



INDUSTRIAL DIVISION ENGINE DATA SHEET

FORM	75.1
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SUBJECT: Currents - Circulating in Paralled Generators
 BUSINESS: Building Services, Marine, Material Handling
 PRODUCT/APPLICATION: Generator Sets

When two or more generator sets are operated in parallel, a current may circulate between the generators. This current will exist when the internal voltage generated by each generator is slightly different, but the terminal or bus voltage is the same. In the most elementary form, current will flow out the line leads of one generator, through the paralleling bus and into the second generator. It does not flow into the load. This current, called "circulating current," is in addition to the normal line current supplied to the connected load. When more than two generators are in parallel, current could flow out of any generator and into one or more of the other generators. Circulating currents can take many paths into and out of the several generators.

We are concerned with these "wattless amperes" only when they interfere with normal generator set operation or when the normal on-line kVA capacity of the generators must be reduced because of excessive line currents. With no-load (zero kilowatts) on a generator in a parallel system, Caterpillar generators can readily tolerate a circulating current equal to 20%-25% of the line ampere rating shown on the generator name plate. At load conditions (100% kW load), Caterpillar generators will tolerate a circulating current of up to 10% of the rated line amperes.

Since circulating currents pass through the generator coils, these currents heat the coils the same as does the load current. Further, since circulating currents are superimposed on the load current passing through the circuit breaker, circulating currents can cause a breaker to trip as the breaker could "see" an actual ampere overload. More complex control systems include "reverse current" relays which sense counter flow currents. Currents in excess of the relay setting will actuate the circuit breaker trip mechanism.

Observed line current (as indicated by panel ammeters) in a parallel generator set system is a summation of two or three currents:

1. Load current -- that current which is supplied to the load. It may be in phase with the voltage (unity power factor) or somewhat out of phase with the voltage (power factor less than unity).
2. Harmonic current -- usually third harmonic current which flows through the entire system when "Y" connected paralleled generators have their neutral leads connected, either directly or through an earth or ground connection.
3. Circulating current -- that current which flows between generators for reasons explained below.

Each of the above currents contribute heat to the generator coils, the amount being equal to the square of the sum total current times the resistance of the coils. Thus, if the current doubles, the heat loss increases by a factor of four. Coil heating reflects in possible overheating and lowered efficiency. In very large generators, this is an important consideration. Significance of efficiency decreases with smaller generators. However, coil heat is always a factor, as it must be removed by ventilation or radiation to keep coil temperatures to an acceptable maximum.

The load alone determines the load current. Reactors or switches can be placed in neutral leads to reduce or eliminate third harmonic currents. Proper generator voltage adjustment can bring operating circulating currents to a minimum.

Circulating currents perform an important function: they account for misadjustment of the generator voltage control system as well as slight variations in the control systems.

The kilowatt (or horsepower) load on parallel alternators is entirely a function of the driving source. Thus, to increase the load demand on one generator set in a parallel system, the governor speed setting of that generator set must be increased.

Changing the voltage setting on one generator does not change the kilowatt load division between generators. This fact is often confusing, as observation of line ammeters after a voltage level adjustment will indicate a current increase, leading to the belief that one generator has picked up "load." It has not. Instead, currents circulating between generators have changed. The panel ammeters indicate this change.

Paralleled alternators must operate at the same terminal voltage since they are physically connected through the paralleling bus. If internally generated voltages are not exactly equal, one alternator will automatically supply an exciting or magnetizing current to the other alternator to raise its internally generated voltage. At the same time, the second alternator will supply a current to the first, which will lower the generated voltage of this unit. The net result of circulating or "cross" current is equal generated voltages.

This action is inherent and automatic. The amount of circulating current flow is entirely a function of the internal voltage generated by each of the several alternators in the parallel system.

The amount and type of connected load also affects internally generated voltage. Induction motors, for example, will tend to lower the generated voltage because the motors require magnetizing current in addition to power producing current. The generator which is trying to produce the higher generated voltage will supply a proportionately greater share of the magnetizing current not only to the motors but to other generators on the bus.

