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RELAP5/MOD3.2 ANALYSIS OF TRIP OF ONE MCP AT KOZLODUY NPP UNIT 6

Malinka Pavlova, Pavlin Groudev
Institute for Nuclear Research and Nuclear Energy
Bulgarian Academy of Sciences
Tzarigradsko Shaussee 72, Sofia 1784, Bulgaria

V. Hadjiev
Kozloduy Nuclear Power Plant

This paper discusses the results of the thermal-hydraulic investigations of the trip of one MCP at Unit 6, Kozloduy NPP.

This investigation is a process that compares the analytical results obtained by the RELAP5 computer model of the VVER-1000 against the experimental transient data received from the Kozloduy NPP Unit 6. The RELAP5/MOD3.2 computer code has been used to simulate the trip of one MCP in a VVER-1000 Nuclear Power Plant (NPP) model.

A model of the Kozloduy Unit 6 has been developed at the Institute for Nuclear Research and Nuclear Energy – Bulgarian Academy of Sciences (INRNE-BAS), Sofia. The model development and validation has focused on the applicability of RELAP5 to this type of transient.

The transient demonstrates the capability of NPP Unit 6 to reduce reactor power from one level to an other (lower power level) in case of losing one MCP. Reactor power was reduced from 82% to 67% during the transient without any need to initiate a scram.

VVER-1000 NUCLEAR POWER PLANT DESCRIPTION

The reference power plant for this analysis is Unit 6 at The Kozloduy NPP site. This plant is a VVER-1000 Model V320 pressurized water reactor that produces 3000 MW thermal power and generates 1000 MW electric power. The basic design of a VVER-1000 plant comprises: a pressurized water reactor of 3000 MW thermal power with 163 hexagonal fuel assemblies in the core, and 10 absorbing rod banks, located in 61 fuel assemblies; four primary loops; and one turbogenerator (1500 rpm) producing 1000 MW of electric power.

The reactor vessel has 4 inlet nozzles of ∅ 850 mm and 4 outlet nozzles of ∅ 850 mm to connect to the four primary loops. There are also 4 inlets of ∅ 280 mm for safety injection of boron solution to the upper and lower plenum in case of primary loss of coolant.

Each loop includes one main circulation pump and a horizontal U-tube steam generator (SG). The behavior of the horizontal SG is very different compared to Western-style vertical SG. For example, the secondary side of the horizontal SG contains much more water and all loss - of - feedwater transients are slower. Steam generators play a very important role in the safe and reliable operation of VVER power plants. They determine the thermal-hydraulic response of the primary coolant system during operational and accident transients.

The feedwater (FW) system feeds condensate water into the SG trough the HP Heaters (or their bypass) and controls the SG during normal plant evolutions. The feedwater system includes two turbine-driven FW pumps (FWP), two auxiliary electrically driven FW pumps (AFWP), and ten control valves.

Reactor control and protection system consists of the following subsystems: control rods and driver; reactor power controller RPC (ARM); reactor power limitation controller RPLC (ROM); reactor scram subsystem; warning protection (WP) and fast load coast down subsystems.

RPC (ARM-5C) operates together with the electro-hydraulic turbine control system (EHSR) and has two modes of operation: ***Mode T:*** *Power control based on constant secondary pressure in the range 10-110% of the nominal reactor power.* ***Mode N:*** *Maintains constant neutron flux density in the range 10 -110% of the nominal reactor power, using AKNP (automated control of neutron flux system) signal.*

Worming Protection is a type of emergency action of the control rods:downward movement of the control rods bank by bank, starting with the "control bank", normally Rod bank #10. When the initiating signal is cleared, rod movement stops.

Power restriction controller RPLC (ROM-2M) decreases reactor power to a pre-defined value in the following cases:

-Tripping of 1 out of 4 RCP - to 67% of nominal;

-Tripping of 2 non- neighbouring RCP - to 50% of nominal;

-Tripping of 2 neighbouring RCP - to 40% of nominal;

-Tripping of 1 out of 2 main FW pumps - to50%;

-Tripping of 2 out of 2 main FW pumps - to 6%;

-Grid frequency less than 49Hz - 10% below the current power;

-Closing of 2 out of 4 turbine stop valves-to 40%;

-Opening of KAG-24 - to 40%;

-Opening of BB-440 - to 40%.

In case of RPLC (ROM) working, ARM-5C is switched off. The power decrease is performed by inserting the operational group into the core with operational velocity of 2 cm/s.

