INTRODUCTION TO SYNCHRONIZING

AUTOMATIC SYNCHRONIZING CONSIDERATIONS AND APPLICATIONS

I. INTRODUCTION
- A. Definition
- B. Necessity for Synchronizing

II. TYPES OF SYNCHRONIZING
- A. Manual
- B. Manual with Permissive Relay (Synch check)
- C. Automatic

III. TYPES OF AUTOMATIC SYNCHRONIZERS
- A. Phase Lock Type Automatic Synchronizer
  - a. Frequency/Phase Correction Option
  - b. Voltage Correction Option
  - c. Dead Bus Option
- B. Anticipatory Type Automatic Synchronizer
  - a. Frequency Matching
  - b. Boost Pulsing
  - c. Voltage Matching

IV. SYNCHRONIZING CONSIDERATIONS
- A. Generator Size
  - a. Small Machines
  - b. Large Machines

V. SUMMARY

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.

To better understand the synchronizing process, let's examine a typical facility with on-site power generation shown in the example of Figure 1.

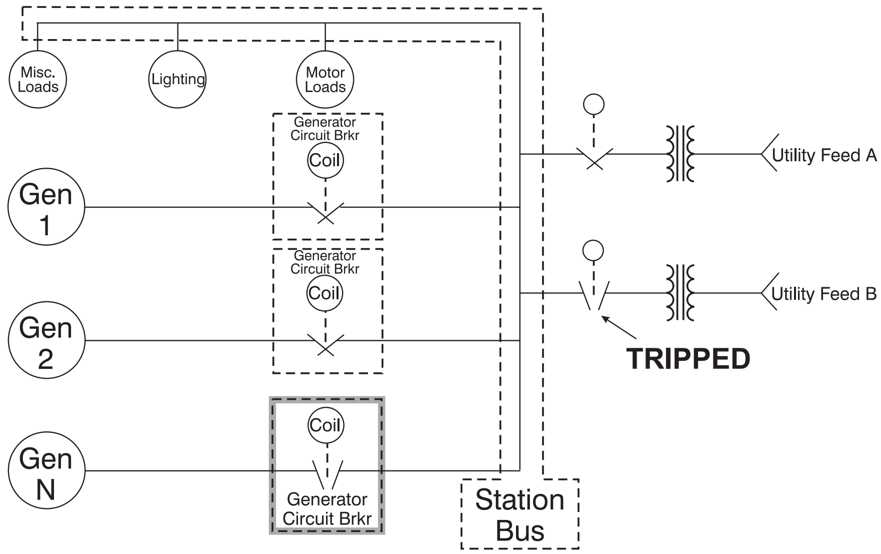


Figure 1: Typical industrial facility with its own on-site generators

Let's assume that this facility has a critical manufacturing process that cannot tolerate a power failure, or the consequence would be an expensive and lengthy clean-up process. Due to an open circuit breaker as a result of a fault on Utility Feed B, the plant manager has decided to start the facility's own generators and supply the majority of its own power demands in the event that Utility Feed A would also trip and would cause their facility to become islanded.

The loads connected to the **Station Bus** (the common power conductors for the facility) are increasing beyond the capacity of Generators #1 and #2 that are already on-line, so it is necessary to parallel another generator to provide the power for the increased load. See Figure 2 for a more detailed electrical diagram of the generator to be synchronized.

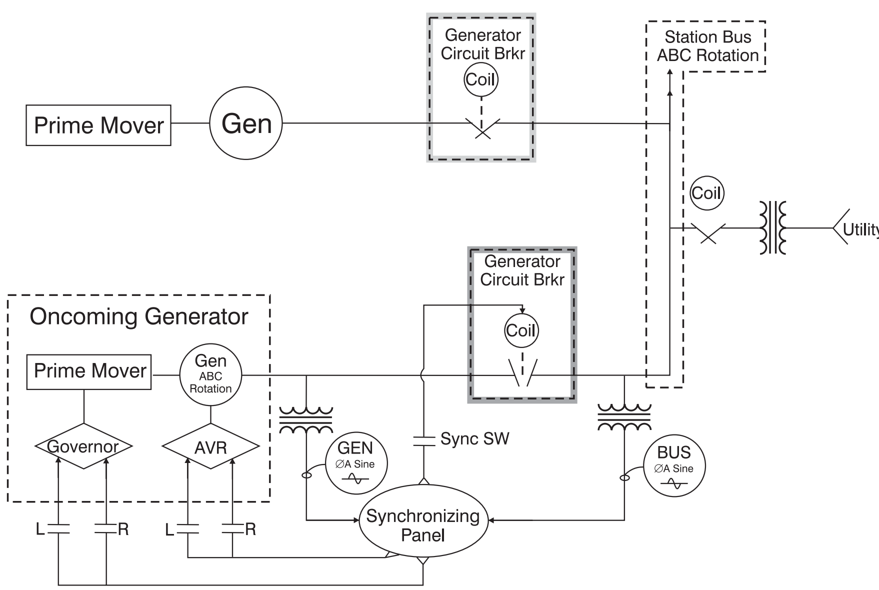


Figure 2: Expanded view of the oncoming generator

The **Oncoming Generator** (the generator to be put on line) needs to have its **Prime Mover** (an internal combustion engine or turbine that turns the generator shaft) started. Once the prime mover is up to rated speed and the generator is producing voltage at nominal frequency, the operator will need to interpret monitoring devices that help make decisions in the synchronizing process.

