INTRODUCTION TO SYNCHRONIZING

AUTOMATIC SYNCHRONIZING CONSIDERATIONS AND APPLICATIONS

INTRODUCTION

It is the intention of this presentation to provide an explanation of the automatic synchronizing process, to explore the considerations involved and to look at some synchronizing applications for selection of the proper synchronizer.

Definition

Synchronizing, in its simplest form, is the process of electrically connecting additional generators to an existing bus.

Necessity for Synchronizing

The necessity for synchronizing and parallel generator operation is often based on the following:

1) The rated generating capacity of an existing system has been exceeded by new load demands.
2) Enhanced reliability (multiple generating vs. single unit generating) is to be considered.
3) Operating efficiency of generator sets is a valid concern.

These additional generators will be connected to operate in parallel with each other and supply power to the same load. The additional oncoming generators must be synchronized properly to ensure:

1) Minimal disturbance to the bus.
2) Minimal shock to the generator, mechanical and electrical.
3) Rapid loading of the oncoming generator to take on its share.

The synchronizing equipment selected depends on the generating equipment.

SYNCHRONIZING CONSIDERATIONS

Generator Size

For power to flow out of the machine and into the system at the time the breaker contacts close, it is desirable for larger machines' speed to be slightly greater than the system prior to synchronizing. Therefore, the synchronizer must be capable of determining that the machine frequency is greater than the system frequency (i.e., that the slip rate is positive). However, with small machines, it may be acceptable to initiate closure of the generator breaker while the machine is slightly slower than the system, providing that the synchronizer parameters are within the preset limits and the machine is accelerating and capable of accepting load.

For this paper's intent, we will refer to small machines as those machines used for emergency and standby operations and to large machines as those used solely for stationary power plants.

Small Machines

The need for generator sets as standby power is crucial for the operation of many facilities. For example, an airport facility requires several engine generator sets to maintain continuity of service during emergency conditions or to supply specific load requirements during peak demand periods. The load demands expected at an airport complex for example exceed the generating capability of one generator and require additional generators to be connected to the station bus.

Manual synchronizing could be performed by power plant operating personnel. The operating personnel would manually adjust the frequency and voltage of the generator to be paralleled and would ultimately close the circuit breaker to tie the generator to the load bus. This type of synchronizing scheme is quite simple and most economical. However, the one drawback is that it requires skilled operators at the controls to avoid costly damage to equipment due to improper synchronizing.

Synchronizing meter panels are used to provide information to operators for **manual synchronization**. The metering devices typically include individual bus and generator frequency meters for matching frequency, individual bus and generator a-c voltmeters for matching voltage, a **synchroscope**, and two indicating lamps. A voltage is provided from step-down potential transformers (in high voltage applications) for the input signal to these devices. Note that single phase, line to line voltages from the same phases are used. In most cases, single phase sensing for synchronizing equipment is adequate, because the mechanical design of the generator dictates that the three phases of the generator are displaced 120 electrical degrees apart. Before the generator is synchronized the first time, it must be confirmed that the **phase rotation (a.k.a. phase sequence)** of the generator matches the same sequence as the station bus. Matching the phase sequence can be accomplished by the appropriate physical connections at the generator terminals or other suitable locations.

The **synchroscope** is a multiple parameter information source. It tells you if there is a **slip rate** (a frequency difference between generator and bus) and if the generator frequency is running slower or faster than the bus frequency by causing the pointer to rotate in a counterclockwise or clockwise direction. As seen in Figure 1, the twelve o'clock position indicates 0 degrees phase angle difference. Any instantaneous position of the pointer indicates the phase angle difference between the bus and generator voltage. Of course, the object of the synchronizing process is to close the generator breaker at a 0 degree phase angle to minimize power flow transients when the breaker is closed. Figure 6 illustrates phase angle displacements of the voltage sine wave.