When generators are run in parallel, a current sensing system must be added to each voltage regulator. The current sensing system samples the generator line current not only in quantity but also in its phase (angular) relation to the voltage. The current sensing or droop system produces a voltage that adds to, or subtracts from, the voltage sensed by the voltage regulating system. (This accounts for the name often used: Voltage Droop System.) The resultant regulating voltage level (plus or minus droop voltage) causes the regulator to adjust the alternator exciting current

downward for lowered generated voltage, or upward for increased generated voltage. Within limits, the complete regulator keeps individual generated voltages nearly equal and amperes balanced.

In any alternator power system -- single or multiple -- the system voltage level is established by the level of generator excitation. When the system is supplying a purely resistive load (unity power factor), generator excitation is normally expected to come from the individual generator exciters (static or rotary). If one generator exciter in a parallel system is somewhat deficient, the additional excitation will be supplied by circulating currents from other generators on the bus.

When the system is supplying induction motors, a higher exciting or magnetizing current is needed to provide the magnetic forces in the motors. This motor excitation subtracts from the total generator excitation, driving the generated voltage downward. All of the voltage regulators in the system sense this decrease and individually raise the excitation level and the generated voltage of their respective generators.

If the voltage regulator action and resultant generator performance are precisely uniform, each generator would supply its exact proportion of additional magnetizing current. In practice this does not occur. Very small differences result in relatively large differences of current supplied. The voltage droop system senses these currents (in amount and in phase or power factor) and causes the voltage regulator to react in the correct direction, raising or lowering the individual excitation level. The result is controlled division of total line current.

Droop systems will function correctly only if the current sensing transformers of the several generators are all in the same phase or line lead. (T-2 in Caterpillar SRCR Generators, T-8 in SR 4 Generators.)

Droop systems are proportionate. This means that droop system reaction is proportionate to the ampere load on an individual generator set. Example: the total kW load on the system is 150 kW at 0.8 P.F. One generator is supplying 50 kW, and the other 100 kW. The total kVA (187.5) should be proportioned with 62.5 kVA on the 50 kW unit, and 125 kVA on the 100 kW unit. Indicated individual line amperes would also be proportionate, with one third of the total current coming from the 50 kW unit and two thirds of the load current coming from the 100 kW unit.

Operating conditions as just described are not always possible over the entire load range of the generators. Electrical and mechanical variations in generators cause a small difference in ampere or kVA division. Neither is exactly proportionate to kW load division. The difference shows up in the panel ammeter indications: the sum of individual generator line currents exceeds the load current.

Acceptable levels of circulating current result if the published procedures are followed for voltage level, regulator gain, and voltage droop on SRCR and SR 4 generators. These adjustments are always made with the generator at or near operating temperature. When a "cold" unit is paralleled to the bus, circulating currents may be noted. However, these will decrease as the incoming generator reaches its operating temperature. These currents are seldom cause for concern. Where excessive circulating currents do exist, the cause is generally found to be error in the adjustment procedure or in operating procedure.

When different sizes of generators are used, or where different types of voltage regulators are used, the best adjustment results from using the actual plant load. Voltage droop levels should be established from a reference voltage level, and at a reference frequency.

It is generally desirable to have the same voltage droop on all generators. This means that each generator should reduce its voltage an equal amount (3% to 5%) between no-load and expected full load. Where different size generators are involved, it may be impractical to make the full load droop adjustment on the larger generators. A close approximation can be made by considering the droop system as a linear device. Select a plant load equal to at least three-fourths of the smaller generator capacity. Set the required droop on this smaller unit (example 5%). Transfer-parallel this same load to the larger generator and establish the reference frequency. Set the droop proportionate to the capacity. Example: 5% was set on the smaller unit with full load. That load is one-half the larger generator capacity. Set the droop on the larger generator at 2.5%. The resulting adjustment will be quite adequate.

Operating errors can cause very high circulating currents. These generally occur where indicating instruments are limited to voltmeters and ammeters. It is entirely possible to have one generator set absorbing power from the system, and have the ammeters showing "correct" currents. To avoid this, the operator should always have the incoming

generator set running slightly fast, as shown by synchronizing light brilliance at 6 to 10 times per minute prior to closing the circuit breaker. This will assure that the incoming generator supplies power (kW) to the load at the time of breaker closure. Load is then added to the incoming generator set by increasing the setting of its governor control, or decreasing the setting of the on-line generator set governor controls.