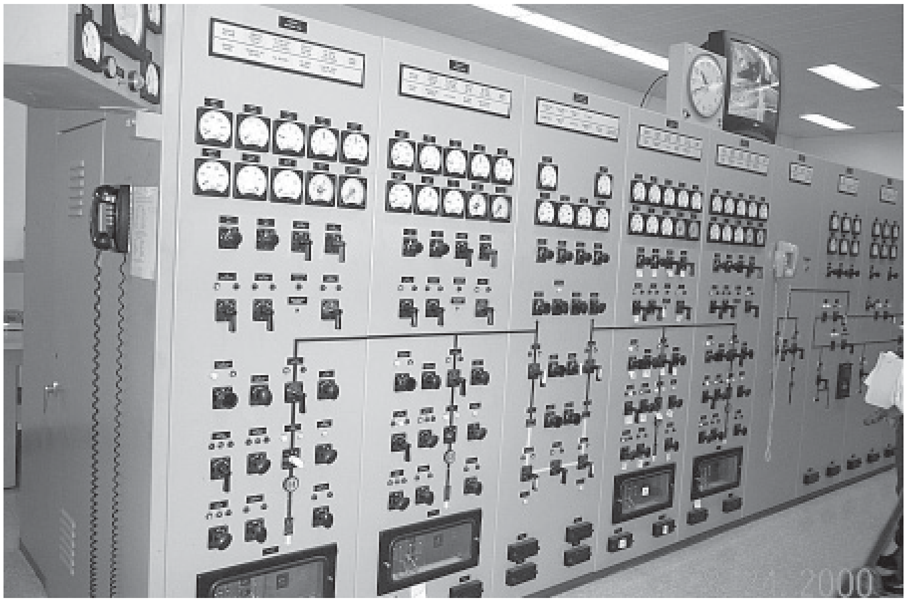


Figure 3: Photo of typical generator control panel

Figure 4: Photo of typical synchronizing meter panel

As seen in Figure 4, 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 5, 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.

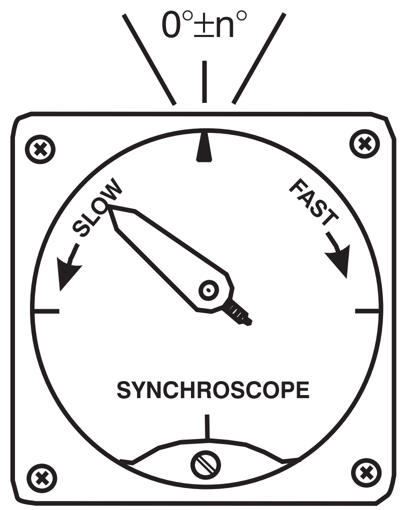


Figure 5: Synchroscope

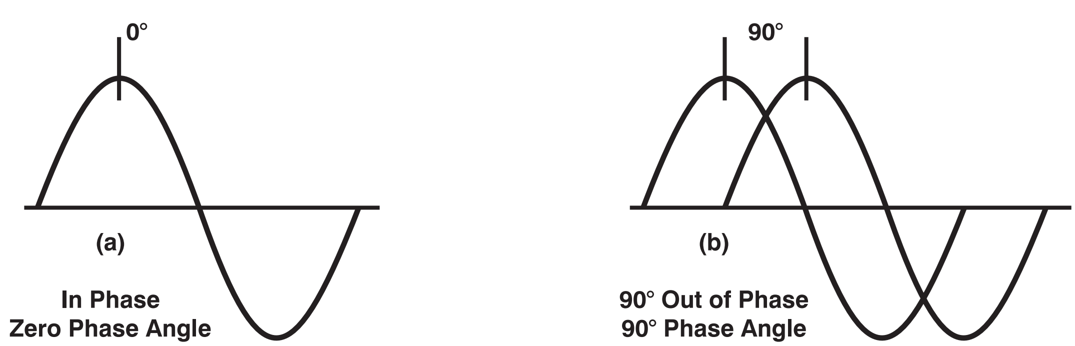


Figure 6: Phase angle displacements

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 7. 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.