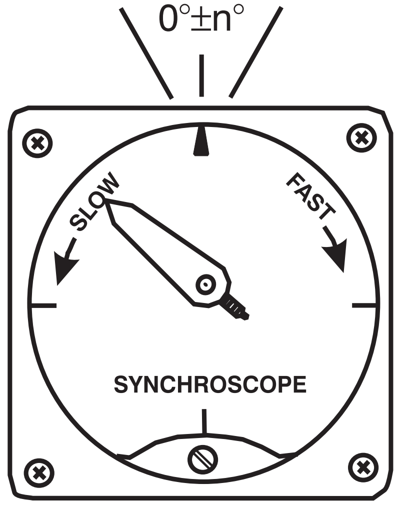

Figure 1: Synchroscope

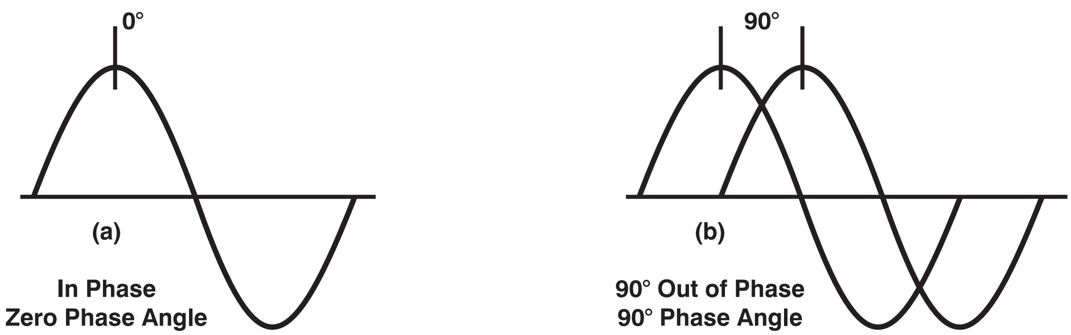

Figure 2: Phase angle displacements

The most primitive device used for synchronizing is a pair of incandescent lamps connected to the same phases on either side of the generator breaker as shown in Figure 3. This demonstrates that if both the generator and bus voltages are "in phase", there is 0 volts potential difference; therefore, the lamps will not be illuminated, hence, the term "dark lamp method of synchronizing". Although simplistic in design, this is a reliable method of phase angle verification when used in conjunction with a synchroscope to verify that there is no malfunction of either the lamps or synchroscope.

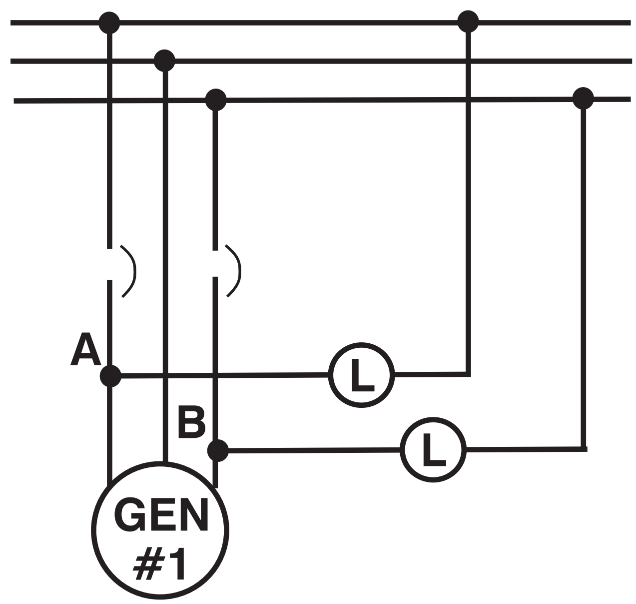

Figure 3: Dark lamp method of synchronizing

In practice, for manual synchronization, an operator creates a very slow slip rate by adjusting the prime mover speed slightly faster than the bus frequency. This allows the generator to pick up kW load immediately rather than have the genset operate in a motoring condition when the breaker is closed. Generators typically aren't operated in the underexcited condition so as not to risk having the generator pull out of synchronism. Therefore, it is preferred that an operator adjust the generator voltage slightly greater than the bus voltage before closing the breaker, so that a small amount of reactive power will be exported from the generator when the breaker is closed.

The addition of a supervisory relay, known as a sync-check relay (ANSI/IEEE Device 25), to the manual synchronization process assists with proper synchronization.

