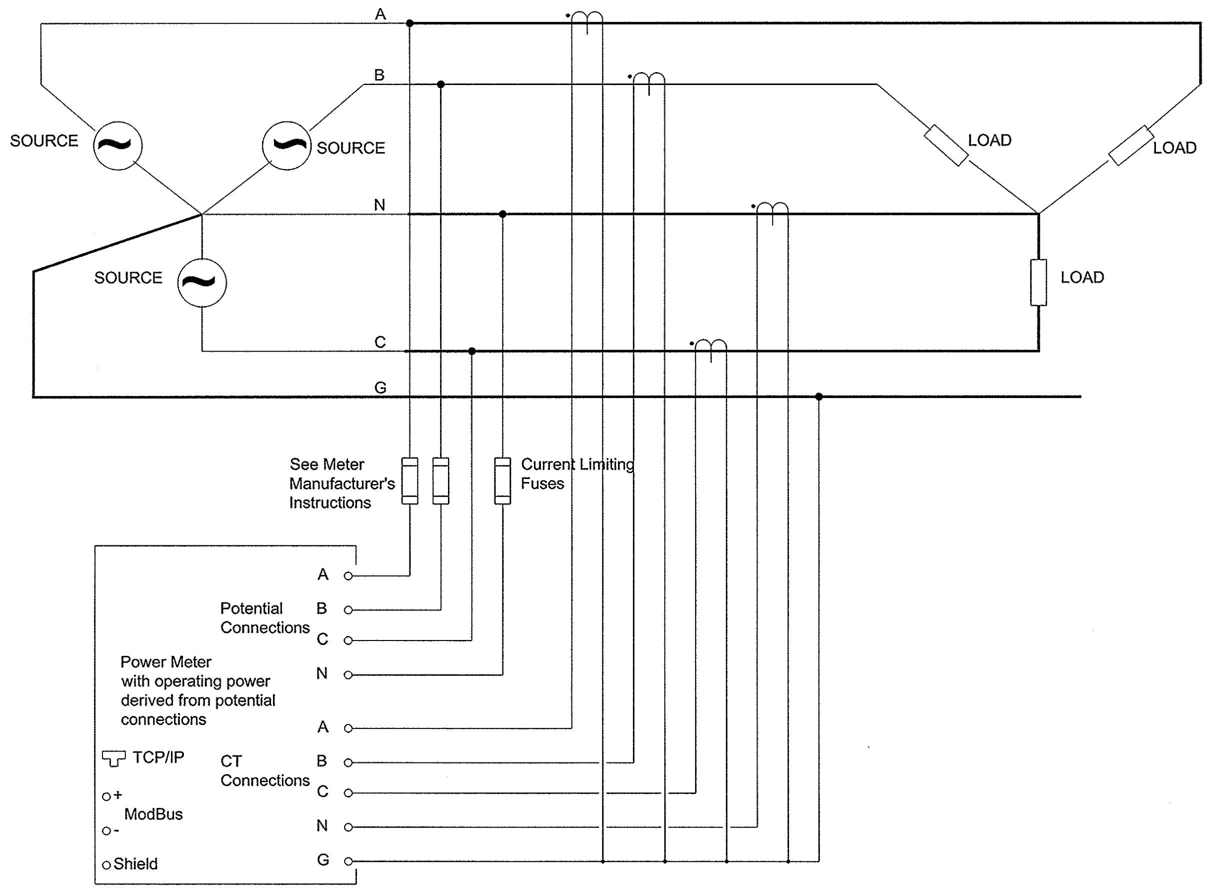
Lindsay Audin
Energywiz, Inc.
www.energywiz.com

A number of sources for very powerful data analysis products are listed in the Related Links section at the end of the course. These give insight into the tools available to utilize the human ability to recognize subtle patterns. They accept OLE data transfers. Prices range from $150 to $5,000.

Meter Installation - The National Electric Code and NFPA 70E, enforced by OSHA, require that electrical installations be performed only by persons trained and experienced in the work. Meter installation is not a good opportunity for an engineer to develop manual skills.

Not long ago, a different meter was sold for 120V, 240V, 480V and 575V. A different meter was sold for single-phase, three-phase delta, three-phase wye, and each of the peculiar special connections, high-leg delta and corner-grounded delta, etc. The reason was that the voltage and phase relationships were different and each required an application specific custom analog computational circuit. Now, with a digital processor inside the meter, all of these connections are handled by a single piece of hardware, with the connection selected as a configuration setup.