DESCRIPTION OF THE TRANSIENT TRIP OF ONE MCP AT KNPP, UNIT #6

The reason for the failure of the main coolant pumps (MCPs) could be electrical – loss of electrical power. The experiment and the RELAP5 analysis have assumed that the MCP failure is due to the loss of electrical power. The transient demonstrates the capability of NPP Unit 6 to reduce reactor power from one level to an other (lower power level) in case of losing one MCP. Reactor power was reduced from 82% to 67%during the transient without any need to initiate a scram. During the *transient primary side pressure and Pressurizer water level have been controlled by the Make up system and by the Pressurizer heaters. Secondary side feed water controllers reduce feed water flow rates corresponding to the new reactor power level.*

One of the four main circulation pumps was tripped and the power level was reduced from 82% [2460 MW] to 67% [2010 MW].

During the transient, a signal from Reactor Power Limitation Controller RPLC (ROM) generates a warning protection-1 (WP-1) signal.

The Reactor Power Controller RPC (ARM) automatically disconnected from operating the control rods (CR) and drives. Changes of the RPC modes of operation automatically lead to corresponding changes in the Electro-Hydraulic Turbine Controller (EHTC) mode and reduces turbine power corresponding to the reduction in thermal power of reactor.

Rod Bank #10 inserted from position 296 cm to 263 cm of the core height in 28 sec at the normal operational speed of 2 cm/s.

When the WP-1 signal is cleared, the RPC continues to work in "N" mode and maintains the neutron power level reached at that time (67% power) and switching to controlling the control rods.

During the transient, the plant staff did not interact with the operation of the automatic control system. The response of the primary and secondary side control system did not reach the reactor scram setpoint. Transient indicated that the steam dump to condenser facility (BRU-K), steam dump atmosphere (BRU-A), and spray system from the cold leg piping are not active.

All plant systems are available during the transient.

The basic scenario is as follows:

Initial conditions: Reactor Power - 82 % N

1) Trip of MCP #3

2) Switching on RPLC and decreasing of Reactor Power from 82 % to 67%.

3) Switches off RPLC

The initial steady state conditions of important plant parameters at 82% power, before starting the test, are shown in Table 1.

RESULTS AND DISCUSSION

The scenario that was followed at the NPP - Kozloduy Unit #6 during the transient was simulated in the RELAP5 calculations. The calculation was performed up to 400 sec of transient time. The presented plant data are in every 4 sec. The interesting event is the reverse flow in one of the loops (in the damaged loop with the MCP switched off). The most interesting parameters for investigated event are behavior of coolant temperature and behavior of flow rates in different loops. All SGs water level was accepted to be 2.45 m.

Initial values of inlet and outlet reactor vessel temperatures are the same as the plant:

- ✓ *inlet temperature 558.0 K;*
- ✓ *outlet temperature 584.0 K.*

The following parameters (available from plant data collected during the transient) were compared between plant measurements and RELAP5 code calculations:

- ✓ *Primary and secondary side pressure;*
- ✓ *Temperatures in hot and cold leg #3*
- ✓ *Temperatures in hot and cold leg #1;*
- ✓ *MCP #3 pressure difference;*
- ✓ *Delta P of reactor vessel;*
- ✓ *Flow rates of loops (Loop #1 and Loop #3);*

One of the important parameters is the pressure in the primary and in the secondary circuit, since this parameter is input to many reactor control systems in primary and secondary side.

