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Power System Restoration with Black-Start Pump Storage Power Plants

One of the main duties of a transmission system operator (TSO) is to be prepared for the power system worst case, which means to restore the power system operation after a total blackout. To this aim two main principles are currently available. The first one is based on power system restoration with external voltage support and the second more challenging one is based on own voltage support from black-start generation units. The current paper describes experiences of power system restoration based on detailed dynamic system modelling and tested in the real system by interconnecting for the first time two hydro-power generation centers over the Alps and also by using as load the currently worldwide largest voltage source full converter-driven-pump of 100 MVA.

Keywords: Power system simulation and control, power system restoration tests

1. Introduction

According to grid code requirements transmission system operators are in charge of preparing and testing power system restoration scenarios, in order to ensure load recovery after serious disturbances or a total system blackout.

In principle there are two types of approaches after serious system disturbances resulting in total loss of power supply. The first and more preferential scheme is based on power system restoration with external voltage support, which means system restoration starts with the help of a neighboring TSO. The Advantage of this option is the significant inertia and reactive power capability of a healthy neighbor and consequently a quite short required restoration time. However, after extreme disturbances it should also be considered that no potential neighboring support might be available and therefore the second scheme has to be based on power system restoration in island mode by using own black-start capabilities.

The current paper describes one of the recent real power system restoration tests in island mode performed successfully in Switzerland by the end of 2013.

2. Preparation of the power system restoration test

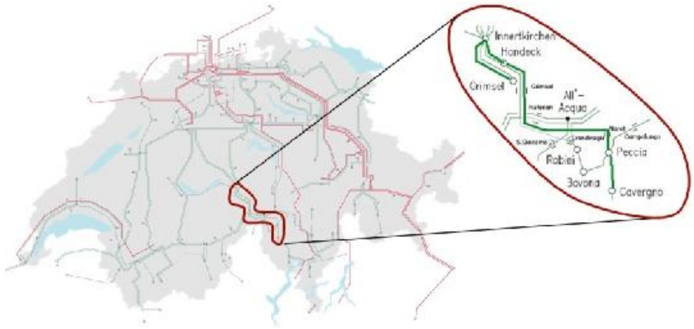
One of the most important preconditions of power system restoration tests is the setup of detailed dynamic models, in order to check the dynamic system behavior prior the real test, in order to avoid the triggering of equipment protections which might lead to undesired events and disturbances. During the first steps of power system restoration, the voltage and the frequency of the island have extreme deviations which are much higher than during normal system operation condition. Therefore the main challenge for generation control is keeping the small system stable for a time period of a few hours.

Within Switzerland there is a long tradition of preparing dynamic system models for power system restoration. Since the early nineties the power system restoration schemes have been set up, checked and adapted based on detailed digital models, see /1-3/. During dedicated projects and related tests the dynamic models have been validated with the help of dynamic identification procedures. In principle within dedicated tests the exact parameters for the governor and AVR of the most important hydro power plants of Switzerland have been identified /4-5/. The preparation and execution of such tests require a close cooperation between power plant operators, turbine controller manufacturer and power system operator as well as universities or consultant companies.

For the autumn 2013 tests most of the material was already available as this test was one of three consecutive tests with the same power plant and careful corresponding dynamic model preparation and validation along the years. However, this time two new aspects were planned, namely the connection of the new 100 MW full converter-driven pump and the first island expansion over the Alps to a second restoration island. Consequently, the number of involved actors had increased; more details had to be considered during the preparatory works. The structure and main details of the island system are depicted in Figure 1.

For the test an exact schedule of the sequence of connections was established and checked by dynamic model calculations, see Figure 2.

The size of all the generation units as well as for the loads/pumps is shown in Figure 3. The total island system was built by 340 MW of rotating mass with about 82 MW load and around 90 km of 220 kV overhead lines.