The most complicated is three-phase, four-wire wye. That connection is shown below:



Power Meter Connection for 120/208V or 277/480V

If the actual installation is three-wire delta, or floating-wye, with no neutral, then no neutral CT is required and no neutral potential connection is made. Check the manufacturer's installation instructions, though, some require that unused terminals be connected to ground.

There are lots of leads and lots of connections. The source has high voltage and very high available currents. An error may just burn the connecting lead in fuse simulation or may initiate a line-to-line fault that burns down the switchgear. The need for extremely high level of care cannot be overstated.

The most common error is reverse installation of the current transformers. All should have the indicating dot towards the source. All should have the black lead connected to the meter and the white lead connected to the common ground.

If a CT installation is reversed, the meter will read considerably off on KW and very strange KVAR and power factor. The reference KW reading is KV x Amps x SRT(3) x .8. This gives three phase power with an assumed .8 power factor.

The engineer should verify the result, not the wiring. Stay out of the busbar compartments.

The initial readings from the meter should be KW as indicated, pf between .7 and .9 and KVAR as calculated from the KW and pf readings. Harmonics are unpredictable, greatly depending upon the loads. 4% THD(V) is the IEEE-519 limit and very hard to exceed. THD(I) up to 20% is fairly normal. Third harmonic comes from computer and HID lighting load. Fifth harmonic comes from 6-pulse variable frequency drives.

Project Justification - Each organization has a different format for submitting capital requests. In essence, however, all contain the same elements, description, benefits, projected value of benefits, approach, alternate approaches examined and reasons for rejection and finally, timetable. There are two keys to getting the project approved, the summary paragraph and having a champion who speaks out loud his belief that it will work and the benefits will have lasting value. Getting the champion is part of draft proposal development and revision and not addressed in this metering course.

The following is an actual metering proposal, which was not accepted, because the firm went into bankruptcy.

XXX Metal Manufacturing Company
Uptown Plant
Electric Power Metering Proposal

Summary
Authorization is sought for expenditure of $12,000 for materials for a plant metering system. The plant electrical maintenance department will procure and install four digital electrical power meters in the main electric room and one digital electrical power meter in the warehouse building. Plant maintenance will run a dedicated communications cable from the meters to the plant engineering office where it will be connected to an existing personal computer. Data from the meter system will be compared with the monthly utility electrical bill. A report will be submitted to management within five business days which identifies monthly variances and sources. The meter system will also be used to develop projects for reduction of electric bills. Improved maintenance productivity is expected but not quantified.

Benefits
The plant presently pays about $80,000 per month for electricity. A one percent bill reduction produces continuing savings of $1,000 per month and project payback in one year. Monthly demand penalty from Uptown Electric Company is about $20,000 per month. This penalty can be reduced 5%, or $1,000, by scheduling discretionary electrical loads away from the recurring demand peak - after the peak characteristics have been determined by use of the meter system.

Electrical power system problems cause process interruptions and overtime production or late deliveries. The meter system will help in anticipating distribution system problems and pinpointing problems as they occur. It is further anticipated that additional electric bill reduction projects will become obvious after several months of analysis of meter data.

Alternate Approaches Examined But Rejected

1. The same meters, without the communications option and central display, alarm, trending, archiving software can be purchased for $8,000 vs the $12,000 requested. Labor for the data cable installation is also avoided.

This approach is not recommended because it trades rigidly scheduled professional labor (visiting the substation at monthly electric billing) for as-convenient tradesman labor (installing the communication cable). The trade for paper data collection and manual computer entry was thought uneconomic.

2. Less expensive meters, with fewer measurements and fewer internal storage registers are available for $6,000 vs the $12,000 requested. Again, labor for the data cable installation is avoided.

This approach is not recommended because the harmonic measurements deleted are expected to become part of the monthly electric billing within the next two years. The plant uses VFDs on several large machines and HID lighting, so we know we have substantial harmonics, but we have no measure of the magnitude.

The maintenance value of measuring harmonics is hard to quantify, but magazines have been reporting plant problems. We need to establish normal baseline harmonic measurements before such problems occur.

Timetable

The meters requested are available from distributor stock and will be delivered within four weeks of receipt of order.

Installation of meters by plant maintenance personnel will be done on a time-available basis over a period of 90-days. One or more electrical interruptions may be required for safe installation of the current transformers. Any interruptions will be scheduled over holidays, weekends or non-production periods.

Installation of the data cable will be performed concurrently with installation of the meters, also scheduled to avoid any interference with production.

Configuration of the meters and software setup will take two weeks, after the meters and communication cable are in place. The meter salesman has promised no-charge assistance.