
POWER MONITORING
For Energy Management Systems

ELKOR Technologies Inc.

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This guide covers only a small portion of the rather extensive field of electrical metering. If you have any questions regarding this publication or power measurements in general, please contact us.

We will be pleased to assist you in solving your metering problems.

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1. Introduction

Computerized Building Automation Systems are used traditionally to control and monitor Heating, Ventilation and Air Conditioning (HVAC) equipment. Today's powerful DDC and PLC systems are commonplace in most modern buildings. Their graphical interfaces, logging/alarming capacities and remote access offer indispensable tools for building operators and facility managers.

The addition of electrical system monitoring to these already well established functions seems to be the next logical step. A new generation of electronic power transducers offers many inputs to a DDC/PLC system for complex monitoring, control and management of electrical installations.

This guide was prepared for Control Specialists and Facility Operators as an introduction to power monitoring and its practical applications for energy management.

2. The Measuring of Power - Basic Definitions

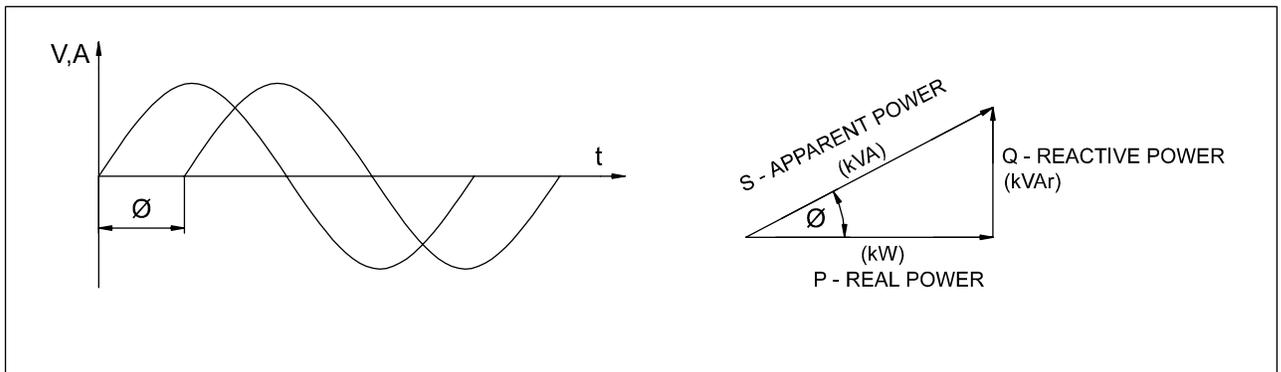
2.1 Power Factor (PF).

The term *power factor* (PF) was originally introduced to describe power relations in AC circuits. It is a factor by which the *apparent power* (VA) must be multiplied in order to obtain the *Real power* (kW). Mathematically, power factor may be expressed as a cosine of the angle between voltage and the resulting current in the line (Fig.1).

When the current is in phase with the voltage, such as for resistive loads, the power factor equals 1, or 100%. In most installations, however, the power factor is below 1, and it is usually *lagging* which means that the load includes *inductive reactance* such as motors and transformers.

In practical applications, a low power factor means that the distribution equipment (transformers, wires etc.) carry a large amount of current. This current is not in phase with voltage, however, and the useful effect of it, the *real power* (Watts) delivered to the load, is minimal.

In drastic circumstances, the transformers and wires may overheat but the load still may not receive enough power.



$$\begin{aligned} \text{PF} &= \cos\emptyset \\ \text{P(W)} &= \text{S (VA)} \times \text{PF} \\ \text{Q(VAR)} &= \text{P (W)} \times \text{tg}\emptyset \end{aligned}$$

Fig.1

This is the reason utilities established a minimum required power factor for larger customers. If the customer's PF drops below a certain minimum (usually 0.90) than a 'penalty' is applied by the utility. The utility may use the customer's apparent power (kVA) consumption for the monthly charges calculation rather than the real power (kW), since the kVA represents a greater number ($kW = kVA \times PF$).

