

Control of Synchronous Generators with Droop and Cross-Current Compensation.

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The excitation of a synchronous generator is usually done by an AVR (Automatic Voltage Regulator) that uses generator voltage and/or current as inputs in order to control its output to a pre-set value.

AVRs include different control modes to optimise performance depending on whether the generator is connected to the grid, or in island mode. Therefore, they can be set to maintain the voltage, the PF or the reactive power.

In this report, we will analyse the principle of operation of the voltage control mode of the AVR, known as droop compensation, when one or more generators operate in island mode or are connected to the grid. Based on droop control limitations, we will study techniques to improve its performance, and compare it with the cross-current compensation method.

1. Voltage control mode – Droop Compensation

In the voltage control or droop mode, the AVR is regulated by a droop characteristic, which is shown in the following drawing.

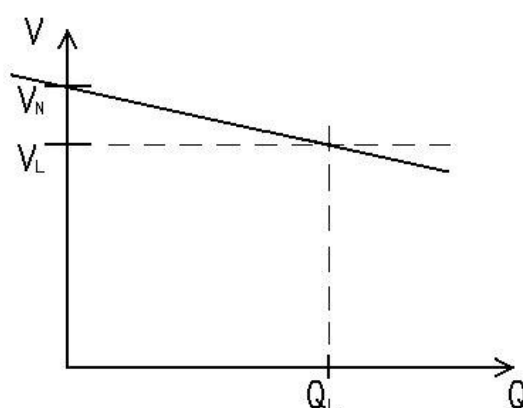


Figure 1. AVR Set-point V vs reactive power Q

The droop characteristic represents a graph of the AVR voltage set-point V as a function of the generator reactive power produced. This set-point regulates the generator terminal voltage when in island mode.

The interpretation of the above graph is that as the reactive power demand from the generator increases, the generator terminal voltage decreases. The set-point in the AVR is chosen so that when the generator reactive power Q supplied is zero, the generator V_N is equal to the nominal voltage. If the initial AVR set-point is not changed, V_L will be the voltage due to droop that the generator terminal voltage will reach operating in island mode against reactive load Q_L .

The reactive power generated is calculated from the generator voltage and current signals, fed back to the AVR.

Droop compensation is set as percentage drop of the nominal voltage V_N for maximum reactive power Q_L generated. Depending on the AVR, maximum reactive power is usually defined either as the reactive power exported at rated power factor, or as the MVA rating of the generator.

Droop setting can be given values from 0%, which effectively disables the droop, to a maximum of usually 20%, which could cause V_L to drop to 0.8 p.u. Typically, a setting of 4-6% is chosen.

Droop compensation is a control technique designed when the generator is connected to the grid, so it is not required when one generator is in island mode.

On the other hand, when connected to the grid, droop compensation is required and the droop characteristic is used below to explain the control of the AVR.

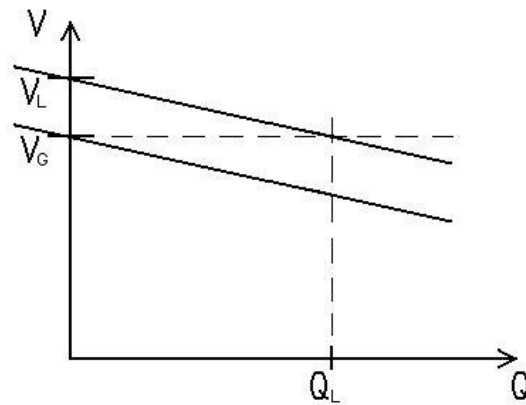


Figure 2. Representation of AVR control when connected to the grid.

When a generator is directly connected to the grid, the grid voltage V_G is fixed and cannot be controlled by the AVR. Any requirement for reactive power from the generator will result in the AVR internal voltage set-point V to change to meet the new demand. So, in the diagram of figure 4, the increased reactive power demand Q_L causes the AVR set-point to increase from V_G to V_L because of the droop compensation control.

2. Generator operation modes

According to the network topology, the following operating scenarios can be identified:

Operating in island mode as a stand-alone generator.

Synchronised to the grid.

Operating in island mode, but in parallel with other generators.

These three scenarios are analysed separately below.

2.1. Island mode operation with a single generator

This is the simplest case in terms of AVR control, as there is only one active component in the circuit that can affect the busbar voltage and react to any reactive load changes.

A single synchronous machine operating in island mode is only responsible for two actions:

Control the busbar voltage to the required nominal level.

Supply the load with the required reactive power and respond fast to any load changes to meet the demand at any time.

The diagram below presents the simple case described.

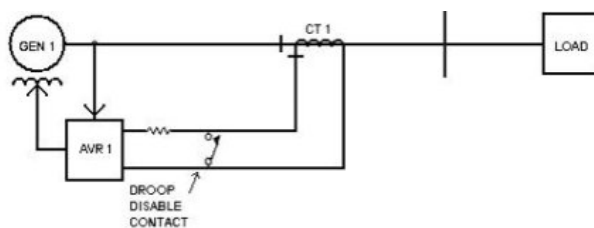


Figure 3. One generator in island mode with droop enable contact.

The AVR in this case does not require droop compensation to control its output. In order to eliminate the droop effect, which would otherwise drop the circuit voltage with any increase in the reactive load, there are two possibilities:

Set the droop setting within the AVR to zero %.

Close the droop enable contact shown in the diagram above, so that the compounding CT current would not flow into the AVR.

