

Generator Sets — Parallel Operation

This technical data sheet is divided into two parts:

I. Preparing Generator Sets for Parallel Operation

This section describes those tests and adjustments required when two or more generator sets are prepared initially to operate in parallel as one system.

II. Procedure for Paralleling Generator Sets

This section describes the actual paralleling operation required each time a set is paralleled with another.

I. Preparing Generator Sets for Parallel Operation

Two or more AC generators will operate satisfactorily in parallel provided these fundamental conditions are satisfied.

- A. Phase sequence must be the same.
- B. Frequencies must be the same.
- C. Voltages must be the same.
- D. Engine governors must have speed droop (one can be isochronous).
Exception: Electronic load sharing governors.
- E. Generators must have voltage droop (or cross-current compensation).
- A. The condition of the units being correctly *phased* or operating with *voltages in phase*, means that the individual sine waves appear in sequence. Voltages must be capable of being superimposed, so instantaneous voltage differences do not exist in the same phase of units being paralleled.

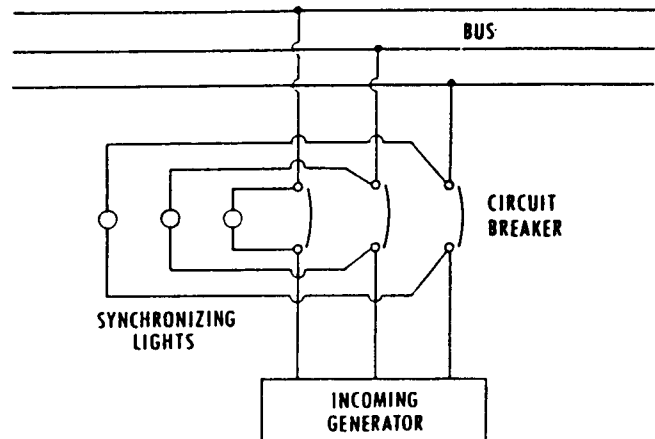


Figure 1

A three-phase generator must be phased to a system at initial installation. Three synchronizing lamps connected as shown in Figure 1 is the suggested method. If a two-lamp synchronizing system is installed on the control panel, a three-light system should be temporarily installed. With a three-lamp system, phase sequence relative to the on-line machine can be positively observed, as shown in Figure 2. If phase sequence is correct on the incoming generator, the lamps will become light and dark together. If phase sequence is not correct, the lamps will never be all light or be all dark at the same time. To change phase sequence or rotation in a three-phase system (to correct phase rotation), interchange any two line leads from the incoming machine. Once correct phase sequence or rotation is established, it is permanent unless leads to the bus bar are disconnected.

Note: At initial installation, the droop transformers (part of the exciter control system) must be in the same line leads to the bus bars. SR 4 Generators have the droop transformer in the T2 line lead. Hence, all T2 leads should be connected to the same bus bar (through the circuit breakers).

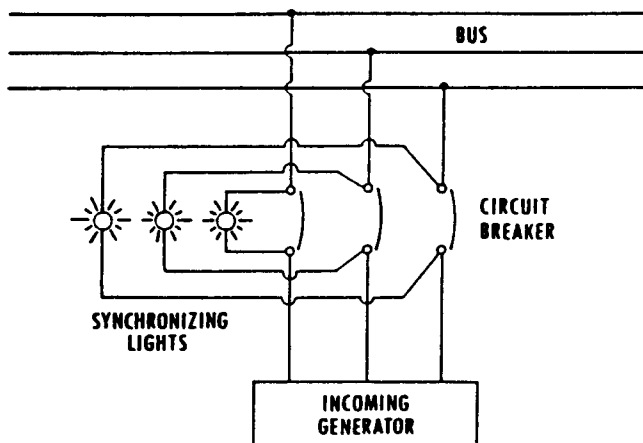


Figure 2A

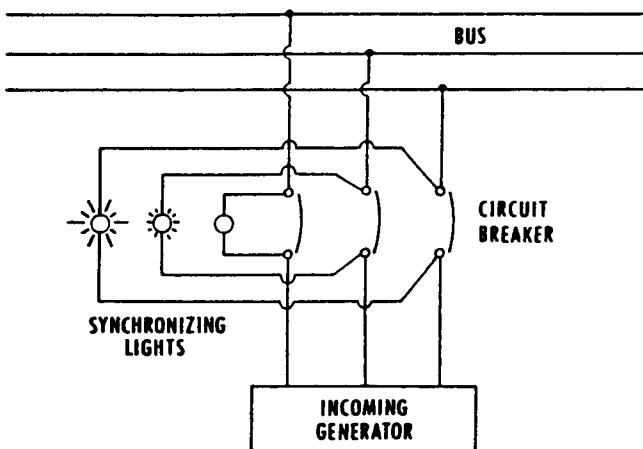


Figure 2B

Correct and Incorrect Phase Sequence Using Three Lamps for Comparison With On-Line Power System

