A Practical Primer for Paralleling Electric Systems

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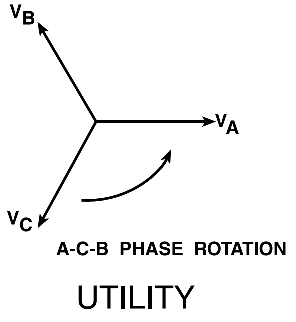
The time-worn method of paralleling two electrical systems by connecting them and throwing the switch can be improved upon by application of a little practical knowledge. The consequences of uncontrolled releases of electrical energy resulting from connecting two unsynchronized systems is adequate incentive to adopt a more rigorous strategy than throwing the switch and hoping it works. This article provides suggestions for improving the odds of success when connecting two electrical systems. Included is an introduction to the parameters of synchronization which must be considered before paralleling two electrical systems. The reader can gain a broader understanding of the often-misunderstood terms of *phase rotation* and *phase sequence*. Additionally, a few real-life examples supplement the technical arguments and provide a greater understanding.

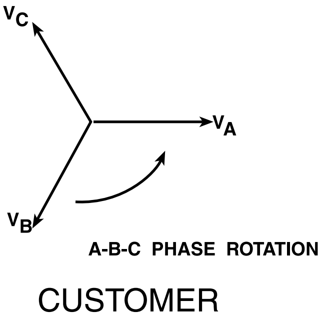
Woodward defines synchronization as the matching of the output-voltage waveform of one ac electrical generator with the voltage waveform of another ac electrical system. For two systems to be synchronized, five conditions must be matched:

- Number of phases in each system
- Direction of rotation of these phases
- Voltage amplitudes of the two systems
- Frequencies of the two systems
- Phase angle of the voltage of the two systems.

The number of phases, voltage level, and frequency are established by long-standing practice. Electrical power is typically either single-phase or three-phase, and voltage magnitudes are determined by utility energy providers and equipment suppliers. Frequency in this country is fixed at 60 hertz. These three criteria for paralleling are, for the most part, taken for granted. However, one of the most confusing and frustrating discussions centers on the direction of rotation.

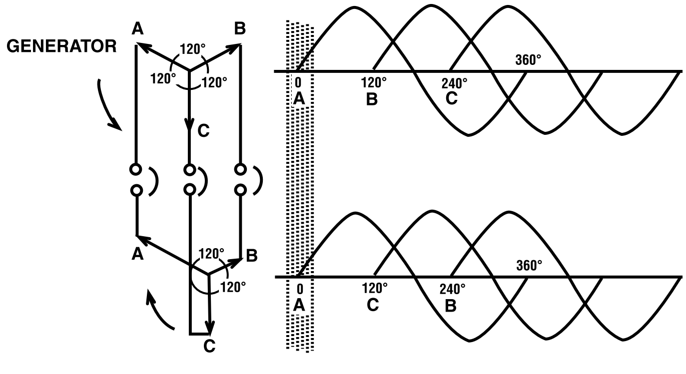
The following is a situation encountered when designing an on-site generation facility for a large commercial complex. At the service entrance equipment, the incoming utility-owned cubicle was marked with an ACB phase rotation, while in the adjacent customer-owned cubicle the phase rotation became ABC. This system parameter was displayed on the switchgear drawings with a suitable hieroglyphic to make the situation clear to anyone interested in determining the phase rotation. What follows is taken directly from actual drawings:





When two or more electrical power sources are paralleled to the same power distribution system, the power sources must be synchronized correctly. Yet predicting and designating the phase rotation in a situation like this is problematic. The actual phase rotation must be determined. Otherwise, when the tie breaker is closed, power surges and mechanical or electrical stresses will result. One system has the potential of placing a dead short on the other. The voltages between the two systems can also be twice the peak operating voltage.