2.2. Synchronised to the grid

In the case where there is connection to the grid, the AVR needs droop compensation in order to control its output. The circuit configuration and the droop characteristic for this case are presented in figures 3 and 4 respectively.

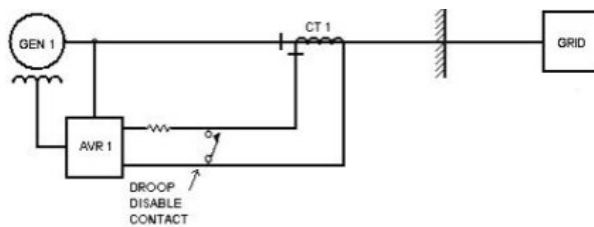


Figure 4. One generator synchronised to the grid.

The configuration above shows that by the operation of a simple contact the droop can be enabled or disabled, allowing the flexibility to disable it when in island operation and to enable it before connecting it to the grid. This eliminates the undesired effect of lower than nominal voltages when in island operation.

2.3. Island operation with paralleled generators

For the case of island mode operation with at least two generators connected in parallel to supply the load, the control of the voltage and the reactive power requirements have to be shared between the generators in parallel.

There are two control methods for the generator AVR's to achieve this:

Control with droop compensation.

Control with cross-current compensation.

2.3.1. Control with droop compensation

In this case the following assumptions have to be satisfied:

The generators must be of equal size.

The AVR's must have the same droop characteristic and the same setting applied.

In the simplest case, the AVR's can operate in droop compensation mode to obtain equal sharing of the reactive load. The relevant diagram is shown below.

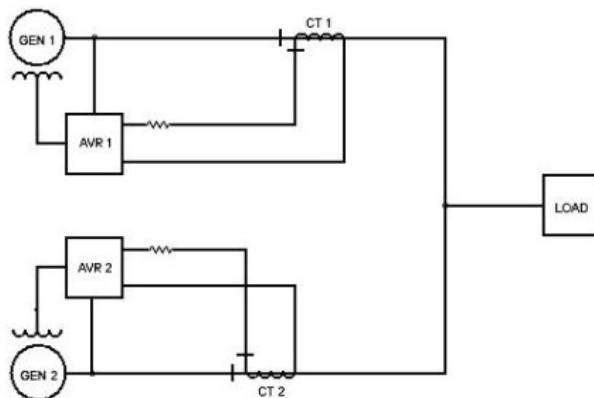


Figure 5. Island mode with two generators in parallel in droop mode.

The two generators in figure 5 share equally the reactive load connected according to the droop characteristic of the AVR's and the setting applied.

Although this control mode is ideal when there is grid connection, in island mode it results in the voltage output being dependent on the reactive power demand. So, as the requirement for reactive power increases, the output voltage from the generators decreases due to the droop compensation.

2.3.2. Control with cross-current compensation

Cross-current compensation or reactive differential is a method that allows two or more paralleled generators to share equally a reactive load, given that the following assumptions are satisfied:

There is no grid connection, i.e. the generators operate in island mode.

The generators are of equal size.

The AVR's have the same droop characteristic, which is set to its maximum setting.

The secondary wiring of the compounding CT's of all the generators to be paralleled have to be interconnected. Below, the wiring configuration for two generators set up for cross-current compensation is included.

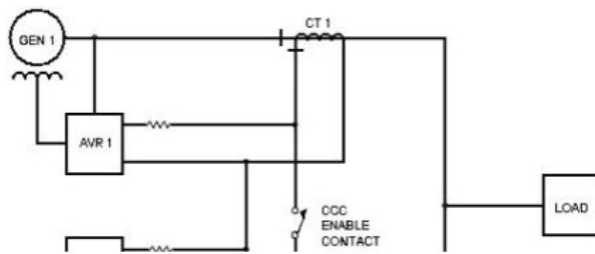


Figure 6. Island mode with two generators in parallel with cross-current compensation

According to this method, the same current develops through the compounding CT's of the generators in parallel, since they are identical, and when the CCC contact closes, it stops flowing through the AVRs, but only flows through the CTs.

The configuration above shows that by the operation of a simple contact the CCC can be enabled or disabled, allowing the flexibility to enable it when in island operation and to disable it before connecting it to the grid. This eliminates the droop effect and allows the paralleled generators to operate in island mode at nominal voltage when the reactive load increases.

The figure below shows the complete configuration with all the techniques explained previously incorporated for maximum functionality. This includes both the droop-compensation and the CCC enable-disable contacts.

In this case, when the generators are connected to the grid, all contacts must be open.

For paralleled generators in island mode, the droop contacts must be open and the CCC contact closed.

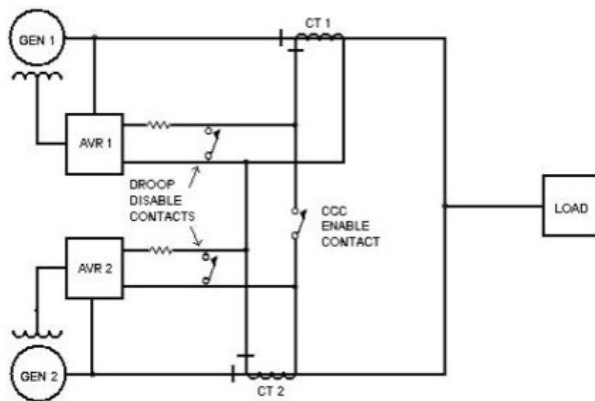


Figure 7. Island mode with two generators in parallel with cross-current compensation and droop disable contacts.

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