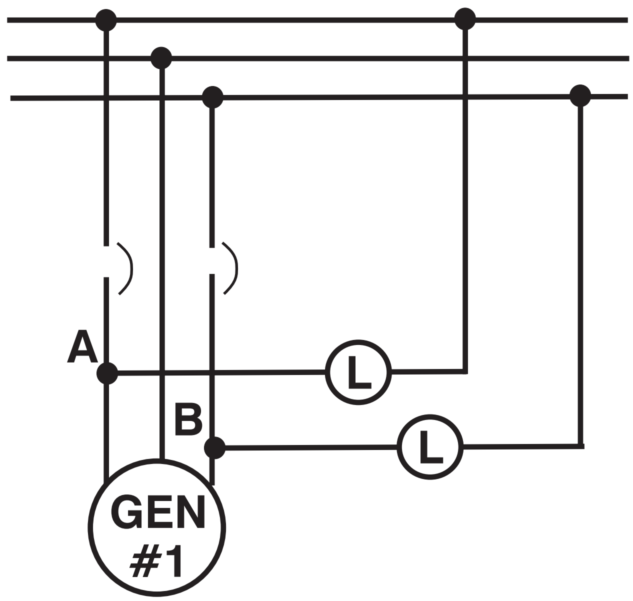


Figure 7: Dark lamp method of synchronizing

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.

TYPES OF SYNCHRONIZING

For the purpose of this presentation, we will consider three methods of synchronizing: 1) Manual, 2) Manual with permissive relay (synch check), and 3) Automatic synchronizing.

Manual Synchronizing

Manual synchronizing is widely used on a variety of machines. The basic manual synchronizing system includes synchronizing lights, a synchroscope, metering, and a breaker control switch.

With manual synchronizing, the operator controls the speed and voltage of the oncoming generator and closes the breaker at the proper time.

The chief advantages of manual synchronizing are system simplicity and low cost. This method may be used with any type of generator where an operator is available to monitor the power plant.

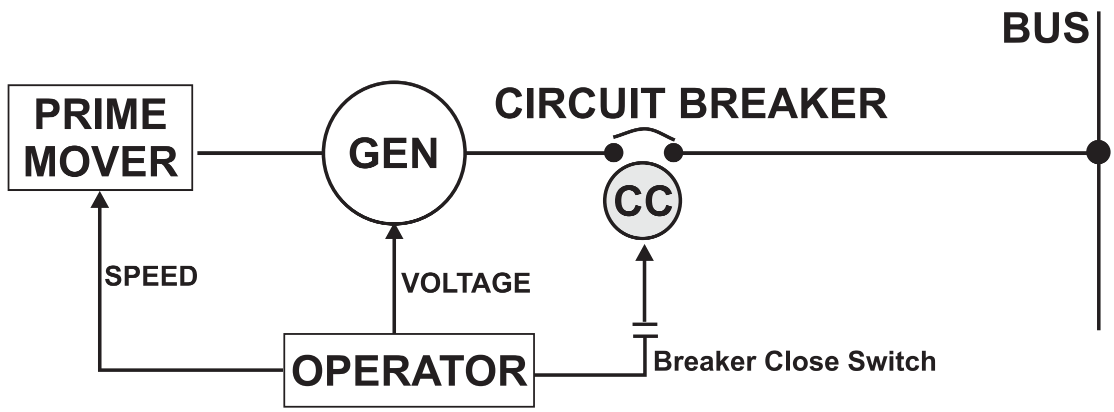


Figure 8: Manual synchronizing

Manual With Permissive Relay
This method of synchronizing is manual synchronizing, with the addition of a sync-check relay (ANSI/IEEE Device 25). The sync-check relay is provided to back up the operator's decision to close the generator breaker. In other words, the sync-check device only allows breaker closure to occur when the phase angle, frequency, and voltage are within predetermined limits. The operator can close the breaker with added confidence from knowing the synch check relay is double-checking the breaker closure.

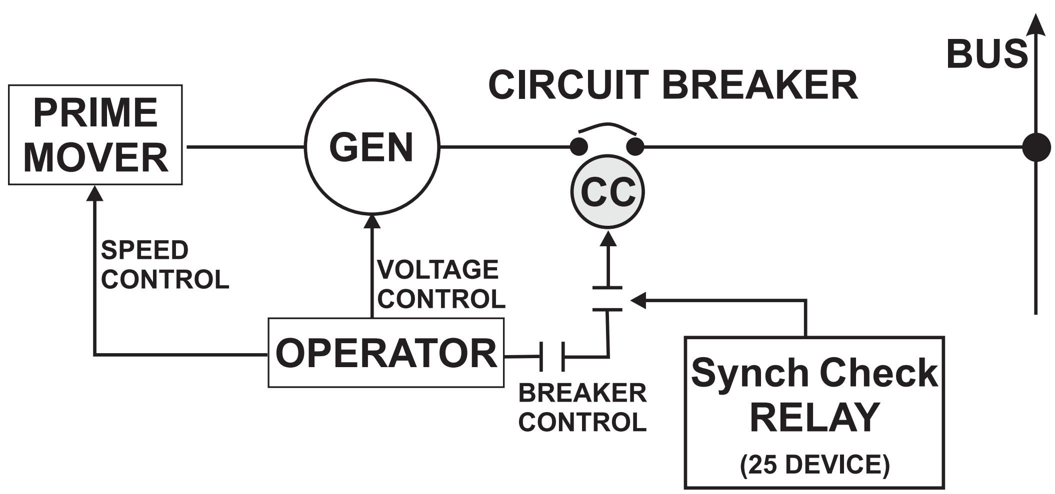


Figure 9: Manual synchronizing with synch check relay

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.