The traditional definition of power factor applies to sinusoidal wave shape and it becomes more complicated for distorted wave shapes. Without going deep into the theory, it may be stated that the originally intended meaning of PF remains generally true if it is considered as a factor that qualifies how efficiently a load utilizes the current drawn from an AC power system.

2.2 True RMS and the Virtues of TRMS Measurements

Alternating current (AC) is said to be equivalent to a direct current (DC) when it produces the same average heating effect under exactly similar conditions. This particular value of alternating current is called the *effective value*. In practice, the electrical units describing AC parameters such as Volts and Amperes represent *effective values*, unless explicitly stated otherwise.

The AC current heating effect depends on the average of the squares of each instantaneous value of the current and it is the same for the negative and the positive half of AC sine wave. It can be calculated by squaring a number of the instantaneous values in a cycle, finding the average of these squares and then extracting the square root. That is why the effective value of AC current is referred to as "*root-mean-square*" or *RMS* for short.

For an ideal sine wave the *effective value* equals 0.707 times the peak value (Fig.2) but a distorted wave may have its RMS parameters dramatically different from those calculated for a theoretical sine wave.

Today, the distorted sine waves are present in almost any system and in the utility grid. Even the residential feeders do not provide a pure sine wave voltage. Power electronics such as variable speed drives, SCRs, dimming devices or switching power supplies in computing equipment are the most common cause of distortions.

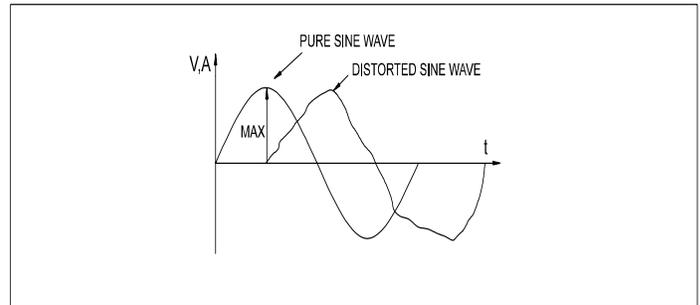


Fig.2

RMS of pure sine = $0.707 \times \text{Maximum}$

RMS of distorted wave = ??????

Inexpensive AC meters are really *average value*
2.3 Harmonics

To quantify and analyze distorted waveforms, a rather complicated mathematical apparatus was developed and the term *harmonics* was introduced. This theory is based on the fact that most periodical functions can be represented by a sum of factors calculated using sine waves for the multiples of the basic frequency.

For simplicity, it is said that the distorted 60Hz sine wave produces *harmonics*. The *harmonics* are numbered depending on the basic frequency multiplication factor and called 'odd' or 'even'. For example, the third harmonic represents the wave with frequency of 180Hz and it is the 'odd'.

In majority of three phase circuits the voltage (and current) waves are shifted 120 degrees in each phase and this causes some harmonics to cancel themselves while some may become more predominant.

The shape of a distorted sine wave and the electrical system configuration (i.e. delta or wye) also affects the harmonic content.

For practical purposes, only the first 10 to 15 harmonics (or even fewer) represent the most energy in the distorted wave form. However, these *harmonics* could produce many undesired effects such as equipment overheating, faulty operation of relays and controls, poor power factor, overloaded neutrals or failures of transformers and capacitors.

Total Harmonic Distortion (THD) factor, expressed in percent, is used to describe the harmonics content or, in other words, the degree of sine wave distortion.

True RMS meters must be used where harmonics are suspected. A meter that is only calibrated to RMS may read high or low where harmonic voltage or current are present.

The National Research Council of Canada conducted a study that reported as much as 20% inaccuracies of standard electro-mechanical power meters when supplied with highly distorted wave forms.

3. ELECTRONIC POWER METERS

3.1 Principle of Operation

Digital metering has been made possible by the integration of Analog to Digital Converters and the microprocessor. Fig.3 shows a simplified block diagram of a digital power meter.

The transducer is connected to a three phase system usually through Potential Transformers (PTs) and Current Transformers (CTs). The internal circuitry scales the signals and passes them to the Analog to Digital Converter (ADC). The microprocessor rapidly samples the output of the ADC and calculates various power parameters.