Manual synchronization with a supervisory relay still requires the operator to manually control voltage and frequency, but the supervisory relay sets up an operating tolerance that must be equaled before the circuit breaker can be closed to parallel the alternator.

The supervisory relay compares the slip frequency, phase angle, and voltage differences between the oncoming generator and the station bus. These parameters and some typical ranges are listed below. The supervisory relay does not close its output contacts until all system parameters are satisfied.

Parameters	**Range**
Slip Frequency	0.1 Hertz
Phase Angle	0° to 30° (adjustment)
Voltage	4 volts

The relay's output contacts are placed in series with the operator's control switch. Closure of the circuit breaker only occurs when 1) the operator manually attempts to close the circuit breaker, and 2) the supervisory relay contacts are closed. This is illustrated in Figure 4.

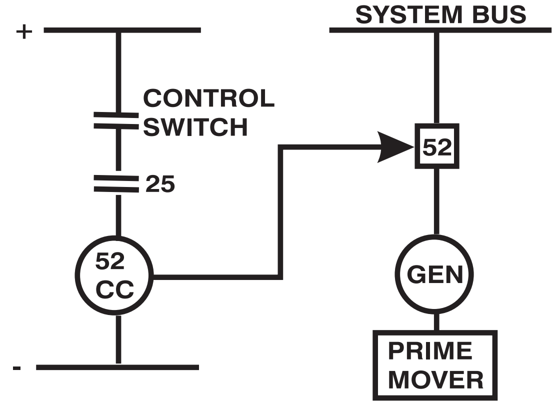

Figure 4: Breaker Closure with Supervisory Control

A function could be included for the supervisory relay to bypass the sync check function and close its output contact when it is desirable to close a breaker during a dead bus condition. A functional block diagram of the supervisory type relay is illustrated in Figure 5.

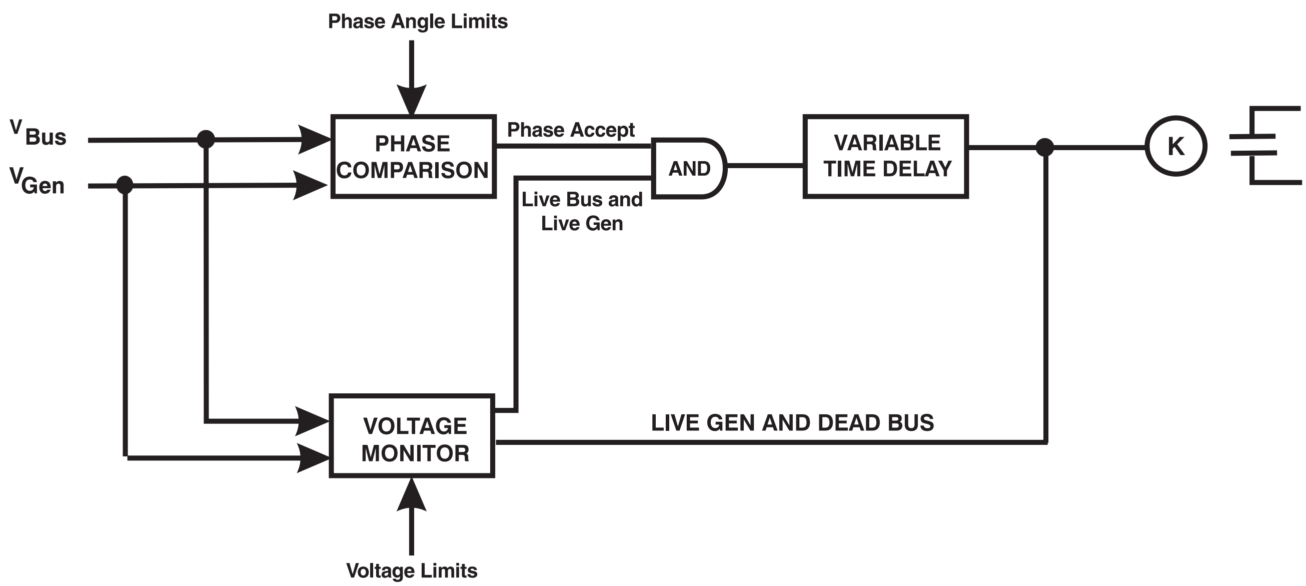

Figure 5: Synch-Check Block Diagram

Some loads within the airport complex require immediate attention from the standby emergency generator sets. This demand for immediate attention rules out the use of operating personnel and manual synchronizing, which leads us to automatic synchronizing.