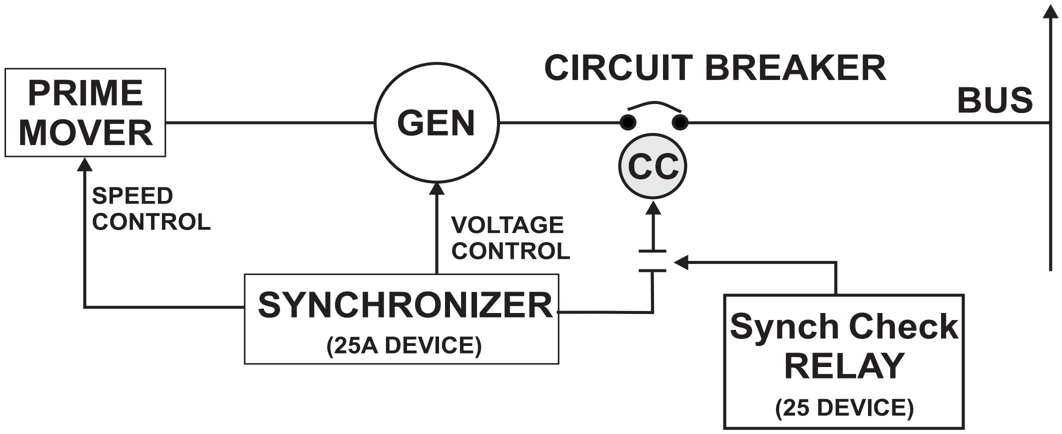


Figure 10: Automatic Synchronizing

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. Figure 11a-e shows a block diagram for a phase lock type synchronizer.