- 90 km 220 kV lines
- approx. 400 MVA generation
- 77 – 117 MW load (pumps)

Figure 1. Island system

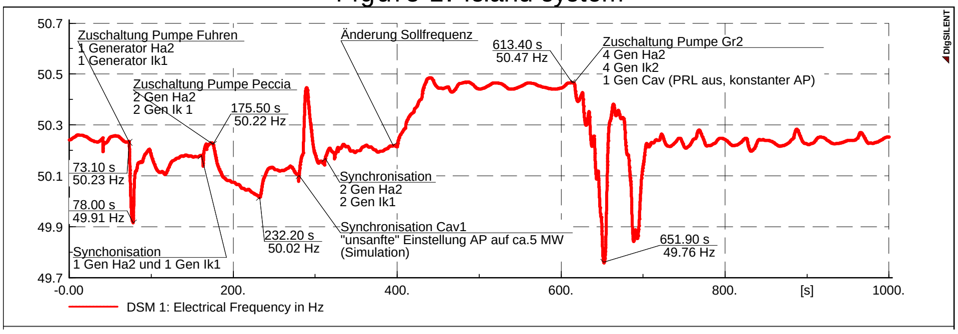


Figure 2. Simulation results for the entire test

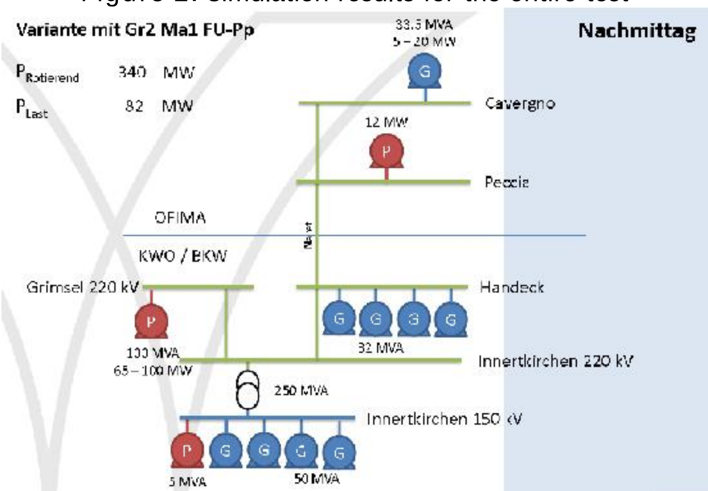


Figure 3. Power plants units and loads, source KWO

3. Test Execution

The test started with the black-start of the auxiliary load turbine of the Handeck 2 power plant. This unit starts automatically as soon the external power supply of the power plant is interrupted and is designed in such a way to deliver the required auxiliary power for the complete power plant and ensure therefore the startup of the main power plant units. After the synchronization of one unit in Handeck and Innerkirchen the first load, namely one 5 MVA pump in Fuhren was connected. Consequently the first load connection step consists in connecting 4.5 MW to a generation park of about 80 MVA, see Figure 4. In order to avoid the triggering of pump underfrequency protection at 49.5 Hz the island setpoint frequency was increased before load connection to a value of 50.35 Hz, identically as pre-prepared in the related models simulation calculation. It can be observed how the simulated frequency match the measured frequency very well, as the exact pump start-up characteristic was available for the dynamic model calculation.

The next step was to synchronize 2 more generators, prepare the link over the Alps before connecting in the south area the second power restoration island consisting of a pump and an additional generator. After stabilizing the enlarged island, additional generators were connected within the main restoration island in order to be prepared for the connection of the huge load – the new full converter-driven 100 MW pump at Grimsel 2 power plant. In spite of full-converter pump control, the challenge was the minimum pump load of 65 MW due to cavitation reasons. The connection phase is shown in Figure 5.

The test was finished by resynchronization of the island to the interconnected power system at the Cavergno power plant substation.