With automatic synchronizing, the automatic synchronizer (ANSI/IEEE Device 25A) monitors frequency, voltage and phase angle, provides correction signals for voltage matching and frequency matching, and provides the breaker closing output contact.

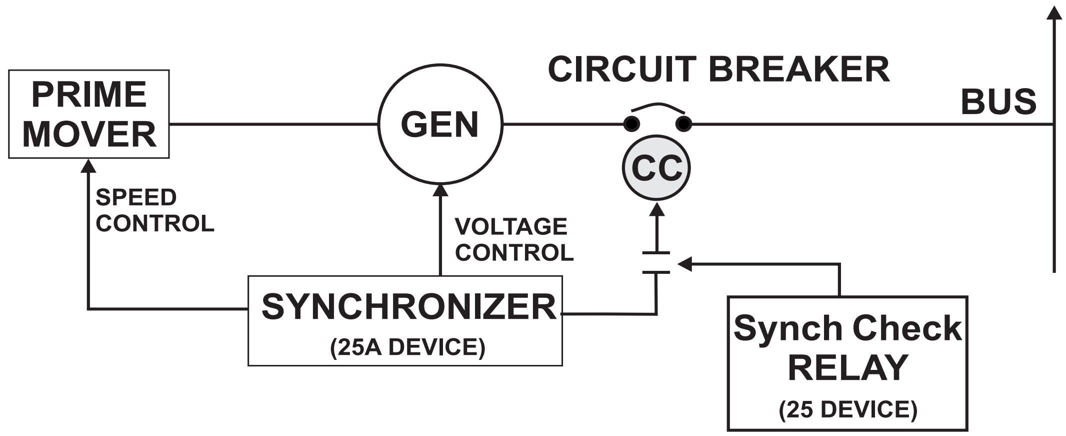

Figure 6: Automatic Synchronizing

Because of the importance of restoring electrical power following an emergency outage, a dedicated synchronizer is desired for each machine. This allows the machines to parallel to each other as quickly as possible. If the automatic synchronizing equipment includes a dead bus provision, it will allow one of the machines to pick up the dead bus and to start the synchronizing process for the remaining machines.

For this application, we could use the anticipatory type synchronizer discussed later. However, this type of device is expensive to apply to a number of machines on a dedicated basis. A sequencing circuit could be used to switch the anticipatory device from one machine to another, but this adds time to the restoration of system power and complexity to the overall control circuitry which might not be desirable in this application. So for this particular job, we would use the phase lock type automatic synchronizer also discussed later.

By applying the phase lock type synchronizer on a per machine basis, the need for sequencing logic is eliminated and each synchronizer/governor/engine combination, together with the voltage regulating equipment, can be optimized for performance and synchronizing speed.

