Martin Shan, Daniel Duckwitz
Fraunhofer IWES
Königstor 59, 34119 Kassel
+49-7294-364

Synchronous Generator System with Enhanced Capabilities for Low Voltage Fault Ride Through

PROBLEM DESCRIPTION

During operation of electrical grids, faults can occur resulting in a voltage break-down of one or more phases for a limited duration. This voltage dip is seen by all generators connected to the electrical grid. The duration is typically in the range of several 100 milliseconds.

During the grid fault, the voltage seen by an individual generator can be significant lower than the nominal value. For this reason the amount of active power that can be delivered into the grid may be very low, the grid will absorb mainly reactive power.

For conventional directly coupled synchronous generators this is a problem, because the electrical torque created by the generator will break down in response to the voltage dip. If the driving torque applied to the generator shaft can not react quickly enough, the generator will accelerate due to the imbalance between driving torque and electrical torque. Furthermore, for flexible drive trains, torsional oscillations will occur that may be related to damages in mechanical components like gears, couplings etc..

The acceleration of the generator during grid faults is a problem because the load angle between generator inner voltage phasor and grid voltage phasor will increase. If the duration of the fault is too long, the load angle is too large at voltage recovery and the generator will not return to synchronism at voltage recovery. Instead, so called pole slipping can occur, which is related with high transient current peaks and can give serious damage to the generator and the connected drive train

Commonly used driving machines for synchronous generators as diesel engines and turbines - especially wind turbines - can not adjust the generator shaft driving torque quickly enough to avoid pole slipping events in every case.

TECHNICAL SOLUTION

The technical problem can be solved by an active power sink device connected to the stator terminals of the generator that can absorb active power during the grid fault. By activating this device during the occurrence of grid faults with related voltage dips, the generator electrical torque can be held up during the grid fault. As advantage, excessive acceleration of the generator during voltage dips can be avoided. The load angle will not vary too much during the fault and the generator can safely return to synchronous operation after the grid fault has been cleared. Furthermore mechanical oscillations in the drive train of the generating unit can be reduced or even avoided by keeping the active power close to the value before the grid fault.

From the literature, the connection of brake resistors close to the terminals of large synchronous generators is known for the purpose of increasing the power system stability in response to transient events [1], [2], [3]. If the power consumption of these braking resistors can be controlled, e.g. by means of power electronics, they can be used to actively damp out oscillations of the generator after grid faults. These braking resistors, however, are usually activated after fault clearance and voltage recovery.

For small generators with small inertias, in contradiction, it is useful to activate the active power sink already during the voltage dip. For this, however, a certain level of voltage at the terminals of the power sink must be maintained during the grid fault. This can be achieved if the power sink is connected directly to the stator terminals of the generator and the generator delivers reactive current into the grid through a reactance that is located between the generator terminals and the grid.

In Figure 1 the basic principle of the generator system with enhanced fault ride through capabilitiy is shown. A synchronous generator (1) is feeding power into an electrical grid (4) through a reactance (2). The stator terminals of the generator are connected to an active power sink (3), which can be activated in case of a grid fault and consumes excessive active power from the generator during the fault.

The required reactance can be provided for instance by a step-up transformer, that is required anyway in many cases. If the generator nominal voltage is in the low-voltage range, this offers the additional advantage that comparably cheap low-voltage components can be used also for the active power sink.

Since fast delivery of high reactive current by the generator is required for maintaining the stator voltage during the fault, a boost excitation of the generator during the grid fault is advantageous. This method of excitation control is known from the state-of-the art (see e.g. [4]).

Preferably the active power delivery of the generator is regulated during the grid fault by means of a controllable active power sink. The active power delivery can be continuously regulated to the value of active power that was injected into the grid before the occurrence of the grid fault. For this purpose, the active power can be measured at the generator stator terminals. Alternatively it is possible to regulate the load angle directly. For this purpose, the generator rotor position must be measured or estimated and compared with the grid voltage phasor.