The computing power offered by the currently available micro processors combined with special software allows for very accurate, true RMS measurements of many electrical parameters.

3.2 Output Signals Available

Microprocessor based power meters can measure and calculate many more electrical parameters than the traditional electro-mechanical meters or analog power transducers. In addition to basic functions,

such as energy (kWh) and demand (kW), they may provide phase voltages, phase and averaged current, power factor, apparent and real power, frequency, etc. Often, the transducer supports a display which allows viewing of these parameters.

Most power transducers offer the energy consumption data as pulses produced by a SPDT or solid-state relay contact (sometimes referred to as KYZ output). Some transducers offer 0-5VDC or 4-20mA output channels proportional to measured signals.

Usually, only the instantaneous real power (kW) is available as an analog signal (4-20mA or 0-5VDC).

Most of the other parameters, however, are available only through a digital output (such as RS232 or RS485). Since true RMS power meters use digital processing it is much easier for the manufacturers to produce output signals in digital format.

3.2 Interfacing with Automation Systems

It is important to be aware of the various digital communication protocols and interfaces offered by different transducer manufacturers.

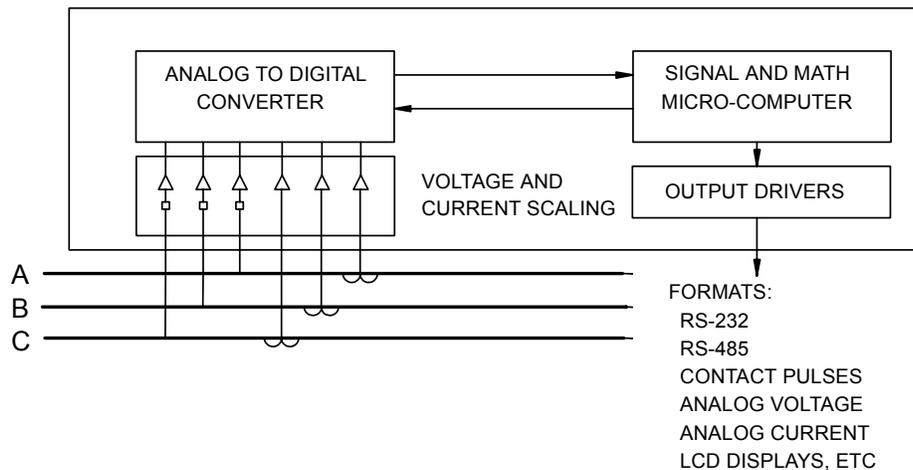


Fig. 3

The transducers' digital hardware communication interface may not be directly compatible with the automation system. The standard analog output(s) provided by electronic power transducers can be easily interfaced with DDC and many PLC systems that accept 4-20 mA or 0-5VDC input. However, due to the Digital-to-Analog and Analog-to-Digital conversions required to obtain and measure such signals, it is recommended to use digital communications to minimize inaccuracies.

kWh output pulses may be represented as "change of state" or a short pulse relay contact output. It is important to realize the necessary input requirements of the specific DDC/PLC when using this output type.

Most DDC/PLC panels do not have their Analog Inputs isolated. Ground loops may be created while interfacing these systems to some power transducers. The transducer's output signal grounding should be done through the DDC/PLC system, as are the other sensors. Transducers with isolated outputs should be considered.

Elkor solved the interfacing problems by developing transducers designed specifically for the Building Automation market. Elkor's transducers offer isolated outputs and permit grounding through the system. They also offer slow rate pulses with 50% duty cycle, as well as 100ms output pulses and multiple analog output signals easily monitored by any standard DDC system. RS485 Modbus communications is implemented to provide comprehensive parameter overview.

3.4 Connection To Power Lines

Electronic power transducers should be connected to circuits that are to be monitored in the same way as any standard power meters. Properly sized CTs (and PTs, when required) should be installed in accordance with the applicable codes. Voltage lines should be fused and CTs should be equipped with shorting blocks.

It is recommended that a CT/PT isolating terminal, referred to as *test switch* is installed between the metering transformers and the transducer. This test switch should be user accessible. It will establish an interfacing point and allow in-line testing. Usually, the test switch contains a fuse block and provides shorting for 5 Amp CTs.