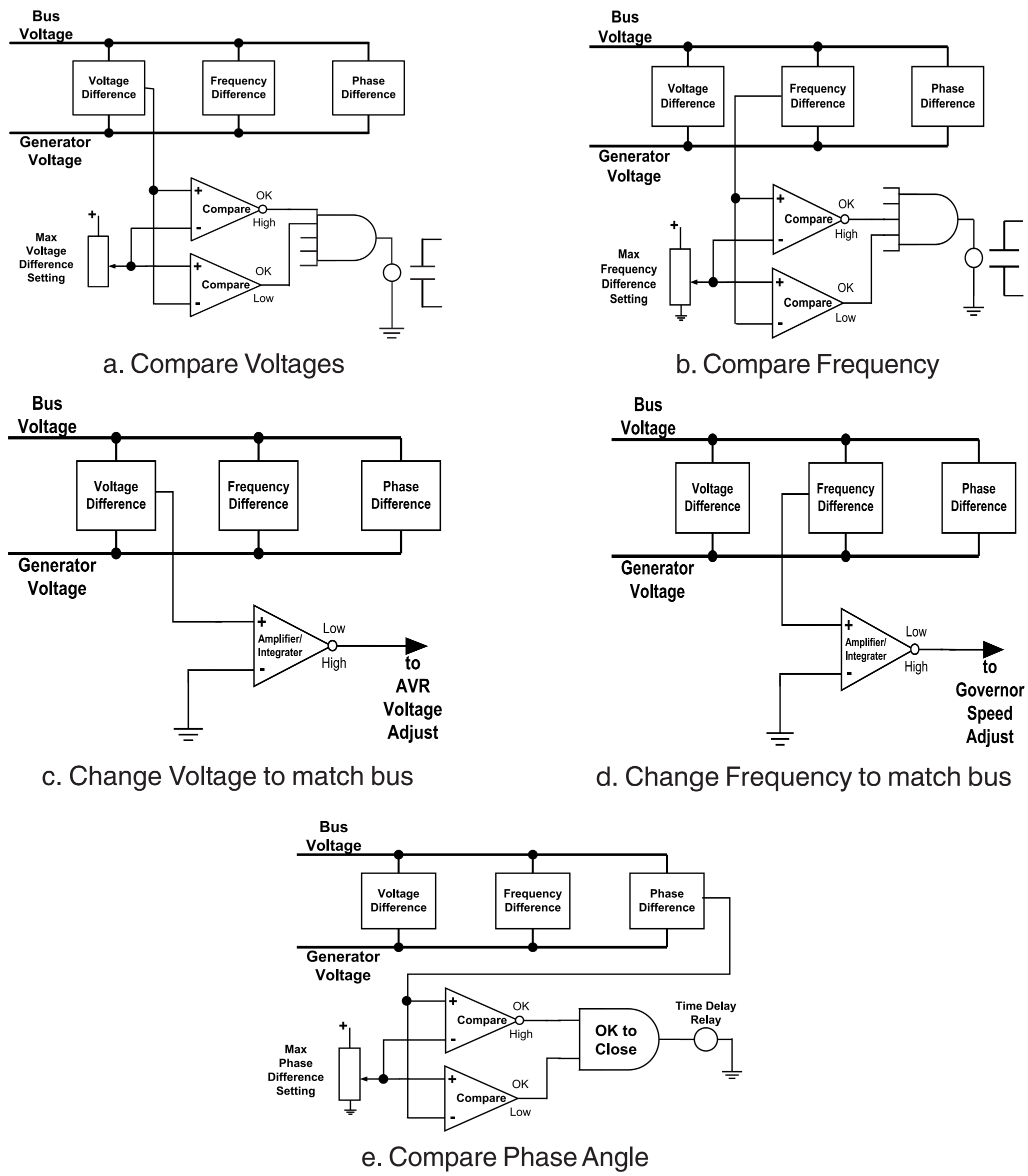


Figure 11: Phase-Lock Synchronizer Block Diagram

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.

Frequency/Phase Correction Option (See Figure 12)
When the synchronizer output is a summing point type, bipolar d-c correction output signals to the governor are at maximum until the generator frequency is corrected to within ±3 Hz of the station bus frequency. Once the ±3 Hz difference is reached, the output signal becomes proportional to the difference frequency. In other words, the output correction signal for a 3 Hz difference is larger than the output signal for a 1 Hz difference.

When the synchronizer has contact output correction signals, the output contact is closed for any phase angle greater than the front panel setting. The contact will openwhen the hase angle is less than the front panel setting.

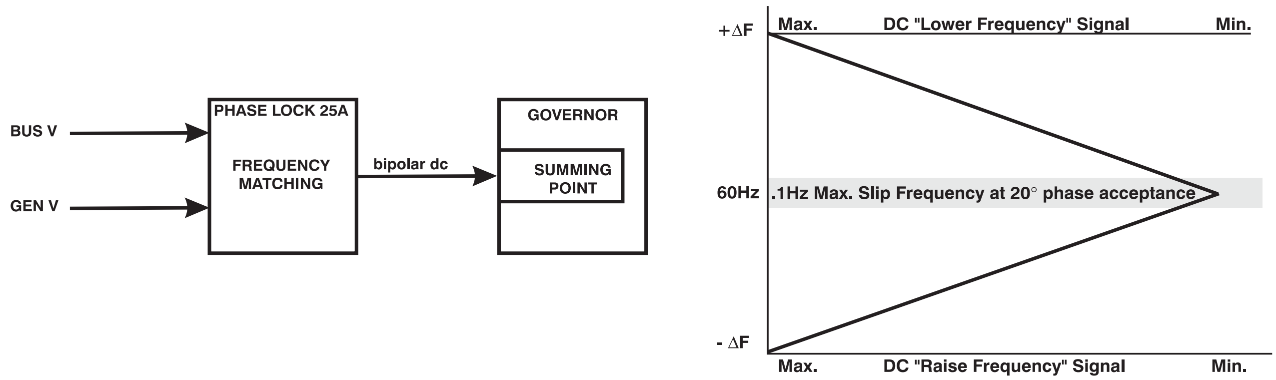


Figure 12: Frequency/phase matching with bipolar output

Voltage Correction Option

Operation of the voltage matching option is similar to that of frequency/phase angle matching, except that the correction signal controls the regulation set point of the voltage regulator. When the synchronizer has the summing point output, the synchronizer outputs a bipolar corrective signal that is proportional to the voltage difference between the generator and the bus. If the reset jumper is installed, the synchronizer stops sending correction signals when the generator voltage is within the front panel setting. If external reset contacts are utilized (i.e., auxiliary contact from the breaker), the corrective signals continue until the external reset contact closes.

When the synchronizer has contact output voltage matching, the contact remains closed until the voltage difference between the generator and the bus is within the preset limit. When the voltage difference is within the setting, the contact opens.

Dead Bus Option

The synchronizer may also have the dead bus option included. This option allows the generator to be connected to the bus even though the bus may be dead or extremely low (i.e., 10 to 50 Vac) by permitting the breaker to close. This feature is very useful for emergency standby systems that require the first generator up to close onto the de-energized 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.