In Figure 2 a possible technical solution is shown in more detail. In this case the reactance is formed by the step-up transformer (2). The controllable active power sink is designed as rectifier with adjustable resistance in the DC-link. The power electronic switch of the adjustable resistor is pulsed by a control unit (5). The control unit activates the controllable active power sink after detection of a grid fault based on measurement of the grid voltage U. During the grid fault the active power supply at the generator terminals is regulated to a mean value that was present before occurrence of the grid fault. Many other solutions for controlled active power consumption are possible and known from the state-of-the-art, using different power electronic switches e.g. IGBTs or thyristors.

The active power sink should be activated only in case of grid faults. This activation can be done based on grid voltage measurements at the generator stator terminals. If a voltage dip is detected there, the active power sink is activated. Once the grid voltage has been recovered, the active power sink can be disabled.

A further application of the controllable active power sink could be the active damping of drive train oscillations in the generating unit. Such oscillations will occur in response to grid faults but can also be excited by other effects coming from the grid or the drive train of the generating unit. For active damping controllers the generator speed and/or the generator voltage would be useful input values.

SIMULATION RESULTS

In Figure 3 the simulation results for a fault ride through event are shown for a 2 MW rated synchronous generator. The shaft torque is hold constant at the rated value. The fault is a 3 phase short circuit on the high voltage side of the step-up transformer with a duration of 200 ms. For the conventional generator, the load angle increases very fast during the fault. On voltage recovery the generator can not fall back to synchronism. Instead, pole-slipping occurs with high current and voltage oscillations. For the generator system with controllable active power sink, the load angle can be stabilised by means of control. On voltage recovery the generator returns to normal operation after some oscillations.

REFERENCES

[1] CIGRE SC38-WG02 Report: *State of Art in non-classical means to improve power system stability*. Electra, No. 118, May 1998

[2] J. Machowski, A. Smolarczyk and J. W. Bialek: *Damping of power swings by control of braking resistors*, International Journal of Electrical Power & Energy Systems, Volume 23, Issue 7, October 2001, Pages 539-548

[3] Rubaai, and D. Cobbinah: *Optimal control switching of thyristor controlled braking resistor for stability augmentation*, Conference Record of the 2004 Industry Application Conference 39th IAS Annual Meeting, vol.3, pp 1488 – 1494, ISSN: 0197-2618

[4] G. Rudolph and K. Stapelfeldt, *Wind Turbine with LVRT Capabilities*, International Patent Application WO2010/085988 A2

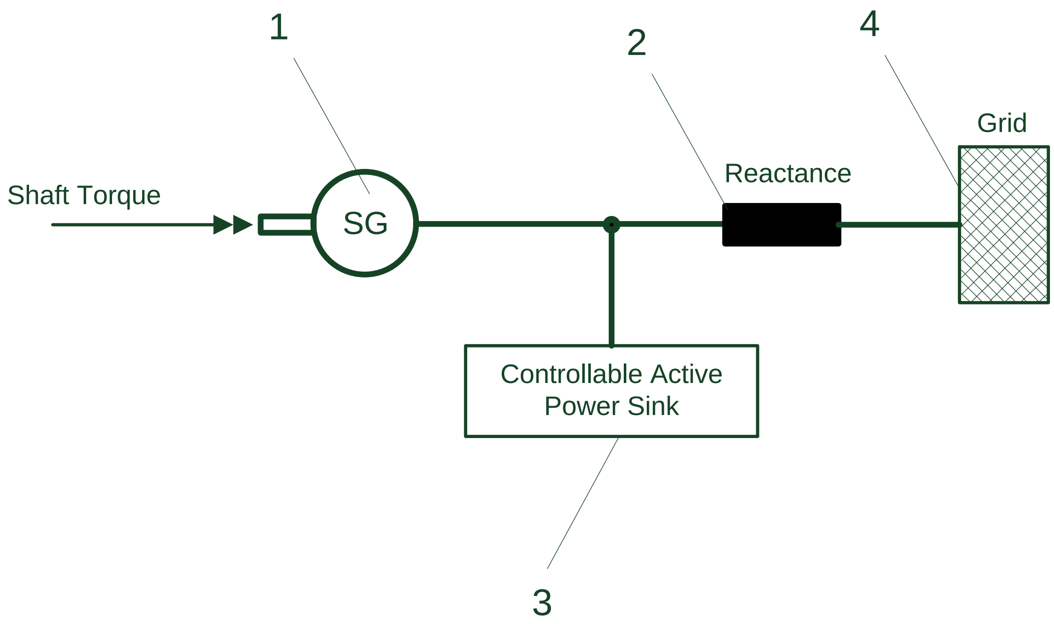

Figure 1: Principle of the Synchronous Generator System with Enhanced Fault Ride Through Capability