The polarity of metering transformers and the phase rotation are important. If CT (or PT) wires are reversed most transducers will not measure properly and it could read 0 or 50% of power.

For Energy Management applications metering on the secondary side (low voltage) is recommended because the cost of high voltage PTs and CTs could be much higher than the cost of the transducer itself. Usually, it is more economical to install a few low voltage metering points than one high voltage (primary side) metering system.

Primary side metering, preferred by the utility, serves the purpose of revenue metering. This method includes the distribution transformer losses in the customer's bill and secures the utility's access to the high voltage metering compartment.

All Elkor transducers accept up to 600 VAC line input without a need for PTs. A variety of inexpensive Current Transformers, calibrated for the specific transducer are also offered. This may help to reduce the cost of the power metering installation by reusing the existing 5 Amp CTs without interference.

3.5 SCADA Systems - A Brief Overview

The term *SCADA* (Supervision, Control And Data Acquisition) originated in the power distribution industry. It might be considered as an electrical synonym to Direct Digital Control (DDC).

SCADA installations provide information on the electrical system and allow for remote control of it. Of course, there are principal differences between the two systems. For example, in electrical installations the remote monitoring has much higher priority over control and there are only limited automatic control applications. However, both systems display many astonishing similarities.

Both systems use dynamic graphics and single line schematics as the operator's interface (example shown on Fig.4). Both offer a complex trend logging and alarming capacities and recently, both are designed as distributed intelligence systems, accessible by a standard PC.

In fact, today's DDC systems frequently offer much higher functionality than their SCADA equivalents, thus the addition of power sensors to the existing DDC/PLC networks seems to be a natural next step in Building Control System expansion.

With this in mind, Elkor introduced a line of power transducers designed specifically for Building Automation Systems. These units and the BAS-inherent computing power make SCADA-like monitoring possible at a fraction of the cost associated with the traditional, electrical only systems.

Energy (kWh) and demand (kW) information are the most common requirements, however, it is straightforward to complement them with current, voltage, power factor and vital electrical ON/OFF status points. This would offer the owner or the facility manager, a comprehensive DDC/PLC based, electrical monitoring system. The information gathered can be used directly by the electrical maintenance department or process engineering. The building operators will be

kept aware with regards to almost everything that is happening with power distribution and the electrical equipment.

4.0 PRACTICAL APPLICATIONS FOR POWER MONITORING

Continuous monitoring of power parameters is necessary for any serious electrical energy management and it could prove indispensable in the maintenance of electrical systems.

4.1 Energy Management

Experience has shown that at least a 1% drop in electrical energy cost can be expected by merely monitoring the loads. Additionally, far more significant savings may be achieved by systematic electrical system monitoring and implementation of load management measures such as load shedding and power factor correction.