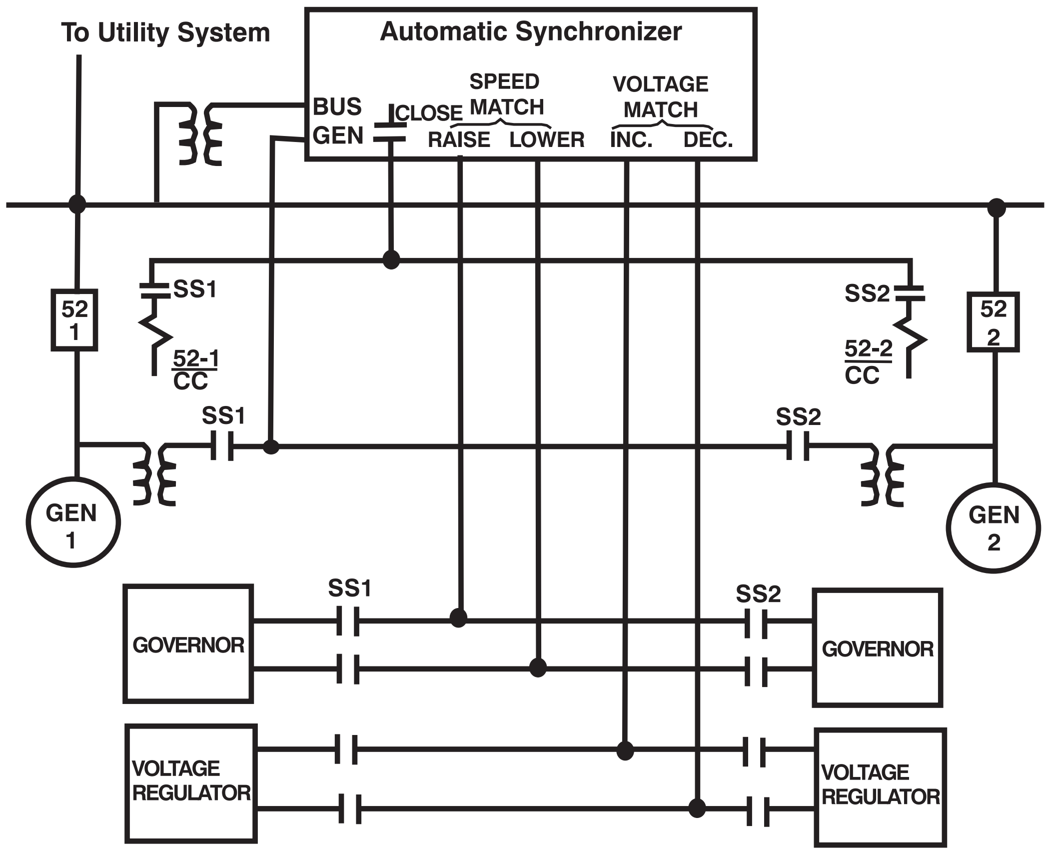

Figure 7: Typical Autosynchronizer Interconnect

Until this point, we have seen the need for synchronizing equipment as applied to engine generator sets for emergency load conditions or peak demand conditions. A majority of these generators falls within the lower generating capacity levels. For installations with greater generating capacities, what type of synchronizing equipment is required? What are some typical applications of these generators, and what features are requested with the synchronizer?

Large Machines

Some typical applications where the larger generators are used include hydroelectric, gas turbine, and steam turbine power plants. These facilities usually provide power for sale to the utility. Typical facilities consist of multiple generators operated in parallel.

In these applications, a single automatic synchronizer can be used and shared by all machines within the installation (See Figure 7).

Some auto synchronizers can be used on multiple-generator systems by simultaneously switching the generator sensing voltage and the breaker closing circuit from one generator to the next. The closing time of each breaker of each generator is entered into the memory of the synchronizer and is recalled by positioning the ganged switch accordingly.

In a hydro installation, the time for the generator to respond to a speed change signal depends on several factors, including 1) the inertia of the machine, 2) the type of turbine,

3) the head, 4) length of penstock, and 5) location of the gates. These installations, therefore, require precise control and typically are synchronized by an anticipating device that predicts when actual phase coincidences will occur. In installations, it is desirable that the prime mover is accelerating so that the generator can pick up and supply the load immediately. In other words, a slip frequency is desired.

In restored hydro installations, it is conceivable that each breaker within the installation may have a different operating time. The synchronizer must, therefore, be capable of compensation for these times. Modules are available in today's synchronizer to provide this compensation.

Because of the time and precise control requirements of the larger generating systems, more control adjustment capability is required within the synchronizer.

In critical installations where precise speed matching is required, there are several factors to be considered in applying an anticipatory type of synchronizer.

First, because of the precise speed matching requirement, very low slip frequencies will be encountered. The synchronizer must be capable of measuring these small frequency differences and calculating the required advance angle. This type of synchronizer also is desirable from the point of view of the recommendation that the generator be running slightly faster than the system to allow the generator to pick up load quickly.

Another part of the synchronizing problem is the precise control of the generator's speed. This is accomplished by supplying a correction pulse once per slip cycle. As the slip frequency decreases, the interval between correction pulses increases.

