PRACTICAL EXPERIENCES OF GRID CODE COMPLIANCE TESTING AND STUDIES IN HEAT AND POWER PLANTS IN SWEDEN

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ABSTRACT

This paper presents experience from grid code compliance testing and studies in a heat and power plant in Sweden. The tests executed consist of four full scale tests in the plant and two different dynamic simulation studies. Due to the rather sensitive process in a heat and power plant and due to the upcoming new Grid Code within EU, we believe it would be of high interest to show our experience in these types of tests.

Image 1 Heat and power plant, 35 MW

INTRODUCTION

The state-owned public utility Svenska Kraftnät (SvK), the transmission system operator (TSO) in Sweden, stipulates that owners of a plant for the production of electricity (production plant) must ensure that the production plant meets the requirements as set out in the requirements in SvK's regulations and general advice concerning the reliable design of production plants (SvKFS2005:2). The ability of production plants to meet requirements set out in this Statute must be verified.
In these regulations, requirements are imposed on certain technical dimensioning of production plants to create the necessary conditions for reliable operation within the national electrical system.
The requirements concern interference tolerance, voltage control, output control, shutdown and start-up de-energization, communication and controllability, verification and documentation.

The purpose of the executed tests and studies was to verify the plants availability to fulfil the demands in the requirements. The tests executed consist of four full scale tests in the plant and two different dynamic simulation studies. The paper will focus in the list of demands with respect to the existing regulation, limiting circumstances of the power plant, test description of full scale tests and description of performed dynamic studies in a commercial software tool. The paper also high lights considerations when, in future, testing Heat and Power plants or making the New EU Grid Code.

LIST OF DEMANDS

The existing regulation (SvKFS2005:2) defines three different sizes of Heat and Power plants.

Large plants: active output greater than 100 MW
Medium-sized plant: active output of 25 - 100 MW
Small plants: active output of 1.5 - 25 MW.

Depending on the size of the plant there are different demands to verify. One of the plants we focus in is a medium sized plant with an installed active output of 35 MW.
Heading 1-4 below shows demands valid for and tested in a 35 MW Heat and Power plant. Demands not described have been verified by documentation.

1.Disturbance durability

Heat and Power plants shall, with the network connection retained, cope with variations in the voltage in one or more phases in the connecting meshed **main** network down to 25% for 0.25 s and then 90% voltage, which then persists. The requirements are illustrated graphically in Figure 1.

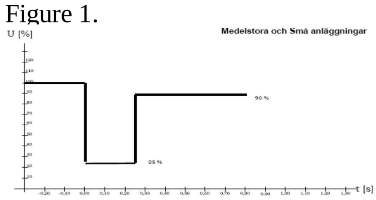

Figure 1 Variations in the voltage in one or more phases in the connecting meshed main network

Heat and Power plants shall, with the network connection retained, cope with the variations in the voltage, in one or more phases, that may occur in connection with an instantaneously disconnected defect in the connecting meshed network. Grid owner of the connected grid has the demand that the plants shall, with the network connection retained, manage a 3-phase short circuit disconnected within 100ms.

2.Voltage controling

Magnetisation system
Requirements of response time T is one second. and the maximum overshoot of the generator voltage must not exceed 15% of the voltage change. The generator voltage must not vary by more than ±5% of the voltage change 2 seconds after the step change. The response time T is the time taken for the generator voltage for idling plants not connected to the network to achieve 90% of the resulting change in the generator voltage after a step change from 1.0 to 1.1 p.u. of

the voltage controller input signal.

Continuous reactive production
Heat and Power plants must be dimensioned with the facility of reactive power production corresponding to one third of the maximum active output. The production plant shall have the capacity to produce reactive power for continuously feeding to the connecting network when needed. Additional to this requirement, the equipment shall be able to regulate the reactive power down to zero. Furthermore, grid owner of the connected grid stipulates that the production plant must ensure to manage reactive power consumption within the capacity of the machine.

3.Output Control

Heat and Power plants shall be capable of changing the output power production 30%, 4%/minute, within the output range of 60-90%.