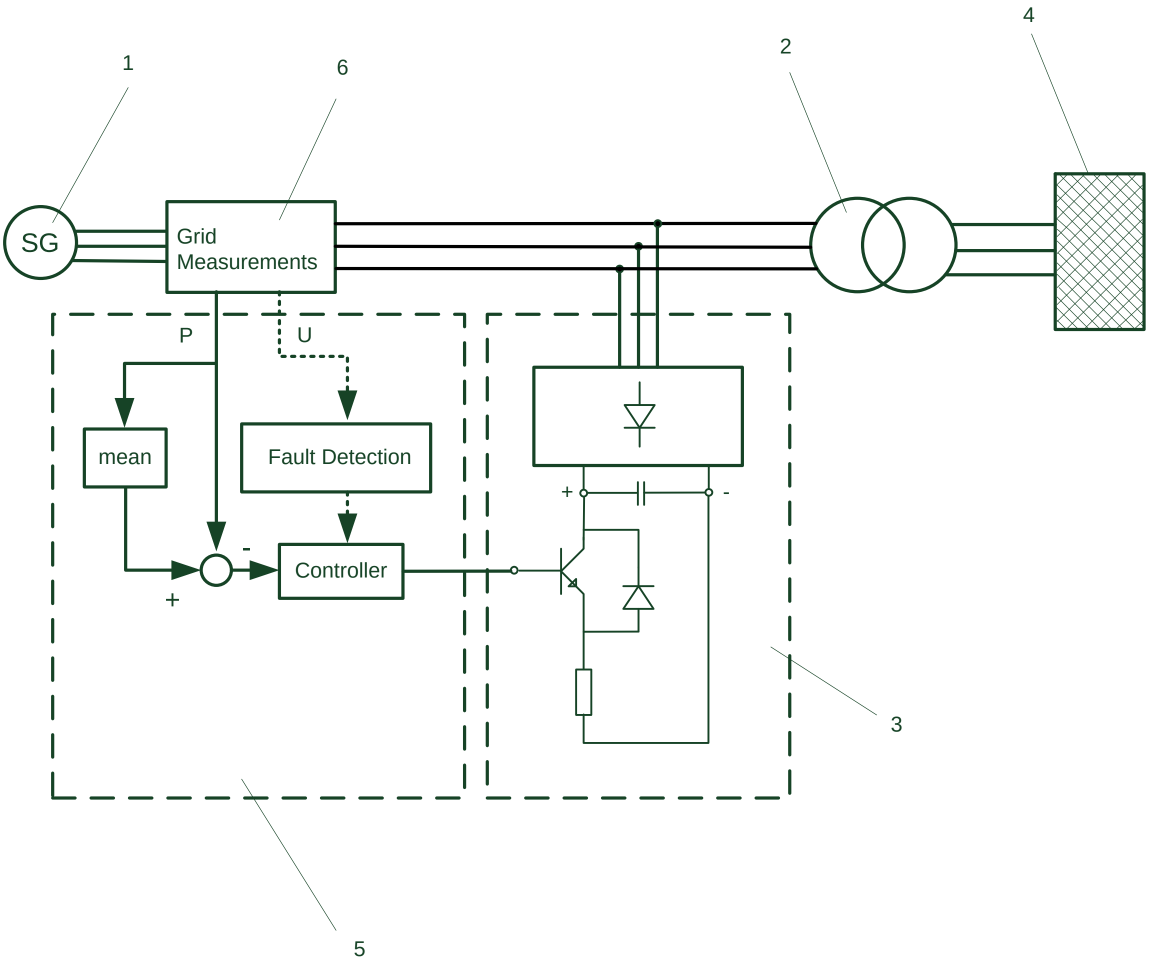

Figure 2: Detailed Schematic of a possible Implementation

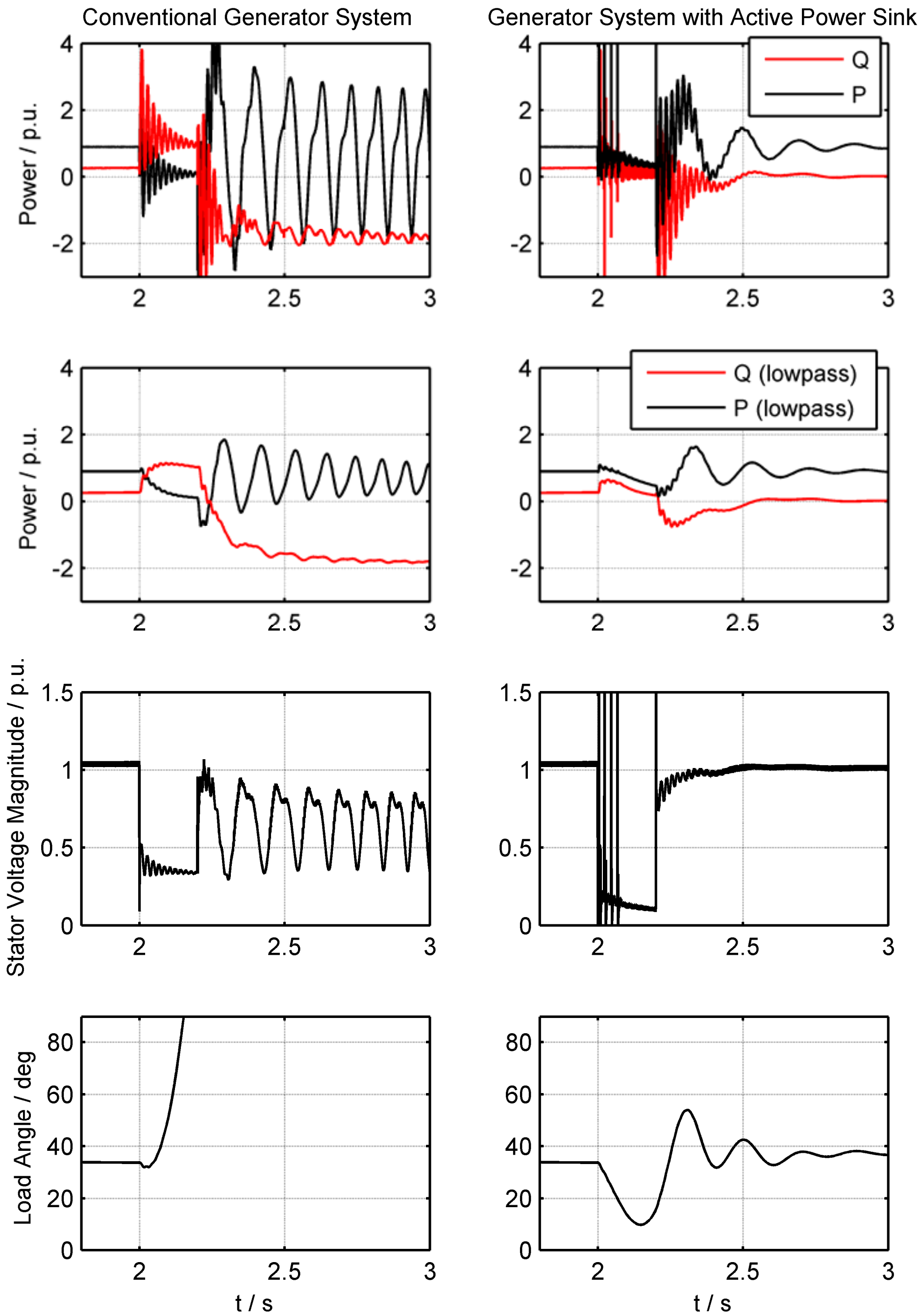

Figure 3: Simulation results for a fault ride through event, left: conventional synchronous generator, right: synchronous generator with controllable active power sink