Therefore, by being able to adjust the duration of the correction pulse, extremely sensitive speed control can be achieved.

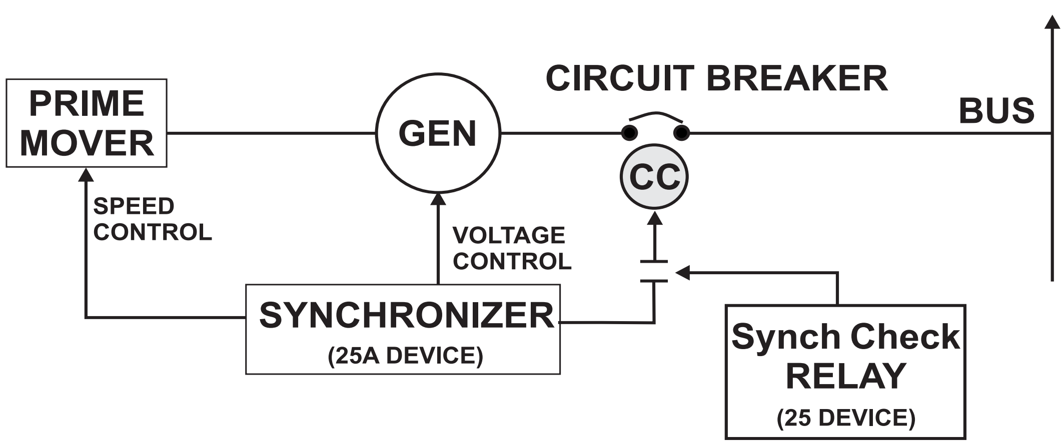

Figure 8: Automatic Synchronizing

TYPES OF AUTOMATIC SYNCHRONIZERS

Automatic synchronizers may be either the phase lock type or the anticipatory type.

Phase Lock Type Automatic Synchronizers

The phase lock or phase matching type synchronizer establishes a window of breaker closing angle and voltage acceptance. When the oncoming generator is within this window of operation (i.e., matched to the bus), the synchronizer energizes a relay, closing a contact to initiate breaker closing.

The phase lock type synchronizer operates on the principle of providing correction signals to the governor and voltage regulator until the two waveforms are matched in phase and magnitude and then initiating breaker closure. Until recently, this type of synchronizer was capable of operating only with electronic governors. Today, it is also compatible with other types of governors that require contact inputs.

Phase lock type synchronizers are intended primarily to be used one per generator.

As the prime mover brings the oncoming generator up to speed, the generated voltage is applied to the synchronizer. When the voltage reaches a minimum threshold, the synchronizer begins to sense both the oncoming generator and the existing bus for frequency, phase angle, and voltage.

a. Compare Voltages
b. Compare Frequency
c. Change Voltage to match bus
d. Change Frequency to match bus
e. Compare Phase Angle

At this point, the synchronizer senses a rather large difference between the sources for frequency/phase angle and voltage, and it begins to give corrective signals to the oncoming generator in an attempt to match it with the bus.

Anticipatory Type Automatic Synchronizer

The anticipatory type automatic synchronizer monitors the frequency, phase angle, and voltage on both sides of the controlled breaker much the same as the phase locking synchronizer. However, it also has the added capability to give the breaker close command in advance of phase coincidence such that the breaker blades close at minimal phase difference. This close command is given while the synchronizer is slowly rotating, approaching zero phase angle, and the advance angle is calculated to send the close command early to correct for breaker closing time. This capability minimizes system transients.

The breaker blades cannot close instantaneously; therefore, the synchronizer must have a way to compensate for the actual breaker closing time as well as for the time spent in moving the armature of the output relay (0.018 seconds). In order to close the breaker blades at or close to zero degrees, the synchronizer must, therefore, initiate the breaker close signal in advance of the synchronism point. In other words, it must "anticipate" the actual point of synchronism.