4.Frequency control

Heat and power plants shall automatically be capable of contributing to the frequency control of the power system with a controlled strength within the range 0.25-1 p.u. Power/Hz in the case of a frequency variation of 50 ± 0.2 Hz. The plants shall be capable to manage repeated output variations around the set decided value and the output power shall be adjustable by ±2% within 30 seconds within the control and output range within 60-90%.

Frequency control units must have control equipment that allows adjustments of several control modes with separate parameter settings. One of these settings must be usable for automatic adjustment to disrupted operation in the power system. Heat and power plants shall in disrupted operation mode automatically be capable to meet a step change in production around the set decided value and the output power shall be adjustable by ±2.5% within 5 seconds or ±5% within 30 seconds within the control and output range within 50-90%.

LIMITING CIRCUMSTANCES DURING TESTS

During the full scale test the plant was still not tested to run at full power. The plant was in pilot operation. During pilot operation the steam system was not fully adjusted to manage high steam pressure variations that will occure during all needed tests of the turbine.

PERFORMED FULL–SCALE TESTS

Test 1 Voltage Control (Magnetisation system)

Description of test
The test to verify the voltage control was made during nominal voltage level 11 kV (1 pu) and with the generator disconnected from grid. The reference signal to the voltage control was applied with 5 different step changes 1%, 2%, 3%, 5% and 7% of nominal voltage. Figure 2 shows that the current limiter is activated during the test. Depending on current limitation and the increased risk for damage of the plant, the turbine manufacturer declined to continue with a new test at 10% voltage step despite of the requirement.

Test results
At 5% and 7% step the current limiter (IFDlim) is activated. This results in a longer response time T but it also reduces the overshoot. In both cases the time response is within the requirement of 1 second. At 3% step the first overshoot is 120V (40% of the step change) which means that the overshoot demand is not fulfilled. At 7% step the first overshoot is 126V (16.5% of the step change) which means that the overshoot demand is not fulfilled.
The results in above shows a decreasing trend of the over shoots. The overshoot at voltage step 10% is not allowed to be more than 165V (15%). If the overshoots follow the same trend as in the cases with 3% and 7% the overshot for 10% step should be around 12%. According to this estimation, the requirement of overshoot should be fulfilled without changing the setting of the current limiter. A recommendation was made to the plant owner to redo this test again during the revision of the plant when the plant is totally up and running.

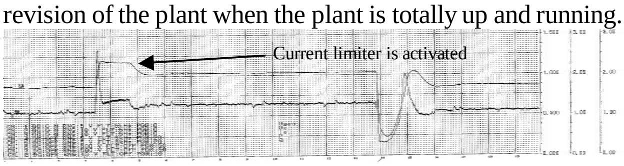

Figure 2 Field current & field voltage at a 7% voltage step

Test 2, Voltage Control (Continuous reactive production)

Description of test
The test was made to confirm over- and under-excited reactive power capability of the generators and the excitation systems.

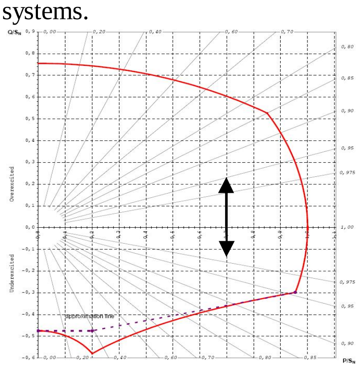

Figure 3 Capability curve. Confirmation of over excited and under excited Reactive Power

The grid operator was informed of the intention of the test in order to be prepared to accept the maneuvers of the test. The target of the test was to perform it at 90-100% of nominal active outut power but was made at an active power production of 24 MW which is about 70% of the nominal output power. As this was a pilot operation, the operators decided to maximaze the output power to 70%. To be able to reach 70% the governor was running in pressure regulation mode to get a stable steam flow.

Test results

Maximum measured reactive power production during the test was 8.9 MVAr which is 26% of nominal output power and 37% of during the test produced output power. The limiting circumstances were the weak grid the plant was connected to. Despite of disconnecting shunt capacitors at the connecting grid there was a threat to reach the upper limit of grid voltage. The operators did not want to use the tap changer when plant was connected to the grid because of the risk for disturbences of the steam flow in the process. An assumption was made that the production plant itself should be able to produce reactive power according to the demands but the distribution grid was to weak at the moment for testing.

