Saving energy through load balancing and load scheduling

Application Note

Engineers, electricians and technicians can find significant energy saving opportunities through load balancing and load scheduling when using power logging test tools. Whether conducting an energy audit or troubleshooting to find energy losses, a typical power logging session should record several factors including: voltage, current, power trends, transients and event logs.

While analysis of each parameter is important in the overall scheme of reducing energy costs, in this article we will focus on how to reduce your energy bill by balancing loads across a three-phase distribution system and, scheduling the operation of certain loads to reduce energy demand. Therefore, we will concentrate on taking voltage and current unbalance readings to determine load balancing issues and on taking power and related events to identify load scheduling issues. Correct load balancing and scheduling is a good, quick way to reduce electrical energy usage.

Load balancing

System designers and electricians usually balance loads across a three-phase distribution system during installation. Loads are calculated in accordance with Article 220 of the National Electrical Code® based on their volt-amperes (VA) or kilovolt-amperes (kVA), rather than watts or kilowatts (kW). This provides an accurate analysis of the ampere values that will flow in the circuit. Even though non-inductive load ratings are expressed in watts or kilowatts, these wattage ratings can be considered the equivalent of the same rating

in volt-amperes or kilovolt-amperes. Understanding this concept of how loads are calculated and the associated units of measurement allows for proper power quality instrument setup, results interpretation and corrective action decisions.

Electricians install equipment and divide kVA between phases such that each phase will carry an equal amount of load. This concept, however, holds true in theory only. In the practical world, the three-phase system is rarely "perfectly" balanced. Load unbalance (imbalance) manifests as a voltage and current unbalance. Therefore, technicians must be sure to monitor and record both voltage and current to determine the extent of the load imbalance in a system.

Figure 1. Unbalance. In this example the Vneg of 9.2 % indicates expected overheating of three-phase motors and transformers and reductions of motor torque and speed. The Vzero of 8.2 % indicates excessive current flow in the neutral due to the unbalance with expected overheating of conductors and transformers.
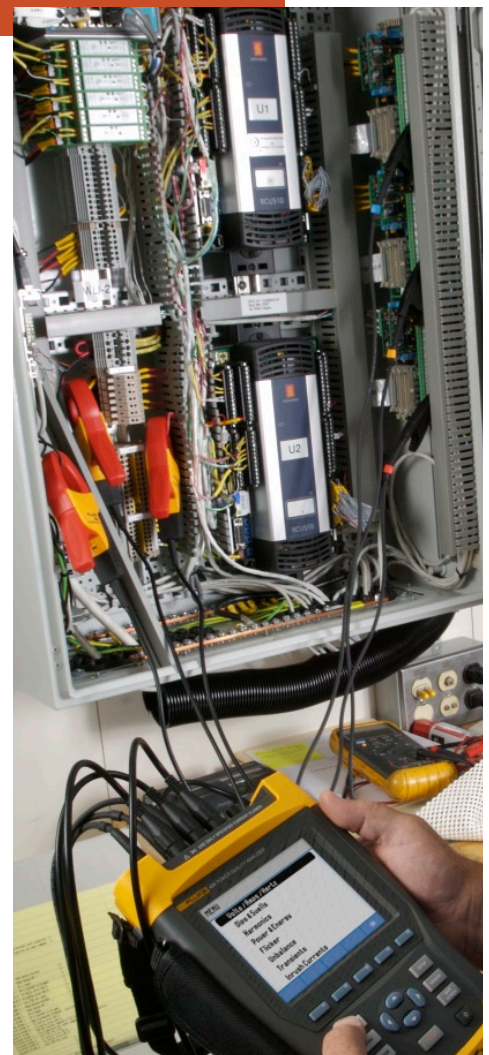
Technicians use one of two methods to determine an unbalance situation. The first, which may be referred to as the IEEE or NEMA method, utilizes a digital multimeter (DMM) to take spot voltage readings. To use this method, measure the three phase–to–phase voltage readings (AB, AC, BC). Sum their values and divide by three to obtain the average voltage. Any phase voltage reading that deviates by more than 1 % from the average value warrants corrective action. While this process should be one of the first steps when troubleshooting an identified unbalance problem, it will not provide for an accurate analysis over time as loads cycle on and off. This requires trending or power logging.
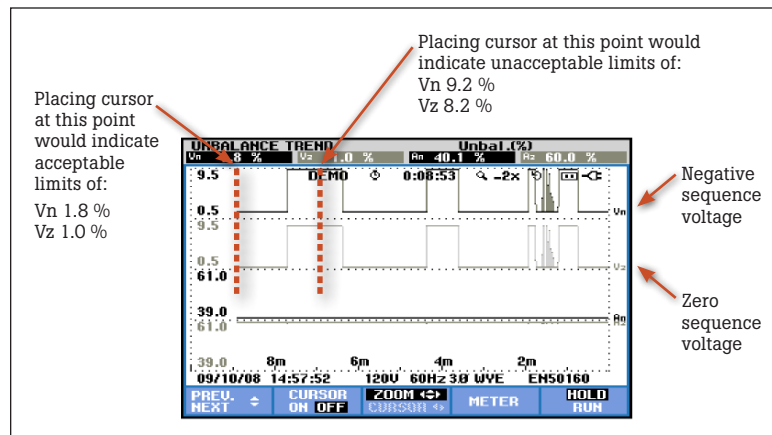
The Fluke power quality analyzers and power loggers utilize a mathematical tool called the "method of symmetrical components" to analyze unbalance. This method not only simplifies the voltage imbalance concept by providing a graphical representation of unbalance in vector format, but also provides accurate and detailed information to be used for analysis. Fortunately, the Fluke analyzers and recorders automatically perform the calculations for us—technicians only need to read the results!