Each source being paralleled must be connected so that all phases rotate in the same direction. If the phase rotation is not the same, only one phase can be synchronized. It helps to visualize this in the form of a diagram, also found in Woodward:

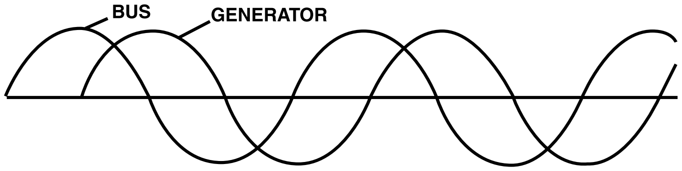


Phase A of the generator matches phase A of the electric system, but phase B and phase C of the respective systems do not match. Typically, synchronization is accomplished with one potential transformer on each system, but matching one phase does not bring the systems into parallel. The phase rotation or phase sequence of each system must match!

Fortunately, phase rotation only has two choices — clockwise and counterclockwise. In a three-phase system, phases are represented as electrically 120 degrees apart and named A, B, and C. These phases are said to rotate in a counterclockwise direction. Their sequence refers to the order the phases appear passing a stationary point of observation. For the phase rotation or phase sequence ABC, phase B lags phase A by 120 degrees, and phase C lags phase B by 120 degrees. For the alternative ACB, phase C lags phase A by 120 degrees, and phase B lags phase C by 120 degrees. A technician can hook up a rotation meter and determine from the meter if the electric system has a clockwise or counterclockwise rotation. The technician can then measure the generator and evaluate whether the phase sequence or phase rotation of the generator and the electric system are the same.

Matching phase sequence can not be be evaluated solely by inspecting the appropriate physical connections at the various electric sources. Many engineering professionals promote that correct phasing can be accomplished by carefully marking and testing power cables during the installation process. This would eliminate phase rotation or phase sequence errors caused only by transitions during connection. Unfortunately, too many opportunities exist for swapped phases, incorrectly marked cables, and incorrectly marked equipment from the manufacturer. As a case in point, during a recent generator installation at an industrial plant, measurements of the incoming-utility phase rotation with a phase rotation meter found the utility service's phase sequence to be ABC. The generator was started up, and the synchronizer brought the two systems into what appeared to be parallel by the synchroscope, but the generator tie breaker would not close. While troubleshooting this issue, the voltages across the tie breaker stabs were measured and were determined to have potential between the respective phases that appeared by the controls to be matched. The Woodward SPM synchronizer and the synchroscope of the generator controls indicated that the two sources were matched. The generator breaker was tripped and locked out, and the generator tie breaker was then closed which effectively back-fed the generator circuit. The phase rotation at the load side of the generator breaker was measured. The phase rotation was ABC. With the generator breaker still locked out, the generator was started with the phase rotation measured ACB on the line side of the generator breaker. The phase rotation of a generator, when received from the manufacturer, is typically configured with an ABC rotation. Evidently, the generator leads had been incorrectly connected to the generator breaker while in the factory.

Typically, the second most confusing and misrepresented aspect of the paralleling process is phase angle. Phase angle match refers to the phase relationship between voltages of the systems to be paralleled. Both the voltage magnitudes and the corresponding voltage phases of the two systems must match to be in synch with each other. More specifically, the voltage wave forms should be within ± 10 degrees to avoid heavy surge currents during paralleling. Again, a diagram from Woodward tells the story much better than words:



For this diagram, the waveforms represent the same phase of each system – in this case the generator and the bus voltage. The generator voltage is lagging the bus voltage by about 120 degrees, and attempting to parallel these electrical sources at this point might damage the generator. In reality, the bus or utility source would pull the generator into synch once the breaker is closed. Unfortunately, the generator shaft might turn 120 degrees relative to the engine shaft in the process. For a synchronous generator, phase matching is usually accomplished by controlling the speed of the oncoming generator's prime mover once the frequencies of the two systems are nearly matched. Note that there are many documented cases of damage caused by failure to match phase angles.

