A Guide to Paralleling Electrical Systems

by Mark Lautenschlager, PE
President, ERC International, Inc.

It's 2:00 AM, and the replacement transformer has been installed and is ready to go. All you have to do now is verify that the transformer's secondary bus voltage is in-phase with the system voltage. You energize the transformer, and across the racked out secondary breaker stabs you check for zero voltages that will verify that phasing is OK.

But the voltages are not zero, and the systems are not in-phase. So what went wrong? What do you do now?

What Are Standard Three-Phase Transformers?

For standard delta-wye and wye-delta connected transformers, the high-voltage phases always lead the low-voltage phases by 30º. For standard connected delta-delta and wye-wye connected transformers, the high-voltage phases always lead the low-voltage phases by 0º. Therefore, except for the fact that the delta secondary systems do not have grounded neutrals, standard delta-wye transformers can be paralleled with standard wye-delta transformers, and wye-wye transformers can be paralleled with delta-delta transformers. Delta-wye transformers cannot be paralleled with either delta-delta or wye-wye transformers.

Nonstandard three-phase transformers and banks of single-phase transformers may be found where the original system was very old and was not tied with other systems. Some municipal electric utilities used transformers connected such that the low voltage led the high voltage by 150º (or 180º out of phase with the standard connection).

What Is Phasing?

Phasing is the act of determining, before two electrical systems are paralleled, that the voltages on the system buses to be connected are nearly the same in both magnitude and phasing (when the maximum positive and negative sinusoidal voltage peaks occur at the same time for the same phases of both buses).

In the USA and some other parts of the world the letters "A," "B," and "C" are usually used to identify primary phase conductors in terms of phase relationships – the relative sequence of the voltage peaks applied to the conductors; "a," "b," and "c" are used to identify the secondary phasing. One purpose for phase identification is to determine where to connect single-phase loads to balance the loads on the three phases. Another purpose for phase identification is to provide a means to determine tie switch and transformer connections to maintain the same phase sequence so that motor load rotation direction will be correct when secondary system loads are transferred between different transformers. The third purpose of phasing is to match both the phase voltages' magnitudes and the timing of the peak sinusoidal voltage peaks, such to allow the paralleling of two secondary systems without causing short circuit current to flow.

Phasing "A," "B," and "C," and/or "a," "b," and "c" indicated on one electrical system might not match the phasing on another system. This may be caused by arbitrary identifications made when the system was first installed, by the phase shifts caused by different transformer connections, or by incorrect connections at tie switches.

The only way to verify that two similar voltage systems are in phase is to determine that zero volts (or nearly zero) exists between the same phases of the two systems. A rotation (or phase sequence) meter is insufficient and unnecessary for verifying phasing. A rotation meter is useful only to check that motors will rotate in the correct direction after reconnecting leads or other parts of the power

Table 1

	Voltage Measured	Displacement Between Phases of Two Systems
1.	0 (or nearly 0) volts	0º (in phase)
2.	Slightly more than 0.5 times phase-to-ground voltage	30º *
3.	Phase-to-ground voltage	60º *
4.	Slightly more than 1.4 times phase-to-ground voltage	90º *
5.	Phase-to-phase voltage	120º *
6.	Slightly more than 1.9 times phase-to-ground voltage	150º *
7.	2 times phase-to-ground voltage	180º
8.	Inconsistent voltages **	Ungrounded

* Leading and lagging cannot be determined by only measuring voltages.

** Ungrounded systems must be temporarily grounded or one phase connected to a grounded system to determined phasing.

circuit. A phase-angle meter or an oscilloscope is useful to determine if the voltages of one circuit leads or lags the voltages of another circuit, but they are not necessary. The minimum equipment required for verifying phasing is either a voltmeter or phasing sticks as necessary for the system voltage.

To understand the phasing process, it is necessary to know the voltage and phase-angle relationships that exist between the same phases of two systems (see table 1). It is assumed that the phase-to-phase voltages of the two systems are identical. In the field, due to loading conditions, the voltages measured may be slightly different than indicated.

Before Attempting to Perform Phasing

Before phasing, verify that the transformers on the two systems are on the same voltage tap. If not, the transformer with the higher secondary voltage will carry more of the load when the systems are paralleled. Also verify that the percent impedance (%Z) of the transformer for one system is closer than 92.5 percent to 107.5 percent of the %Z of the transformer for the other system. The system with the transformer with lower %Z will have a higher voltage when loaded and, therefore, will carry more of the load when paralleled.

Determining Phasing by Measuring Voltages across Two Systems

Phasing problems can be determined and resolved by simply recording the voltage measured between each phase of two systems and comparing the results with the following:

SITUATION # 1: Correct Phasing

Zero voltage (or nearly zero) is measured between the phases of each system. The two systems are in-phase with the same rotation. The systems can be paralleled.