The instruments split each phase voltage and current into three separate components: the positive sequence, the negative sequence and the zero sequence. The positive sequence component represents the normal voltage or current in a balanced three–phase system. The negative sequence voltage or current is created by an unbalance in the system and results in overheating in inductive loads such as motors and transformers. This component is also responsible for reducing motor torque and can affect speed. The zero sequence

Figure 2. Unbalance Trend. This is the Trend function of the Fluke 435 meter screen in Figure 1. By selecting Cursor "ON" and then moving the cursor along the signatures, the amount of unbalance can be identified at different times. These trends should then be compared to operation of single–phase equipment during these times to determine the source of the unbalance.

component represents the unbalanced current that flows in the neutral of the three–phase, four–wire system. This results in energy losses in the form of heat in conductors and transformers.

The EN50160 power quality standard sets the maximum unbalance at 2 % at the point of common coupling. The analyzer or power logger displays and records the percentage. This percentage is the ratio of the negative sequence component to the positive sequence component, or the zero sequence component to the positive sequence component.

Technicians will be relieved to find out they must not memorize the theory but, only learn to operate the equipment and read the results. When checking for unbalance, select "Unbalance" on the power quality analyzer menu. Then, simply read the ratios on the meter screen. Neither the "Vneg" nor the "Vzero" values should exceed 2 %. (See Figure 1, Unbalance.) If these limits are exceeded, isolate and correct the source of the problem or energy losses could become substantial.

Since the meter screen on the power quality analyzer updates constantly, the analyzer meter function is best suited for checking for unbalance at a particular point in time. Select "Trend" when in the Unbalance mode to observe both negative sequence and zero sequence voltages over time. After recording has stopped, use the cursor to determine at what time the unbalance occurred and its severity. (See Figure 2, Unbalance Trend.)
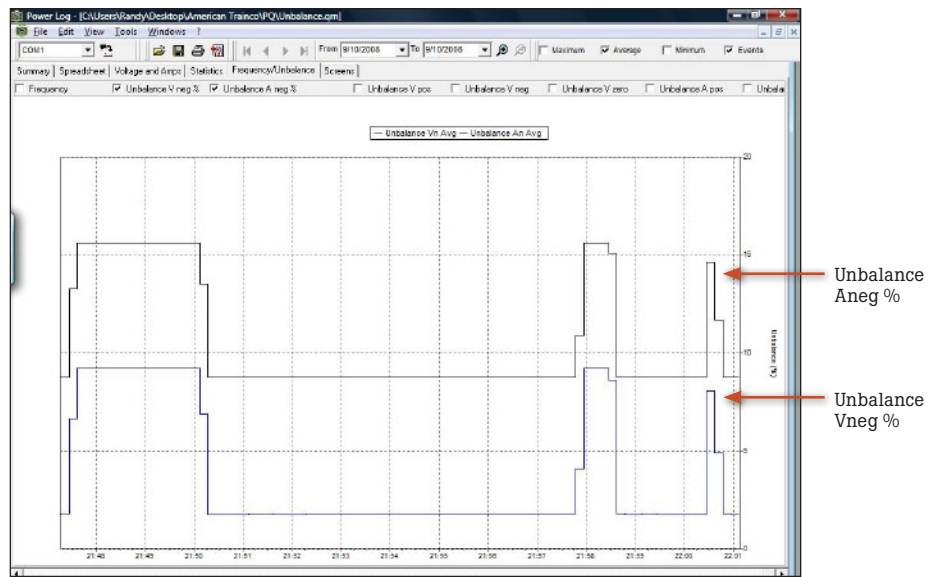
After a power logging session, download the data to a PC and analyze using the Power Log software. This software analyzes voltage unbalance recordings from several different types of recording instruments including the Fluke 345 and 435.

Technicians must also consider the options available when setting a recorder instrument to log voltage unbalance situations. The Power Log software allows for plotting of the following values if they are present in the recorded data:
• Frequency
• Unbalance Vneg %
• Unbalance Aneg %
• Voltage: positive, negative and zero sequence
• Amperes: positive, negative and zero sequence

The more data available to analyze, the more likely you are to come up with energy saving ideas. However, do not be overwhelmed with data. In the Power Log software, select only the specific set of data you wish to analyze at one time by checking the appropriate checkboxes on the top menu.