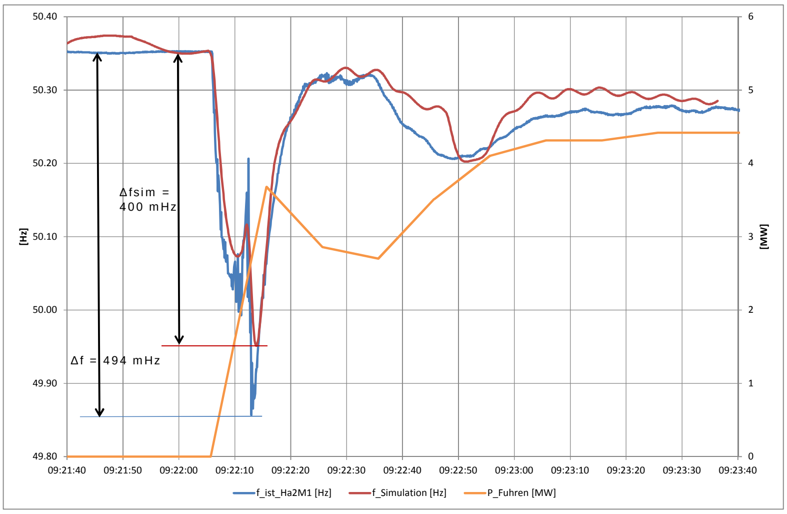


Figure 4. Connection of the Fuhren pump.

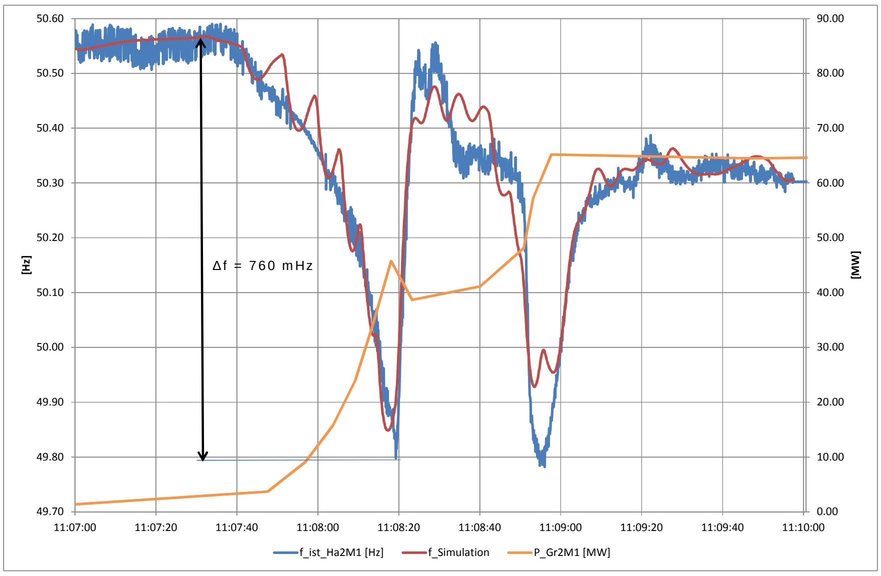


Figure 5. Connection of the 100 MW full converter-driven pump Grimsel 2

4. Conclusion and outlook

The described test was one of similar successfully performed power system restoration tests within Switzerland with the participation of power plant operator together with the Swiss power system operator Swissgrid. Each new test profits from the experiences gained during the preceding tests and the permanent dynamic model improvements based on in depth comparison between simulation and measurement.

In conclusion it can be stated that extreme power system situations with a lot of different geographically distributed participants needs a very careful preparation. Reliable and robust telecommunication infrastructure is a must. This important backbone is required for the transfer of online measurements, remote control and phone connections between the involved control rooms. The corresponding responsibilities and duties will have to be clearly and carefully addressed and agreed on beforehand. Regular common tests on network simulator tools as well as within the real system are the basis for a common understanding and confidence between all involved actors.

Worldwide all the latest serious power system disturbances have demonstrated that it is of crucial importance to reduce the system restoration time to a minimum as the overall impact of a complete loss of electric power supply increases dramatically with the duration of the loss and the number of affected areas. Consequently carefully elaborated and well-tested system restoration plans are important components of the power system operator's emergency toolbox.

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