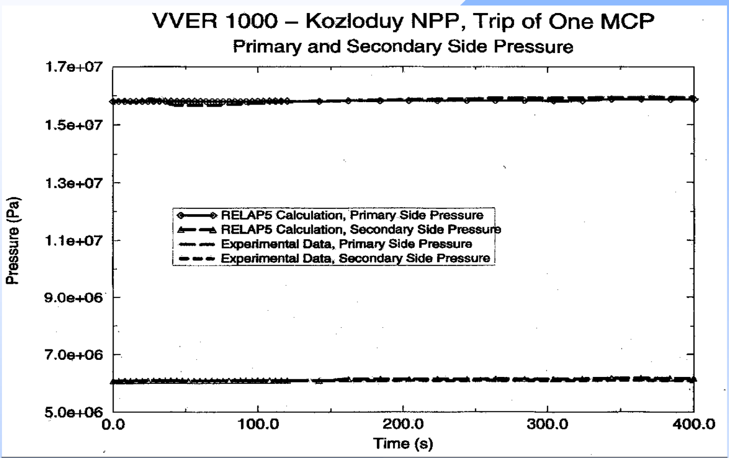

Fig.1 Comparison of Primary and Secondary Side Pressure

Figure 1 presents the measured primary and secondary pressure during the experiment and the calculated by REALP5 primary and secondary pressure. As shown, the calculated secondary side pressure are almost identical to the measured secondary pressure. In comparison of RELAP5 calculated primary side pressure with plant data there is a small difference. While in the plant data there is no changes during the transient, in RELAP5 the calculated primary pressure has a small increasing of pressure for the first 30 sec. and decreasing of pressure for the next 30 sec. Maximum pressure of 16.10 MPa was reached at 30.sec. Due to work of Make up/ Let down system primary side pressure was stabilized at level *16.0 MPa after first 120.0 sec. for both cases calculated and measured.*

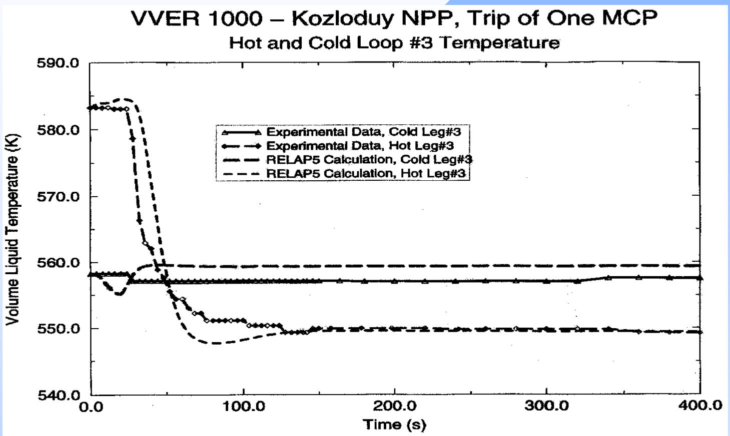

Fig.2 Comparison of Hot and Cold Leg Temperatures of Loop #3

The comparison of hot and cold leg #3 temperature is presented in ***Figure 2****. The initial values of these parameters are same for both cases – calculated and measured. Decreasing of hot leg temperature becomes faster in recorded plant data compared with RELAP5 calculation between 30.0 sec. and 50.0 sec. and later for next 50.0 sec. decreasing of hot leg temperature is faster in RELAP5 calculation. The hot leg #3 temperature in the end of transient is the same for calculated and measured. The calculated cold leg # 3 temperature in the end of transient is 2 degrees higher compared to plant data, which is in the range of measurement accuracy. Nevertheless, it is seen that the calculation closely follows the results obtained from the plant event.*