The reactive power consumption was regulated down to -4.5 MVAr, 13% of nominal active output power, which is showing that it is possible to reduce the reactive power below zero and less.

Test 3 Frequency control

The Machine is able to run in three different modes.
Normal frequency mode is a carefully adjustment that take the steam process into consideration by ramping up the output power to the new level according to the frequency change. In the Droop Mode the control is a PID regulator which takes no care about the steam process. In the Disturbed grid operation the control is a faster PID regulator. The mode Disturbed grid operation was not in the scoop of delivery of the turbine but the manufacturer installed the mode during the test. The mode for disturbed grid operation is faster and is automatically connected when the frequency diverge more than ±0.3 Hz.

Test of normal frequency mode

In the test of normal frequency mode the input frequency signal to the control system is intentionally disturbed by two different superposed signals forms as showed in Figure 4 according to the demands.

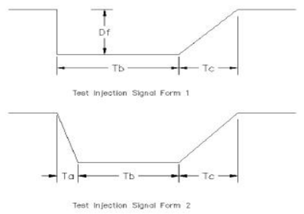

Figure 4 The forms of superposed signals applied to the input frequency signal to the control

The test was meant to be done at 60%, 80% and 90% active output power. Because of the circumstances earlier described, the test was done only at 60% and 70%. Table 1 shows the test cases performed.

Table 1 Test conditions and amplitudes

Case	Initial	Test	Test	Ramp on	Ramp off	Hold
	Power	Form	Amplitude	Time, Ta	Time, Tc	Time, Tb
	MW		Hz	sec.	sec.	sec.
1	21 (60%)	1	0.1	0	0	60
2	21 (60%)	1	0.2	0	0	60
3	21 (60%)	2	0.2	10	10	60
4	21 (60%)	2	0.5	10	30	60
5	24 (70%)	1	0.1	0	0	60
6	24 (70%)	1	0.2	0	0	60

The results in Table 2 shows that the plant is within the demands (range 0.25-1 p.u./Hz) according to frequency control for normal frequency mode.

Table 2 Test results of control strength

Test nr	Pådrag [%]	$P_{initial}$ [MW]	P_{final} [MW]	ΔP [MW]	R [MW/Hz]	R [pu/Hz]	ΔP/ΔT [%/30sec]	Pass/Fail
2	60	21,0	23,3	2,3	11,5	0,33	4,4	Pass
6	70	24,0	24,0	2,0	10,0	0,29	3,2	Pass

Test of droop mode

Two tests have been made to test the control strength. First one test with a frequency step +5% (0.25Hz) at 60% output power was performed. After that one test with several small positive frequency steps (0.1%) were applied to the frequency signal, starting at 70% of the output power and continued until the output power had dropped to 20%. After that the frequency signal was increased in small steps (0.1%) until the output power is back to 70%. The results of the first test gives that the control strength is 0.42 pu/Hz and the change of output power is 2.6 MW (7.6%) within 30 seconds. The result of the second test gives that the control strength vary between 0.33 and 0.6 p.u./Hz which is within the demand 0.25 p.u./Hz.

Test of disturbed grid operation

The input frequency signal to the control system is intentionally disturbed by a superposed signal of 50.4 Hz with a step of -0.2 Hz at 60% of active output power. Figure 5 shows the response time at 90% of the whole step (2 MW) which is about 12 seconds. The output power is adjustable by about 0.17 MW/sec or 0.9 MW/5 sec which corresponds to 2.5% within 5 seconds. The demand is fulfilled.