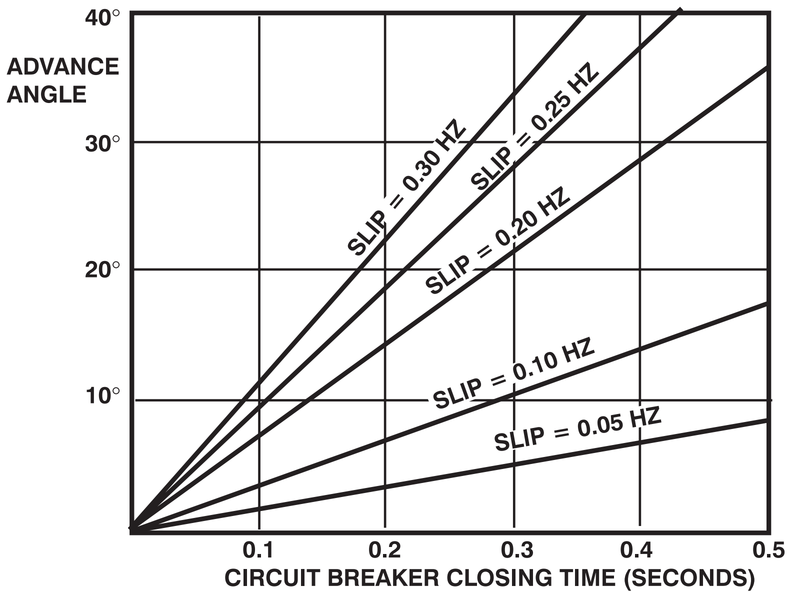


Figure 13: Slip Frequency Advance Angle Characteristic

Figure 13 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.

Frequency Matching

The frequency of the machine relative to the bus is important, because if the machine frequency is significantly less than the bus, the system must supply the power necessary to accelerate the machine to synchronous speed. This power flow may result in tripping by the reverse power relay or damage to the machine itself. On the other hand, if the machine is rotating faster than the system, the machine attempts to supply the power required to accelerate the system. If the frequency difference (F_S) is too great, the transient power flow is reflected into the prime mover shaft, and this may result in excessive shaft or coupling stress.

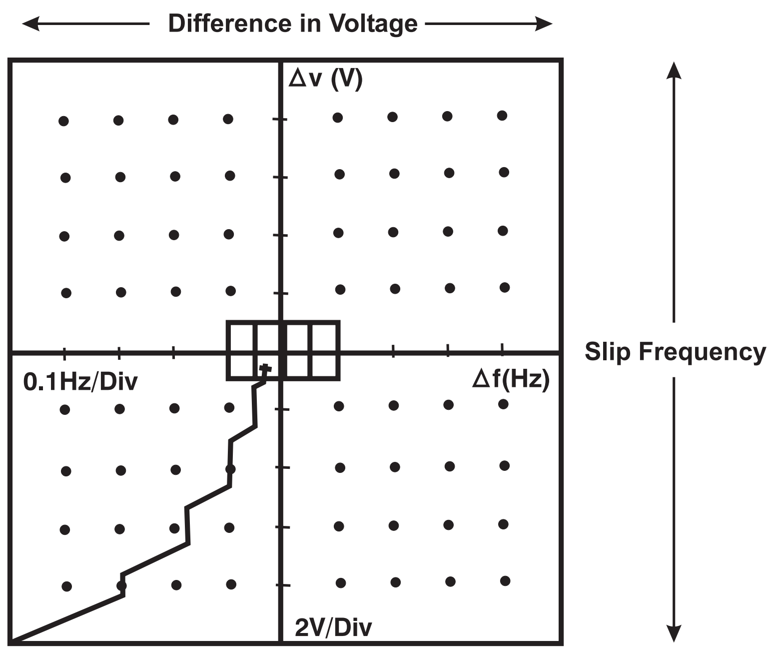


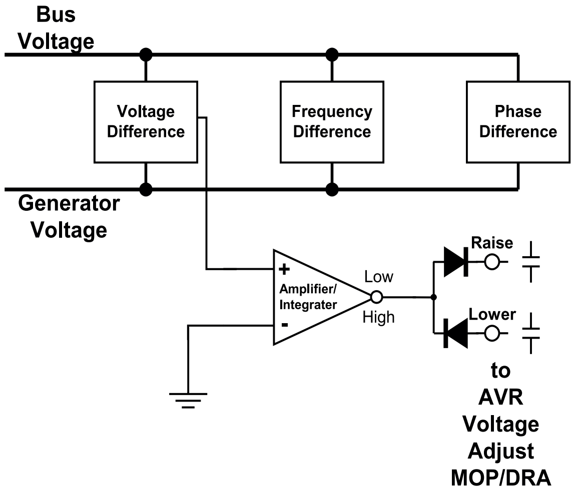
Figure 14: Proportional frequency matching

A significant advancement has been made regarding the problem of hypersensitive governor control on generators by utilizing proportional speed matching correction pulses. Several factors inherent to hydro generators such as length of penstock and machine inertia can cause a synchronizer with fixed correction pulses to repeatedly overshoot targeted slip frequencies.