Operating refinements to regulator adjustment are easily made on installations equipped with VAR meters, power factor meters, or wattmeters and line ammeters. (If the system includes only ammeters, regulator adjustments must be made with a single unit on the line.) Where power factor or VAR meters show equal indications, each generator is supplying its share of the load current reactive amperes, and circulating current between generators is at a minimum. Example: load power factor is 0.8. Generator No. 1 indicates 0.7 P.F. Generator No. 2 indicates 0.85 P.F. These meter readings tell the operator that Generator No. 1 is supplying too much magnetizing current to the load, and possibly to Generator No. 2. The magnetizing current of Generator No. 1 can be reduced simply by lowering its voltage level. Or, if desired, by raising the voltage level of Generator No. 2, the operating power factors can be equalized. Circulating current is then at a minimum.

Wattmeters and ammeters can provide the information necessary to accomplish operating or on-line voltage level adjustments. Example:

Load kW 500, Load Line Amperes 750,
Voltage 480
Generator No. 1, Load kW 250,
Line Amperes 350
Generator No. 2, Load kW 250,
Line Amperes 450

These meter readings indicate that Generator No. 2 is supplying more than its share of magnetizing current. This is true because Generator No. 1 is operating at a power factor of 0.86 which is higher than the load power factor of 0.80, and generator No. 2 is operating at a power factor of 0.67 which is lower than the load power factor. Decreasing the voltage level setting of Generator No. 2 will reduce its magnetizing current and increase the power factor. At the same time the magnetizing current from Generator No. 1 will increase, and its power factor will decrease.

When loads are not equal, the calculated power factor of each generator can be used

to correctly distribute magnetizing current and keep the circulating currents to a minimum. Example:

Load kW 700, Load Line Amperes 1,100,
Voltage 460
Generator No. 1, Load kW 250,
Line Amperes 500
Generator No. 2, Load kW 450,
Line Amperes 630

It should be obvious that the voltage level setting on Generator No. 2 is too low. Adjustments could be made to one or both until No. 1 shows a line ampere reading of about 390, and the line ampere reading of No. 2 shows about 700 amperes. At these conditions, both generators will be operating at the same load power factor of 0.8. Circulating current is at a minimum. Refinements as described above will assure highly satisfactory operation of paralleled generator sets.

Summary

Circulating currents exist in paralleled generators when the several generators are attempting to operate at different voltages although they are connected together through the common bus. These circulating currents reduce the effective excitation of one or more generators, and increase the effective excitation of others. Generator voltage is directly related to exciter output. Hence, an attempted generator voltage difference is the result of different exciter output. Exciter output is controlled by the voltage regulator, and ultimate control of circulating current is a function of the regulator.

Effect of Circulating Currents On Load Sensing Electronic Governors

The Woodward 2301 load sensing governor can react to excessively large circulating currents. With correct adjustment of generator voltage regulators, the load sensing governor responds to true power or kW load on the generator set. However, when the value of circulating current between generators approaches the value of the actual load current, the governors may react to these excessive circulating currents and change the kW load division between generator sets. Load transfer may be slow, or it may be rapid. There is no predictable pattern since the observed action depends on the condition of the generator voltage regulators controlling the several generators.

Incorrectly adjusted voltage regulators are the most common cause of the "load shift" problem. It is generally found that initial

generator regulator adjustments fail to include adequate voltage droop or cross-current compensation. This difficulty can also cause operating errors.

Some commercially available generator control panels for use with commercially available generators include a switch that bypasses the voltage droop circuit in the voltage regulator. These switches have various names such as "Single-Parallel" or "Droop In - Droop Out." Operators incorrectly position these switches during parallel operation, causing one or more generators to operate without voltage droop or cross-current compensation. Circulating currents can greatly increase under these conditions. Governors will generally react.

Switchboard wiring errors, such as reverse-connected current transformers (used as part of the droop or cross-current system), can also cause load shift problems. In these instances, the voltage droop system causes a rise in generated voltage as the line current increases. Circulating currents can increase rapidly, and possibly cause circuit breakers to open. Governor reaction may be noted just prior to circuit breaker opening.