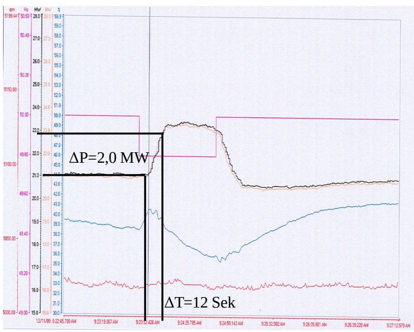

Figure 5 Step response disturbed operation

Test 4 Output Control

Normally the control system is configured using different ramp times for controlling the output power of the turbine in different operation temperatures. When the turbine is warm it will be regulated with a ramp 0.63MW/minute. At high output power, when the turbine is warm, the ramp is 0.5 MW/minute. This is due to the very sensitive steam process that cannot be disturbed too much. During the test the ramp is temporarily adjusted to 2 MW/minute. The settings for the output power are changed from 60% to 76% in a step. The diagrams from the test show that the change in output power is following the settings of the ramp function.

DYNAMIC SIMULATION STUDIES

Validation of model

A model of the generator, turbine, governor, exciter, internal- and the connecting grid was made. Validation of the governor model was made by comparing the step answer in the model with the full scale test when a step at 0.2 Hz is applied during 120 seconds at 60% output power.

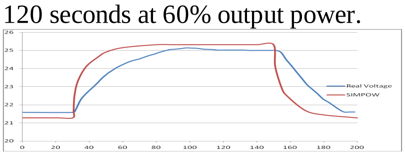

Figure 6 Validation of governor

Validation of the exciter model was made comparing the step answer in the model with the full scale test when a voltage step at +3% is applied to the input signal during idling of the generator.

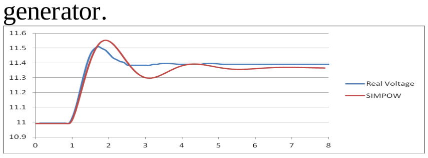

Figure 7 Validation of exciter

Study 1 Disturbance durability (connecting meshed Network)

The purpose is to analyse what happens during instantaneously disconnected defect in the connecting meshed network. A 3- phase short circuit to earth is applied in the connecting meshed 130 kV network. The durance of the applied fault increases from 100ms in steps of 100ms/step until an instability in the grid is reached. The result shows that the critical disconnection time is 400 ms.

Study 2 Disturbance durability (connecting main meshed network)

The purpose is to analyse if it's possible, with the network connection retained, applying the voltage curve in figure 1 to the 400kV grid. The result shows that the plant manage to recover with the network connection retained. The study of the relay protection system shows that they will not disconnect the plant during this kind of voltage variation.

LESSONS LEARNED

Operation of Plant

A heat and power plant has a very sensitive process and the priority is to deliver steam and not to deliver electric power. The normal way of thinking when running the plant is to try to produce as much active power as possible without disturbing the steam process. Because of the large proportion of hydroelectric power used in Sweden, frequency control and instantaneous interference control can normally be expected to be needed only in the hydroelectric units. The frequency control in heat and power blocks do not normally need to be activated but the plants is fully capable of running in frequency control mode.

Experience of tests

1) When defining the size of Heat and Power plants for testing it is the total output power to the grid and not the nominal output power at the generator that is meant. 2) The test of the plant was made before the plant was in full operation and it was not possible to do all tests properly. In the heat and power plant tested the generator is oversized according to the possible output power of the steam and may never be possible to run at full power.

3) Current limiter was activated during the test of Voltage Control and the turbine manufacturer declined to continue with the test.

4) The weakness of the connecting grid or the sensitivity in the process that makes it impossible to switch the tap changer during production could be the limiting factor when producing reactive power.

5) Frequency control shall consist of three different frequency regulation modes. One mode was missing but implemented during the test.

6) The available ramp time for controlling the output power of the turbine does not match the demands. There is no problem to chance the ramp temporarily but a faster ramp time decrease the life of plant.

7) In the requirements there is no exact description of which models that should be used for dynamic studies and how to verify the simulation models against reality. This is a necessity to make analyses on different plants comparable.

CONCLUSION

Test methods used, works well for this type of plant. For best result, the tests should be performed during winter and when the plant is fully trimmed and can be operated at full power. Because of oversized generator according to steam power a suggestion, for upcoming projects, is to verify the size of the plant by a full scale test before verifying of demands. There is a potential for increased frequency-controlled thermal power plants in the future as the grids are connected within Europe and the requirement for control possibilities is increasing due to more wind- and solar energy in the grid.