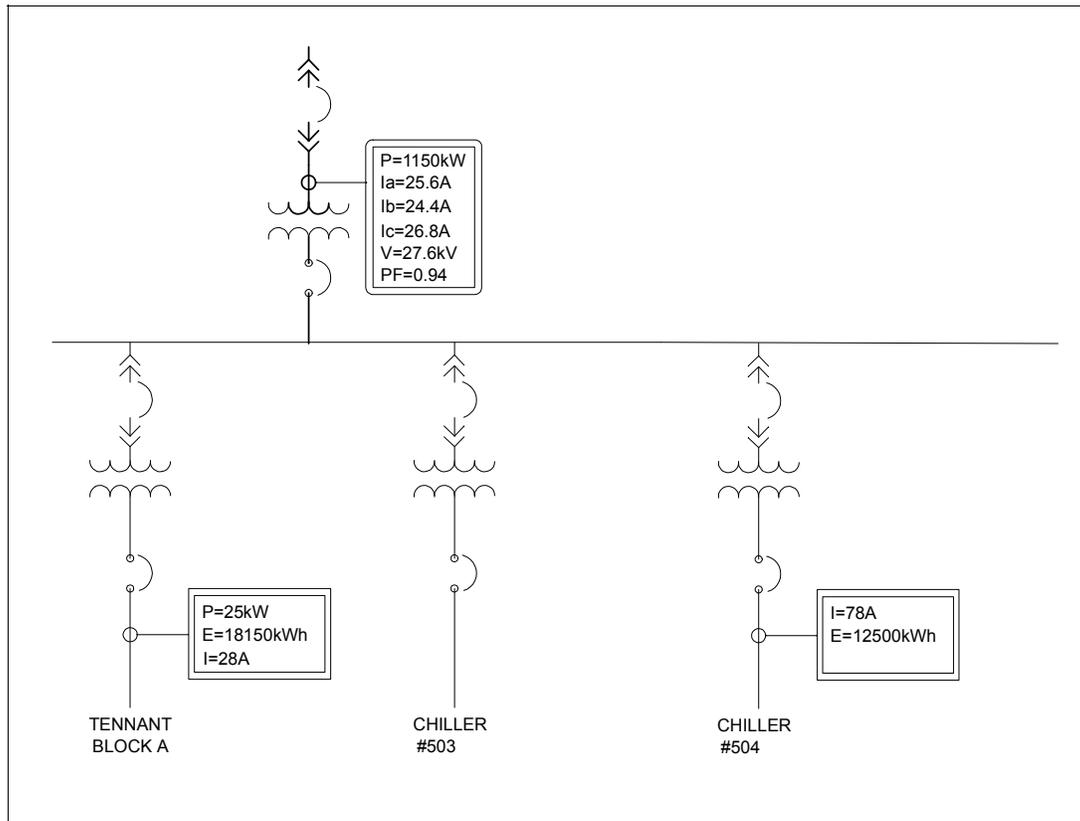


Fig.4

4.1.1 Demand (kW) Monitoring and Load Shedding

Most utilities include the maximum monthly demand (peak value), usually metered in 15 minute intervals in their rate structure for large users.

Continuous monitoring of plant/facility electrical load is required to reduce the peak demand charges by staggering the electrical equipment use during peak periods. A daily demand profile can be established and, in some cases, the energy consuming processes may be shifted outside the peak hours. Although it is difficult to "shift loads" in commercial or institutional buildings, the nature of HVAC and building thermal capacity allows for load shedding on a rotary basis, so that the users would not see any dramatic change.

All HVAC related electrical loads should be categorized for priority of operation and if the monthly peak limit is approached they should be switched to the reduced load operation or even entirely 'off' in pre-selected groups, for no longer than 30 minutes each.

This process can be fully automated but in larger systems some operator discretion would be advised. The detailed knowledge of daily and seasonal peak demand patterns will be very helpful in making the 'load shedding' decisions.

Use of stand-by generators for 'peak shaving' could also be implemented to further reduce the peak. Accurate monitoring will help optimize co-generation performance.

4.1.2 Power Factor Correction

Power factor is a very dynamic parameter although it practically changes only between 0.7 and 1.0. In most installations the PF (inductive by nature because of transformers, pumps, fans and chillers) is corrected by centrally located capacitor banks. By monitoring power factor, the corrective capacitor banks can be switched in sequence to maintain the highest possible value of PF.

High PF will reduce the amount of current flowing in the distribution system and eliminate the unnecessary transmission losses (referred to as to I^2R losses) in cables, wires and transformers.

Power factor control may help avoid low PF penalties imposed by some utilities. It will also contribute to better voltage stability, especially during off-peak hours.

If a PF correction system already exists, independent PF monitoring will verify its proper operation and eliminate frequently unnoticed malfunctions (such as capacitor bank loss or one phase correction loss).

4.1.3 Electrical Efficiency Monitoring

By continuous monitoring of power consumption and load profile, the effectiveness of HVAC control strategies can be dynamically assessed. The performance of chillers, pumps, fans and VAV systems can be constantly monitored and the most energy efficient strategies can be implemented. True RMS measurements offered by electronic transducers may prove indispensable when Variable Speed Drives are used.