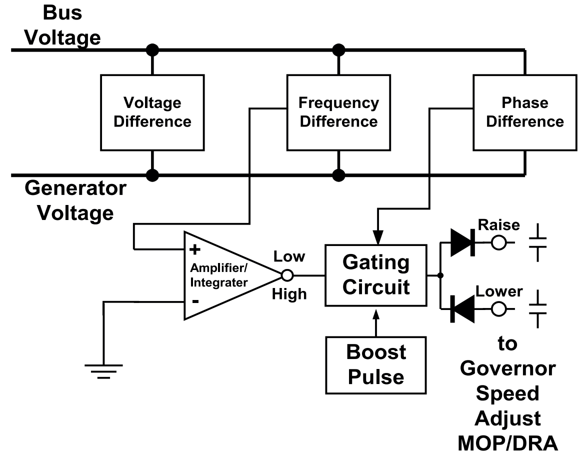
A proportional speed matching function, such as the F5 option in the BE1-25A, will allow maximum correction pulse width trains at large slip frequencies. Correction pulse width is then proportionally decreased when slip frequencies become smaller. It eliminates overshoots and hunting by responding instantaneously to changes in slip frequency.

In the event that the generator speed is very closely matched but the phase angle between the generator and bus voltages is excessive, a bump pulse can gently increase the generator speed and reduce the phase angle.

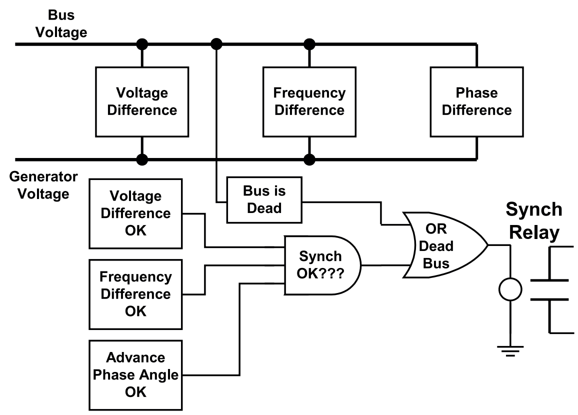
Boost Pulsing (Refer to Figure 15c)
Modern day synchronizers apply a boost to the governor control circuitry to increase the machine speed if the slip frequency falls below the minimum slip frequency capability of the synchronizer. This will increase the machine speed and slip frequency slightly, enabling synchronization of the machine.



a. Change Voltage to match bus



b. Change Frequency to match bus



c. Final Check Close Breaker

Figure 15: Anticipatory Autosynchronizer Block Diagram

The boost pulse circuitry is a part of the speed matching capability of the synchronizer. The speed matching feature should be capable of locking onto the generator voltage signal when the generator frequency is within ±10 percent of the system frequency, at which time it begins the appropriate corrections.

Voltage Matching

Another consideration in the synchronizing process is the terminal voltage of the machine. If it is not matched to the bus voltage, reactive power will flow either into or out of the system at the instant of breaker closure. If the machine voltage is less than the bus voltage, reactive power will be drawn by the machine from the system and excite the generator to the voltage level of the system. Similarly, if the machine voltage is higher than the bus voltage, reactive power will flow from the machine into the system. If this voltage difference is too great, the reactive power flow may result in high transient stresses that could damage the windings of the machine. Various voltage matching options, such as continuous contact closure, fixed pulse and proportional pulse contact closure, are available.

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 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.

The addition of a supervisory relay 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 16.

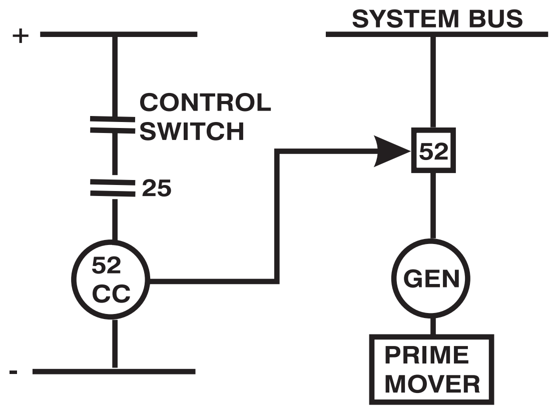


Figure 16: Breaker Closure with Supervisory Control

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 17.