Once the data is downloaded to the PC, select the "Frequency/Unbalance Tab" in the Power Log software. View data graphically by selecting the minimum, maximum or average value of each desired set of information. (See Figure 3, Power Log Frequency/Unbalance Tab). For further analysis of the data, export the data to a spreadsheet by selecting "Export data" under the File tab. You can then compare the exact dates, times and voltage unbalance values to other plant data. Savvy engineers and technicians, armed with knowledge of what single-phase equipment was operating at what time and, with an up-to-date one-line diagram of the distribution system, can now isolate loads and equalize them across all three phases to correct the unbalance problem.

Load scheduling

In addition to reducing energy costs through load balancing, technicians and engineers can also create immediate energy savings through load scheduling. Load scheduling is the part of energy load management that minimizes demand.

Electric utilities charge large commercial and industrial customers a "peak demand penalty." This peak demand penalty is in addition to the total usage of electricity over the billing period. "Maximum Demand" is the maximum amount of electricity used by a customer at any point in time. The utility must be capable of supplying this load, must size its distribution equipment accordingly, and will therefore charge the customer to be able to meet this need.

Figure 3. Power Log Frequency/Unbalance Tab. By selecting the various checkboxes at the top of the Power Log software Frequency/Unbalance Tab the various sequence components can be compared. In this comparison the negative sequence voltage component and its effect upon amperage are plotted.

Date	Time	Unbalance An Avg	Unbalance An Max	Unbalance Vpos Min
10/9/2008	21:47:16 909ms	8.79	8.79	159.46
10/9/2008	21:47:26 909ms	8.79	8.8	159.46
10/9/2008	21:47:36 909ms	13.28	15.64	139.09
10/9/2008	21:47:46 909ms	15.63	15.64	139.09
10/9/2008	21:47:56 909ms	15.63	15.64	139.09
10/9/2008	21:48:06 909ms	15.63	15.64	139.09
10/9/2008	21:48:16 909ms	15.63	15.64	139.09

Data can be easily exported to a spreadsheet program for further analysis.
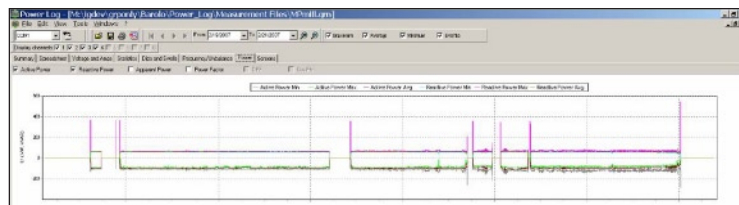
This maximum electrical energy usage, or demand, is averaged over a 15 minute period, (typical), and determines the rate schedule at which a customer will be charged. Peak demand is usually caused by a spike in power consumption, most often when multiple loads come on simultaneously. These additional penalties can be high and add significantly to the cost of electrical energy. It only makes sense to minimize the amount of peak power being used, if at all possible. Power logging provides this opportunity.

If you are attempting to more effectively schedule load operation, conduct power logging recording sessions to measure energy usage over time and identify large loads that operate concurrently. Use one-line diagrams to determine the energy demand of various loads and compare them to operating needs. Do not look for just one particular load to be causing the problem. Quite often you must work with operations personnel and adjust a process by staggering cycling times, or complete certain processes during off-peak hours to reduce demand. Engineers and operations management must work together to review the electrical energy bill and compare it to collected power logging data to aid in making the best plant operations and energy cost savings decisions.

Figure 4. Power Log Power Tab. The Power Log Power tab plots total power values including kW, kVA, kVAR and power factor against time. Determining power usage at specific points in time is the first step in controlling demand.

You should always begin monitoring at the service entrance to determine total energy usage. Set the averaging time in the power logger to 15 minutes if that is the time used by your utility. Consult with your utility to determine the actual averaging time as 30 minutes may also be used. Also, monitor power for an entire billing cycle of thirty days; that will provide the most comprehensive information. Consider repeating this on a seasonal basis, as power consumption requirements change. Import the data to the PC upon completion of the logging session and use the "Power" tab and the "Energy" tab to search for periods where energy usage exceeds desired limits. Identify the equipment creating the peak demand charges by observing excessive uses of "Active Power" (kW) on the Power tab. (See Figure 4, Power Log Power Tab.) Adjust plant operations and processes as necessary, to minimize demand charges. Do not be intimidated by the amount of data. Spend some time breaking the data down into manageable time frames and use the checkboxes at the top of the menu to indicate only one or two parameters at a time on your graph.

Engineers, electricians and technicians play a large role in reducing plant energy costs. If you will set up a power quality instrument to record needed voltage and power values, and use software to analyze the recorded data, you can reap the benefits of significant energy savings through proper load balancing and load scheduling.