4.1.4 Multi-tenant Power Cost Redistribution

The installation of inexpensive power monitors for each tenant, department or production line in a facility would provide a DDC based power cost redistribution system. For time-of-day electricity users the demand information and the total energy consumption can be automatically incorporated into comprehensive and objective billing for various occupants of the facility. Experience has shown that this approach is much more appreciated by most occupants than the flat rate based on square footage of rental space.

4.1.5 Utility Metering Verification

Utility provided revenue metering is, in most cases, accurate. But it is the customers' ultimate responsibility to verify the readings. The utility will not reimburse the customer for erroneous metering. They will replace the meter and correct the deficiency but any overpaid bills are the customer's loss. Independent power monitoring will help avoid these situations and provide the owner with yet another tool to control energy spending.

4.2 Electrical System Maintenance

4.2.1 Phase Load Balancing

It is essential that electrical loads within a building are equally spread among three phases (balanced). The use of continuous current (load) monitoring in each phase and the trending of data will help to rebalance the feeders to avoid such problems as overheating, undervoltage and overload, as well as, unnecessary I^2R losses.

4.2.2 Voltage Monitoring

Voltage monitoring is usually neglected in most large systems. It is important to know about voltage fluctuations and the seasonal changes to better manage the feeder loading and transformers' tap changes, when required.

Some occupants, such as computer centers or research labs may even demand voltage monitoring for their facilities. The DDC system can provide accurate trend logs for these facilities plus a trend log of the utility voltage at the main feeder.

4.2.3 System Troubleshooting and Emergency Switching

Historical data on building load, including phase load, voltage level and power factor will prove indispensable while troubleshooting is performed by the electrical maintenance personnel. This data may be essential, if not critical, in case of system failures.

Realistic load information is very helpful for any system reconfigurations after the failure (bypass switching) or an anticipated system modernization.

Any planned expansion or addition to the facility will benefit from this historical data. In some cases, oversized (or undersized) electrical equipment will be discovered and the consultant or contractor will be able to recommend properly sized equipment.

5.0 GLOSSARY OF TERMS

- Apparent Power** - the product of Volt x Ampere multiplication (expressed in VA); equals to *real power* only in resistive loads
- Burden** - available load handling capacity of CT or PT expressed in VA
- CT** - current transformer; scales down the primary load current; usually in multiples of 100 A primary to 5 A secondary (i.e. 400:5)
- CT Ratio** - a multiplier to be used for scaling the transducer's output (i.e a 400:5A CT has ratio of 80)
- DDC** - Direct digital control refers to the application of microprocessor technology to building environmental controls. With DDC it is possible to control heating and cooling functions with software that takes into account a wide range of variables, thereby achieving greater efficiency.
- EGU** - Engineering Unit the output scaled in real values (i.e the transducer's analog mA Output Signal of 12mA may represent 1000W as a generic signal; after being scaled by CT and PT multipliers of, say, 800 this will become 800kW in Engineering Units).
- EMS** - Energy Management System, computerized system for control of building electrical and mechanical systems (also referred as DDC system).
- kW** - kilowatt (1000 W) unit of real power, a rate of energy consumption.
- kWh** - kilowatt-hour (1000 Wh), a unit of electrical energy used
- kVA** - (1000 VA) a unit of apparent electrical power
- PLC** - Programmable Logic Controller; A device used to automate monitoring and control of industrial plant. Can be used stand-alone or in conjunction with a SCADA or other system
- PF** - power factor; relation between real and apparent power ($kW = kVA \times PF$)
- PT** - potential (voltage) transformer; to reduce primary line voltage to lower level acceptable by a meter; usually 120VAC output in North America
- PT ratio** - a multiplier to be used to scale the transducers voltage output if PTs are used (i.e a 4200:120 V PT has ratio of 35)
- Real Power** - a result of Volts x Ampere x PF multiplication, the rate of energy consumption by the load; equals to apparent power in resistive loads, expressed in Watts.
- RMS** - Root Mean Square, effective value of AC voltage or current (the measure of AC effectiveness)
- SCADA** - (Supervisory Control and Data Acquisition) Systems are used in industry to monitor and control plant status and provide logging facilities. SCADA systems are highly configurable, and usually interface to the plant via PLCs.