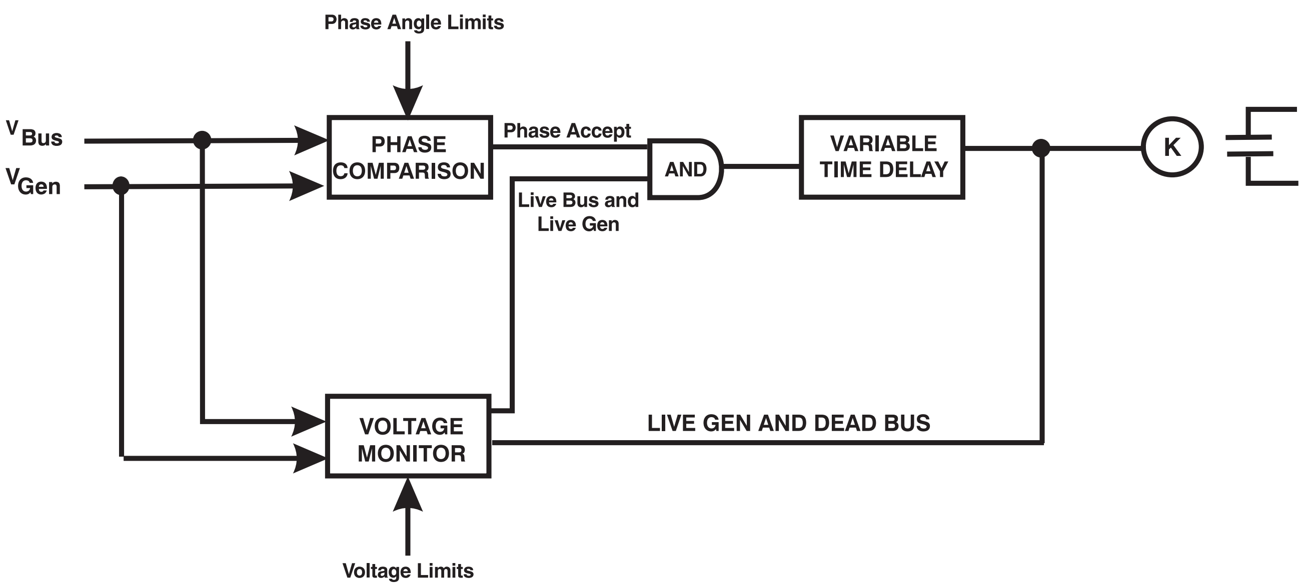


Figure 17: Synch-Check Block Diagram

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.

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 earlier. 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.

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.

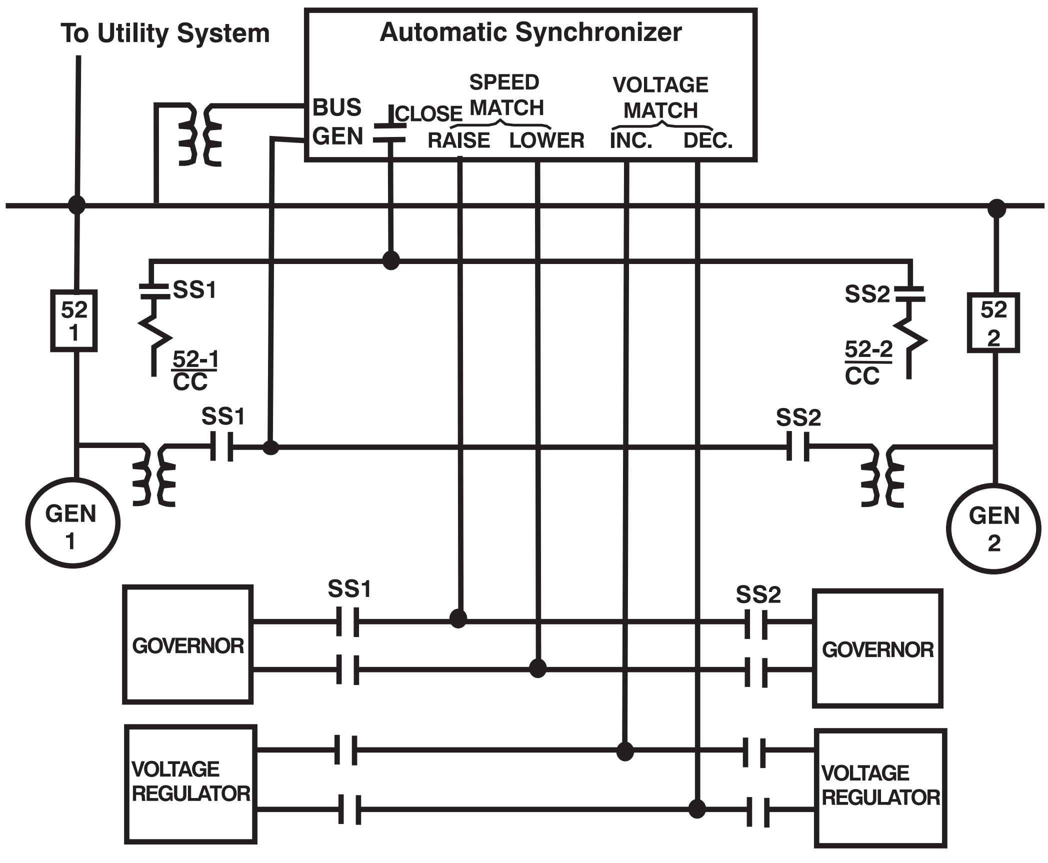


Figure 18: Typical Autosynchronizer Interconnect

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 18).

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.

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 **Basler Electric Company**.
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