A municipal utility was generating at 480 volts and had an option of stepping up to the distribution voltage of 4160 volts through one tie breaker or paralleling a 12.5-kilovolt utility source with another step-up transformer and tie breaker. Typically, the generator speed is adjusted to enable the systems to parallel. The utility personnel could parallel to one source or the other, but they could never get the generators paralleled to both sources, simultaneously. Through investigation, it was determined that one step-up transformer was a delta-delta connection and the other was a delta-wye connection. This resulted in a 30-degree phase shift which could not be resolved through generator speed adjustment. The ultimate solution in this case was to replace one of the transformers, thus enabling the utility to feed both buses simultaneously.

A key measurement for paralleling two electric systems is the potential difference between the respective phases. No significant potential must exist between what are thought to be the same phases of each system to be connected together. Further, if the measurements yield near-zero potential between the respective phases of the two systems to be paralleled, the line-to-line potential to the other phases should approximate the system voltage. For safety reasons, the meter to be used for performing this measurement should be rated for the voltage being measured. Additionally, do not assume that using the secondary metering as an alternative to measuring the actual potentials across the open point is adequate. The Woodward SPM synchronizer states that the source is in synch when the lights are out on the synch scope. However, it is still highly recommended that this voltage measurement be performed. The single most important requirement in the paralleling process is zero potential between the corresponding phases to be connected on closing the circuit.

Having now obtained a basic knowledge of the technical issues involved in paralleling two electric systems, it is apparent that no errors of judgment can be permitted when commissioning circuitry for paralleling two electrical systems. Never disconnect or disable applicable protective relaying when connecting two sources in parallel. In fact, don't even try to close the connecting device without being confident the protective relaying will operate. Make testing and verifying the protective relay operation a priority before closing the device as part of the paralleling process. Many utilities and industrial users will hire an independent testing firm to test protective relaying as part of the commissioning process of new facilities to avoid the bias of those involved with the design and construction effort.

Many opportunities exist for a nuisance trip in the process of bringing a new generator installation on line. Further, the ultimate user of the electrical energy typically does not tolerate more than one outage for accomplishing a tie in to their system. This results in a temptation to lift the trip circuit of the protective device. This is *not recommended*. The risk of serious damage or potential electrical flashover as a result is too great. Electrical surges have resulted in electrical fires during the commissioning process. The typical cause of the problem is that the protective relaying was disabled or not allowed to operate. If outages cannot be tolerated, the start-up process should be rescheduled for a period when an outage can be tolerated.

A final word with respect to commissioning activities associated with parallel generation activities: make certain the shorting screws are removed from the currrent transformer blocks and all fuses are restored to their respective holders prior to performing operational testing. You would be surprised to know how many times attempts to parallel systems have failed due to the synchronizing potential transformer fuse having been removed and not reinstalled.

In summary, for two systems to be synchronized and operated in parallel, five conditions must be matched:

- Number of phases in each system
- Direction of rotation of these phases
- Voltage amplitudes of the two systems
- Frequencies of the two systems
- Phase angle of the voltage of the two systems.

The number of phases, voltage level, and frequency are established by long-standing practice and easily addressed through design and field measurement. Further, each source being paralleled must be connected so that all phases rotate in the same direction, and the voltage waveforms for each electrical source must be within a minimum of ± 10 degrees. This requires that the phase rotation and phase angles be verified during the commissioning process. Finally, safety should always be considered during commissioning activities. Test equipment should be rated for the voltages being measured. Additionally, the protective relays associated with the system should be verified as operable and functioning prior to actually tying the systems together.

References

1. Woodward Governor Company, 2004, "Governing Fundamentals and Power Management," *Woodward Reference Manual 26260*.

David Charles is a professional engineer in electrical engineering. He is also a Senior Project Manager at ESCO Energy Services Company with over 20 years of experience in energy projects for industrial, commercial, and utility clients. His project experience includes over 200 megawatts of turnkey generation facilities, transmission and distribution line design and construction, substations, SCADA systems, metering systems, and protective relaying and control systems. He also has extensive experience in fault current and coordination studies, arc flash analysis, and substation equipment testing and commissioning.