B. To meet the second and fourth conditions, the engine governors must be adjusted to give similar frequency under conditions of proportionate load sharing. If one set is trying to operate at a lower frequency than the others, the active or kW load will not be proportionately shared and motoring current will flow to the lower frequency machine to make it run at synchronous speed.

It is impossible to have stable parallel operation if two or more units are set for isochronous (zero speed droop) operation, except with an electric load proportioning governor such as the Woodward 2301A system. For best results in almost all other cases, all units should have 3% speed droop from no load to full load. (1.8 cycles at 60 Hz, 1.5 cycles at 50 Hz.)

Active load (kW) sharing is regulated by the engine governors, not the generators. If all units to be paralleled are built by Caterpillar and the engines are equipped with 3% speed regulation governors, set no load speeds at 1236 rpm (61.8 Hz) for 6-pole generators or 1854 rpm (61.8 Hz) for 4-pole machines on 60 Hz systems. On 50 Hz systems, set no load speeds at 1030 rpm (51.5 Hz) for 6-pole generators or 1545 rpm (51.5 Hz) for 4-pole generators.

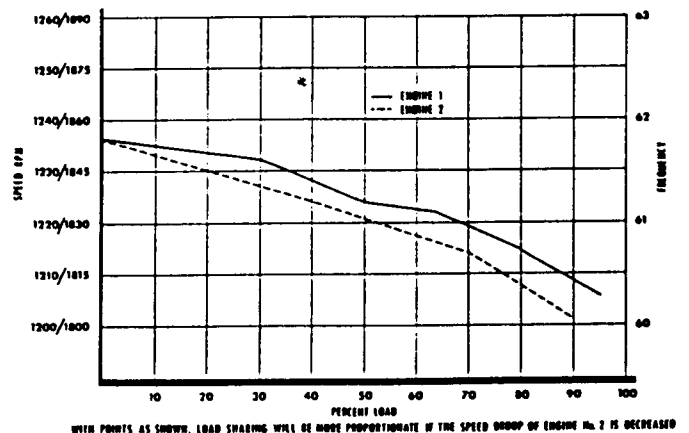


Figure 3

For parallel operations where some of the machines are non-Caterpillar and/or some of the machines are equipped with hydraulic governors, the speed droop characteristics of each machine should be checked. See Figure 3 for speed droop characteristics. The procedure for checking can best be illustrated by the following example:

Conditions: 60 Hz System

Set No. 1 Competitive engine, generator — 1800 rpm, governor characteristics unknown

Set No. 2 Cat Generator Set — 1200 rpm, Woodward UG8 Governor

Step One — Operate both machines for approximately one hour to obtain stable heat conditions. Note: A convenient method of bringing generators up to normal operating temperatures is to parallel them and purposely allow circulating currents to flow between generators, making sure not to exceed about one-half of the generators' full load current ratings.) Set no load speed on engine No. 1 at 1854 rpm, using its speed adjustment or synchronizing control. If possible, add loads of approximately 25%, 50%, and 80-100%. Check and record frequency or speed at each load. Plot these points on Figure 3. Do not be too concerned with differences in plotted points or variations from these points at light loads. If it is possible to get only one load point, attempt to obtain it as near full load as possible. Most engine-governor characteristics are not entirely linear. Many governors achieve most of their speed droop at nearly full load.

Step Two — Turn the speed droop on engine No. 2 to zero and set the no-load speed to 1200 rpm, using the speed adjustment or synchronizing control. Then turn the droop control until the no-load speed rises to 1236 rpm. Load the set and plot the points as in Step One. If the points taken are *below* the points from Step No. 1, the speed droop is too large and possibly can be readjusted until the points match Set No. 1. The closeness of the plots indicates the closeness of the load sharing. Governor instability may occur as the droop is reduced. If this happens, operate the machine at a droop setting that keeps the governors stable.

Note: When taking frequency or speed points, use an accurate frequency meter or tachometer and take several readings on each point.

