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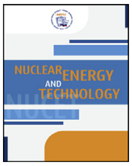

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Dynamic stability of the VVER-1200 power unit

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Abstract

The paper presents the results of critical experiments to study the dynamic stability of a power unit with the VVER-1200 reactor conducted as part of the pre-commissioning activities at the pilot operation stage of Novovoronezh NPP II’s unit 1.

The following dynamic tests were conducted:

– trip of one main feedwater pump (MFP) with no standby MFP starting to operate at the power level of 100% N_{nom}, involving a detailed analysis of the variation in the process parameters of such mode and the process dynamics, and an assessment of the test results on a full-scale simulator;

– trip of one out of four reactor coolant pump sets (RCPS) in operation at the power level of 100% N_{nom} and the reactor plant safety assessment in the context of the reactor core thermal reliability;

– turbine generator (TG) load shedding to the auxiliary level with assessments for the behavior of the key reactor plant characteristics.

The paper presents records for transients and safety-related process parameters, and describes the operation of the unit components and essential controls in the dynamic test process. A conclusion is made based on an analysis of the test results that the VVER-1200 unit has a high dynamic stability.

The results of the dynamic stability studies for unit 1 of Novovoronezh II make it possible to provide a number of recommendations for further designs, including specifically the following:

– accelerated warning protection (AWP) should be used instead of power reduction and limiting for modes with tripped main feedwater pumps;

– generator-grid timing devices should be used for modes with the unit operating for auxiliary power supply;

– Russian-developed software and hardware tools should be fully switched to in implementing both normal operation and safety control systems, since the adjustment of protection and interlocking algorithms used in the AREVA software and hardware package introduced at Novovoronezh II requires the developer’s authorization which involves substantial time and financial expenditures.

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Introduction

Dynamic stability of an NPP unit during transients is the capability of systems and components to maintain the design limits for the variation of process parameters without scram and the unit disconnection from the grid [1].

Modern NPPs have thousands of monitored and controlled interdependent process parameters capable of varying rapidly and within broad intervals even in conditions of normal operation [2]. Such variations can be caused, e.g., by trips of nonredundant components or off-peak load and the subsequent partial or full unit curtailment. Dozens of safety-related parameters are monitored by the unit’s automated process control system (APCS) and are capable to trigger the reactor scram directly [3–5].

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This, undoubtedly, makes it critical to ensure and improve the dynamic stability of power units.

One of the ways to improve the dynamic stability of an innovative unit with the VVER-1200 reactor, with [6–9] taken into account, is to optimize its control algorithms involving trips of nonredundant key components, including the development and implementation of proposals for adjusting the effective process protections and interlocks based on the experience of pre-commissioning activities at the power ascension stages.

The skills of coping with the unit malfunctions with failures of key components were developed in the operating personnel of Novovoronezh NPP based on a full-scale simulator (FSS) put into operation two years before the unit startup.

The simulation of conditions with the trip of one main feedwater pump (MFP) and the failure of the standby pump on the FSS to operate included generation of the process protection signal for the MFPs in operation to trip in response to the permissible feedwater flow rate having been exceeded at the pump outlet, leading to the loss of levels in the steam generators, trip of all reactor coolant pumps (RCP) and the resultant scram.

With regard for the FSS simulation results and taking into account [10–14], the conditions during preparations for the tests with the MFP trip at the 100% power level, the protection settings for the MFP trip were changed:

- from 8.3 to 8.0 MPa for the pressure protection at the MFP discharge end;
- from 2050 to 2100 m3/h for the feedwater flow rate protection;
- from 90 to 300 s for the delay of the MFP to trip in response to the discharge end flow rate increase.

Tests with trip of one MFP and the standby MFP failure to start at the 100% N_{nom} power level

After the trip of MFP-1, the following operation sequence of the power reduction and limiting (PRL) systems and the automatic power regulator (APR) was recorded:

- in response to the MFP trip, the PRL started to operate and began to reduce the reactor power using the first-order warning protection (WP-1) circuits, while the APR tripped stopping to control the control and protection system (CPS) rods in response to the operation of WP-1;
- the PRL stopped to reduce the reactor power at the 79th s with the neutron power being N = 74.5%; the APR started to operate to control the CPS rods in the “N” mode and was keeping the neutron power at that level.

The PRL operation led to the reactor power having been reduced from 100% to 74.5% N_{nom} for 75 s. The reactor power reduction rate during the PRL operation was 0.34%/s. The position of the regulating 12th CPS rod group changed from the initial 83–43%. The 11th CPS rod group went down to 95% (Fig. 1) and then moved back to the position for the operation of the upper limit switches (ULS).

The electrical parts of the turbine regulation system (TRS) changed over to the “RD” mode in response to the APR trip and initiated the turbine generator (TG) power reduction. The power was decreasing from 1157 to 835 mW for 176 s. In the end state, the TG power stabilized at 830 mW. Meanwhile, the pressure in the main steam header (MSH) varied between 6.66 MPa and 6.84 MPa. The primary circuit pressure varied between 15.34 MPa and 16.02 MPa being regulated by the operation of the pressurizer’s tubular heating elements (THE). The initial pressure level in the primary circuit was reached by the 385th s.

The level in the feedwater deaerator varied between 2.19 m and 2.66 m being regulated by the main level regulator (MLR1,2). The position of MLR1 was between 2% and 59% and that of MLR2 was between 0% and 36%. The position of the starting level regulator (SLR) during the tests was 47% (Fig. 2).

The pressure in the feedwater deaerator varied between 0.68 MPa and 0.86 MPa. The fast-acting steam dump valve with discharge to the deaerator (BRU-D1) started to operate at the 266th s at a pressure of 0.7 MPa, and BRU-D2 started to operate at the 290th s at a pressure of 0.69 MPa. The BRU-D1 position was between 0% and 43%, and the BRU-D2 position was between 0% and 21%.

The level in low pressure reheater (LPR) 2 was regulated by MLR1,2 and was between 2.0 m and 4.2 m. The MLR1 position was between 3% and 70%, and the MLR2 position was between 6% and 28%. The SLR position was 50% throughout the tests.

The steam pressure in the auxiliary header (AH) during the tests was between 0.68 MPa and 0.86 MPa, and no auxiliary BRUs were in operation.

The level in the turbine condenser increased from initial 0.9–1.12 m and stabilized at 0.93 m at the test end.

Prior to the trip of MFP1, the total flow rate at the MFP discharge end was 7422 m^3/h. The flow rate in the tripped MFP1 decreased to zero for 7 s. The flow rates in MFPs 2,4,5 increased to between 1953 and 2046 m^3/h (in each MFP) and was maintained by the level regulators (LR) in the steam generators (SG) in the MFP discharge end feedwater rate maintenance mode. As the result of the reactor power reduction, the flow rates at the MFP discharge end stabilized at 1700 m^3/h (in each MFP). At the 220th s, after the level in SG-3 increased to the rated value, the level regulators in the SG changed over to the SG level maintenance mode. The pressure at the MFP discharge end did not go down to below 8.18 MPa. At the end of the tests, the MFP discharge end pressure was about 9 MPa. As the result of the tests, the time delay for the MFP trip in response to the flow rate being in excess of 2100 m^3/h is recommended to be set at not less than 300 s.

During the transient, the levels in SGs 1–4 varied between 2.38 m and 2.81 m (Fig. 3). The positions of the starting SG LRs were between 26% and 28%. The positions of the main SG LRs were between 30% and 82%.

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