The anticipatory type synchronizer calculates the advanced angle that is required to compensate for the breaker closure time by monitoring the slip frequency (frequency difference between the oncoming generator and the bus) and the set in value for breaker closing. It also factors in the constant of the armature movement (0.018 seconds) to complete the calculation. The calculation relationship is:

$$\theta_A = 360\ (T_B + T_R)\ F_S$$

where

θ_A = the advance angle, which is the electrical phase angle of the generator with respect to the system bus when the synchronizer initiates closure of the controlled circuit breaker.
T_B = the circuit breaker closing time. This is the time between the initial application of the electrical stimulus to the closing circuitry and the actual contact of the breaker poles. This is considered to be a constant by the automatic synchronizer.
T_R = the response time of the output relay, which is approximately 0.018 seconds.
F_S = the slip frequency, i.e., the difference between the oncoming generator frequency and the system bus frequency.

Anticipatory Type Synchronizer System Operation

In the synchronizing process, the machine is started and the synchronizer is initiated as the machine comes up to speed. The slip frequency is initially greater than that allowable by the slip frequency control setting. But as the machine accelerates and approaches the system frequency, an automatic synchronizing system with speed and voltage matching capabilities will make the adjustments required to match the machine's speed to the system frequency by stimulating the governor controls. The voltage monitoring portion of the automatic synchronizer system will attempt to adjust the voltage regulator to bring the machine's terminal voltage within the tolerances set on to the synchronizer's front panel controls. When the voltage difference between the machine terminals and the system bus is within the limits established on the automatic synchronizer and the slip frequency is within the predetermined limits, corrections made by the synchronizing system will cease. The synchronizer then will calculate the advance angle required to close the breaker blades for a zero degree phase difference based on the programmed breaker closure time and the actual slip frequency existing at that point in time. Note that in order for the synchronizer to function properly, there must be a small slip frequency between the system and the generator in order to make the proper calculation.

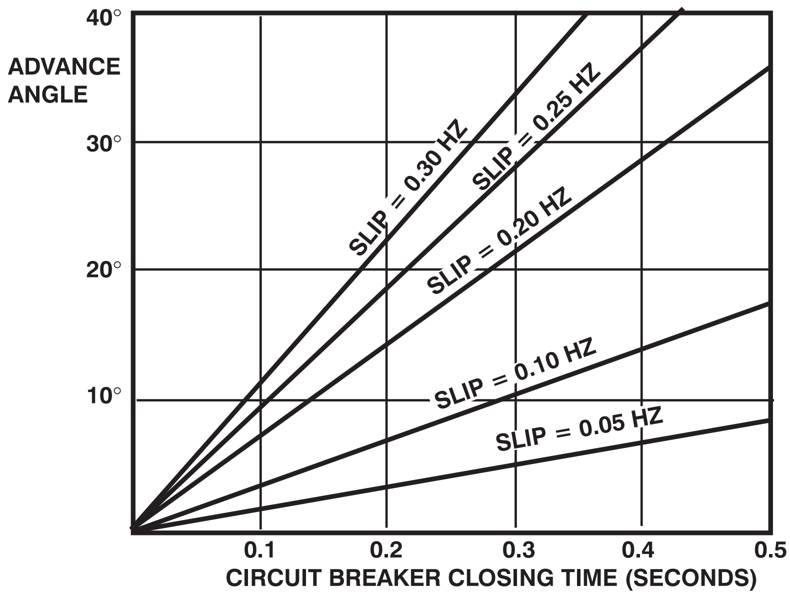

Figure 9: Slip Frequency Advance Angle Characteristic

Figure 9 illustrates the relationship among slip frequency, breaker closure time, and the advance angle required prior to initiation of closure for a zero phase difference across the blades at the instant of contact.

Modern synchronizers have the capability to match precisely or to control both speed and voltage as well as to operate for very slow slip rates.

Units furnished with voltage matching and frequency or speed matching circuits will automatically adjust the voltage and frequency to within limits acceptable to the synchronizer. Both voltage matching and frequency matching corrections are through relay contacts.

SUMMARY

We have looked at the automatic synchronizing process and explored some of the considerations involved. We have also evaluated some applications for automatic synchronizing and have seen that there are many different factors that make up the application. Through this process, we have tried to establish some guidelines for the selection of the proper synchronizing system for the application.

If you have any questions or need additional information, please contact

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