- C. If the voltage load characteristics (voltage droop) of the units are not the same, proportionate reactive load sharing will not result. Circulating current will flow between the units. Caterpillar Generators use a voltage droop transformer to maintain proportionate

reactive load sharing. Similar voltage droop is achieved by adjusting the voltage droop control on the generator, see EDS 70.0.1 and 71.0. A circulating current of 20-25% of nameplate line ampere rating is not harmful at no load in parallel operation. The circulating current should decrease as load is increased and should be no more than 10% of rated line amperes at full load. When checking for circulating current, be sure that both generator ammeters and the load ammeter are connected in the same phase. Voltage droop should be set in individual generators, depending on the load power factor involved. If the load is pure resistance or incandescent lighting load (1.0 pf), a 2% voltage droop from no load to full load should be satisfactory. If the load is reactive (primarily motors of 0.8 pf), a 5% voltage droop should be used, see Figure 4.

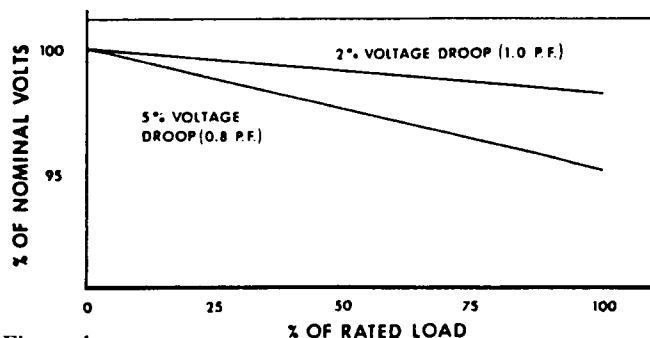


Figure 4

The selected system voltage should be compatible with each generator set to be used. Assume the competitive generator (above) has a nameplate voltage of 480 volts and the Caterpillar SR4 Generator 460 volts. A system voltage will have to be selected within the voltage adjustment range of each generator. In this example, 470 volts will be selected as the system voltage.

The sets to be paralleled should be operated for at least one hour to ensure stable operating temperatures while adjustments are made. If the generator sets to be paralleled are all Caterpillar units, proceed as follows:

Use the same voltmeter for all voltage measurements.

1. Turn generator voltage droop control to zero droop position.
2. Run the engine at full governed speed (approximately 3% above rated load speed).
3. Turn generator voltage level control until the no load voltage is equal to the selected system voltage.
4. Apply nameplate rated load and adjust the engine governor to rated speed. Use an accurate speed indicator or frequency meter.
5. Adjust generator regulator gain control until the full load voltage is equal to the selected system voltage.
6. Leave the regulator gain control in this position.
7. Again operate the engine at full governed speed at no load. Repeat Steps 3, 4, 5, and 6 until the loaded voltage equals the no load voltage.
8. Readjust voltage level control until the line voltage is approximately 2%-5% above the selected voltage.
9. Adjust voltage droop control clockwise, approximately one fourth of full range.
10. Apply nameplate rated load and adjust the governor to rated speed. (Same conditions as Step 3.)
11. Turn voltage droop control until voltage is equal to selected system voltage at rated load.
12. Repeat the last three steps until the generator voltage is equal to system voltage at rated load and rated speed is approximately 2%-5% above system voltage at no load and no load speed.

Follow the above procedure for each SR 4 Generator to be paralleled. The units will then be properly adjusted for parallel operation. This procedure is also outlined inside the right-hand corner of the regulator housing on Caterpillar Generators.

For generators other than SR4 and for paralleling SR4 Generators with other types and makes of generators, it is advisable to first determine the voltage speed characteristics (voltage droop) of each unit in the system. After the machines are thoroughly warmed, the voltage level adjustment of each should be set so the no load voltage is 2%-5% above system voltage.

Apply and remove individual machine load, recording load (current or kilowatts) and voltage. Make voltage droop adjustments to approximately duplicate one of the curves in Figure 4. Without further adjustment, parallel the machines at high idle (no load) using the procedure outlined in the section of this data sheet.

Record the value of any no load circulating current.

Apply available load, observe, and record the line current for each machine.

If operation is satisfactory, leave voltage controls locked in position determined. If operation is unsatisfactory, adjust voltage level and voltage droop. At the same time, make sure frequency limits and operating temperatures are uniform and constant.

The procedures described for determining phase sequence, setting engine speed droop, and generator voltage droop must be repeated when a new or different unit is added to the system. Once these initial adjustments are made and the controls are locked in position, it should not be necessary to go through this procedure again.