SITUATION # 2: Transformer or Tie Switch Leads Connected in Wrong Sequence

Phase-to-phase voltage is measured between the same phases of each system. The systems both have the same rotation but are 120º out of phase as indicated by the phase-to-phase voltage. To correct, move the leads on one system at the transformer primary, secondary, or at the switch such that what was A is B, what was B is C, and what was C is A. If the systems are still 120º out of phase, repeat the process one more time. The use of a phase-angle meter would indicate which way to shift the leads, but that is not actually necessary.

SITUATION # 3: Two Leads Reversed on Wye-Delta Transformer

Phase-to-phase voltage (120º) is measured between two buses of each system and zero volts (0º) is measured between the third buses of each system. This indicates that the systems have opposing phase sequence (rotation). This occurs when the systems have wye-delta transformers. To correct, exchange either the transformer primary or secondary leads (or on the switch) on the phases where the phase-to-phase voltages were measured.

SITUATION # 4: Two Leads Reversed on Delta-Wye Transformer

Phase-to-ground voltage (60º) is measured between two phases of each system and "two times phase-to-ground" voltage (180º) between the third phase buses of each system. This indicates that the systems have opposing rotation. This occurs only with a delta-wye transformer. To correct, exchange two leads on the primary. The rotation will be correct, but the systems may still be out of phase by 120º. If so, rotate the primary leads once as indicated in Situation # 2.

SITUATION # 5: Double-Ended Substation Transformer with Incorrect Phasing

Phase-to-ground voltage (60º) is measured between each of the three buses. This occurs on the 480 volt buses between the two delta-wye transformers in a double-ended substation where one transformer is correctly connected but the other is not. If the transformers are identical (not mirror images of each other) and are facing each other, the second transformer may have primary "A" phase connected to H3 and "C" to H1 and secondary "a" phase connected to X3 and "c" connected to X1. To correct the problem, two primary leads must be exchanged and the same two secondary leads exchanged. It does not matter which leads are exchanged, except, for example, if H1 and H2 are exchanged X1 and X2 must be exchanged also. This is a major problem since it is often difficult to exchange the secondary (480 volt) leads. This usually occurs when a standard transformer replaces a mirror image (H1/H3 and X1/X3 are reversed) nonstandard transformer in a double-ended substation.

SITUATION # 6: Nonstandard Delta-Wye Transformer Bank

Two times phase-to-ground voltage (180º) is measured between the three buses on two systems supplied by delta-wye transformers. This is caused when one system has a nonstandard delta-wye transformer bank. The secondary winding polarities are reversed in a nonstandard transformer. A standard transformer bank made up of three single-phase units can be made to match the system by reversing the wye winding connections.

SITUATION # 7: Attempting to Parallel Transformers with Different Phase Relationships

Slightly more than 0.5 times phase-to-ground voltage is measured indicating that the two system voltages are 30º out of phase. Slightly more than 1.4 times phase-to-ground voltage is measured, indicating that the two system voltages are 90º out of phase. Slightly more than 1.9 times phase-to-ground voltage is measured indicating that the two system voltages are 150º out of phase. Two systems that have any combination of these phase relationships have wye-delta or delta-wye transformers on one system and delta-delta or wye-wye transformers on the other system. These systems cannot be paralleled. If all three measurements are the same, either 30º, 90º, or 150º, the rotations are the same and the motor loads may be safely transferred by dropping one system and picking up loads on the other system.

SITUATION # 8: Phasing Ungrounded Systems

Inconsistent voltages are measured across the buses of two systems, indicating that one or both systems are ungrounded. This can be verified by measuring the phase-to-ground voltages of each system. Due to imbalanced phase-to-ground capacitances, a phase-to-ground voltage on an ungrounded system can be more than two times the phase-to-phase voltage.

To verify phasing if both systems are ungrounded, the systems must be temporarily grounded by (1) verifying that the systems are ungrounded, (2) installing fused ground jumper (this wire must carry only a small amount of insulation capacitive charging current) on one and the same phase of each system, and (3) energize the buses and measure the voltages between the same phases of each system. If all three (one phase must be zero since they are both grounded) measurements are nearly zero, the systems can be paralleled after the temporary grounds are removed.

If one system is grounded and one is ungrounded, the two systems can be phased by connecting the same phase of the two systems together and measuring the voltages across the other two phases. Care must be taken because if the wrong phases are connected together, the phase-to-ground voltage on the other two phases of the ungrounded system will be 2.0 and 2.75 times normal phase-to-ground voltage.

Conclusions and Comments

The intent of this article is to show most of the basic phasing problems encountered when designing electrical power systems and when verifying phasing in the field. Whenever performing phasing, always follow good, electrical safety practices. Use equipment that has been inspected and tested and wear body, head, face, and hand protective clothing when working near energized parts.

Mark Lautenschlager is President of ERC - Electrical Risk Consultants International, Inc., of Tampa, Florida. He is retired from High Voltage Maintenance Corporation as Vice President of Engineering and is a past president of NETA.