II. Procedure for Manually Paralleling Generator Sets

To parallel a generator set with one or more generator sets already on the line, the first three conditions outlined in Section I (see Page 1) must first be met. If there is a difference between the frequencies or voltages of the generators being paralleled, there will be an undesirable line voltage disturbance when the incoming generator circuit breaker is closed. Extensive damage may result if generators are paralleled while the voltages are out of phase. Always use synchronizing lamps or a synchroscope and

exercise care in the paralleling operation.

By use of synchronizing lamps, as shown in Figure 5, an idle unit can be put in service with no disturbance. The *dark lamp* method is most commonly used as the indicator of when to close the incoming circuit breaker. This method lights the synchronizing lamps when there is a potential between the phases of the incoming and the on-line generators. This means that when all the lamps are dark, the generators are synchronized. To synchronize an idle unit with an on-line generator, proceed as follows:

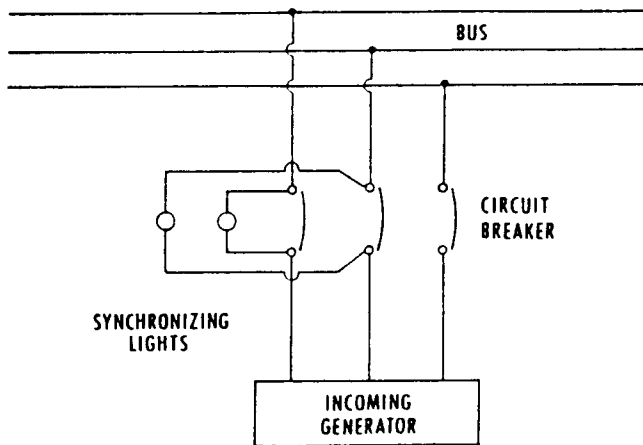


Figure 5

The on-line circuit breaker should be closed and the incoming circuit breaker should be open.

With the incoming unit governor control lever in the full governed speed position, turn on the synchronizing lamps switch and observe the lamps for the frequency at which they flash. By means of the governor control, vary the incoming engine speed until the synchronizing lamps come on and fade out about six to ten times a minute. Always have the incoming generator initially slightly higher in frequency. Doing this will assure that the incoming engine will absorb a small amount of load instead of consuming power when initially connected to the bus.

To put the generator set on the line *in sync* (at the proper time) wait until the lamps are dark, then very quickly, while the lamps are still dark, close the circuit breaker. The incoming generator is now in parallel with the bus and on-line generator.

After the circuit breaker is closed, one of the following two conditions will exist:

1. *First condition* — the unit on the bus was at no load. In this condition both units in the parallel system are at idle and ready to receive the load.
2. *Second condition* — the unit on the bus was carrying load. The engine governor of this unit was operating some place below high idle. The generator voltage regulator was operating some place below open circuit voltage. Load division between generator sets will remain as described until:
 - a. The governor control of the incoming generator set is advanced. Part of the total load will then be transferred from the set which was on the line to the oncoming set. Frequency will rise.
 - b. The governor control of the on-line generator set is reduced. Load will be transferred to the oncoming generator set. Operating frequency will go down. After paralleling, the governor control on the incoming unit should be advanced to the full governed speed position. This causes the incoming unit to pick up its proportional share of the kilowatt loading. If kilowatt meters are installed, the readings should be approximately proportional to the ratings of the units paralleled. If desired, various loads can be placed on either generator set by adjustment of the governor control. At the same time, also with governor control speed setting, operating frequency can be set as desired.

Another panel instrument is the synchroscope, as shown in Figure 6. It is used instead of the synchronizing lights for synchronizing two or more generator sets. The direction the pointer rotates indicates whether the frequency of the incoming generator is slower or faster than the frequency of the on-line generator. Similarly, the frequency at which the pointer rotates indicates the magnitude of difference in speed between the generator sets. For paralleling, engine speed is changed until the synchroscope pointer rotates very slowly (less than 10 rpm), again keeping the incoming generator set faster than the on-line

generator set. When the pointer is at 0 position, the circuit breaker can be closed (the units are synchronized).



Figure 6

To remove a generator set from the line, follow these steps.

Before removing a generator from the line, be sure that the on-line is equal to or less than the rated capacity of the units remaining on the line.

Slowly reduce the speed setting of the outgoing generator to remove load from the generator.

Open circuit breaker.

A short cooldown period of running at idle, with no load, is suggested before engine shutdown.

Also refer to related articles:

- Engine Data Sheet 75.2, Transfer Paralleling
- Engine Data Sheet 75.1, Circulating Currents
- Form FE36060-1: Principles of Electric Set Governors, Parallel Operation, Alternators and Regulators