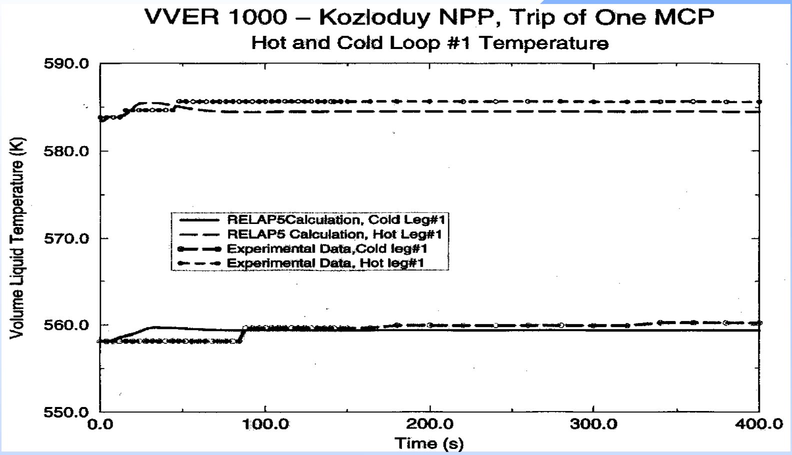

Fig.3 Comparison of Hot and Cold Leg Temperatures of Loop #1

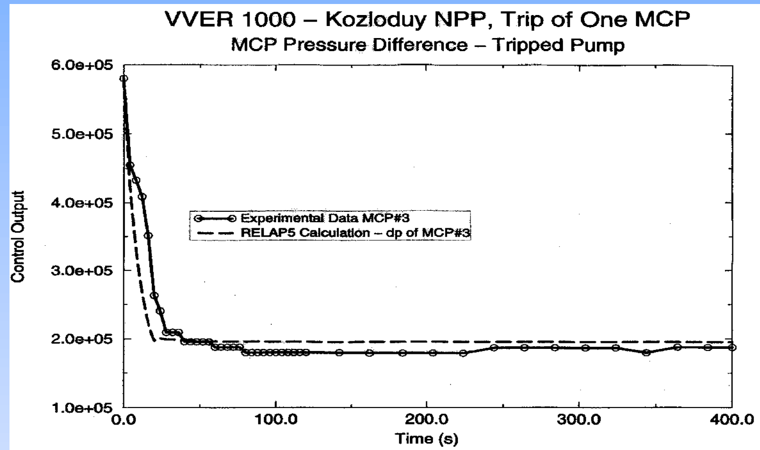

Fig. 4 Comparison of MCP Pressure Difference for Tripped Loop

*Comparison of hot and cold leg #1 temperatures is shown in **Figure 3**. Cold leg temperature closely follows the results obtained from the plant event except for the first 50 sec, where calculated results are 2.0 – 3.0 degrees higher. This value is comparable to the different values of the measured hot legs.*

*Main coolant pump pressure difference are compared in **Figure 4**. Decreasing of RELAP5 calculated MCP pressure difference is faster in first 50 sec. In RELAP5 calculation this value became 2 bars at 30 sec, while in experiment data this parameter became 2 bars at 45 sec. After that there is no big difference .*

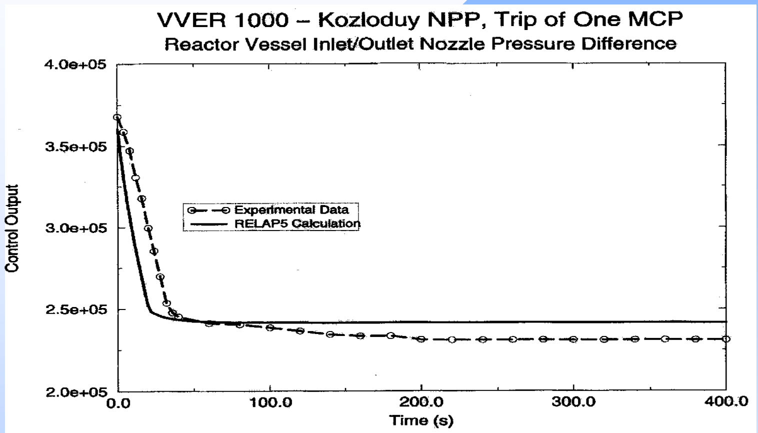

Fig.5 Comparison of Reactor Vessel Pressure Difference

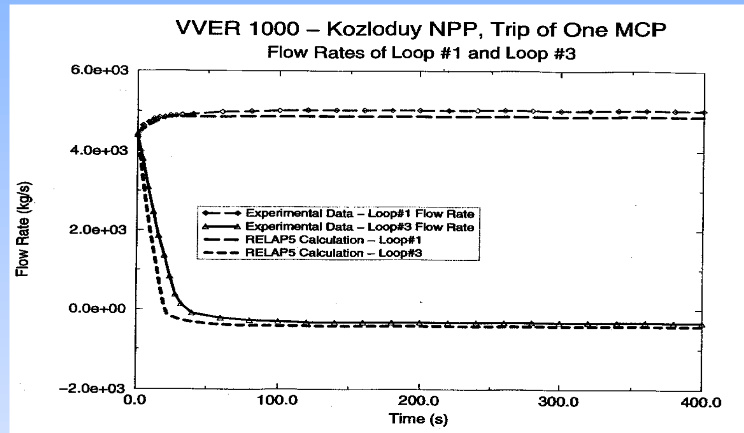

Fig. 6 Comparison of Flow Rates of Loop #1 and #3

Figure 5 *provides comparison of Reactor Vessel Pressure Difference. As it is shown in this figure, there is also a good agreement between the plant data and the RELAP5 calculation.*

Comparison of flow rates in Loop #1 and Loop #3 are shown in ***Figure 6****. In both cases a reverse flow rate is indicated. The flow rates of tripped loop and RELAP5 calculated results decreases rapidly in the first minute of the transient. The flow rates of intact loops increase in the same time.*

CONCLUSIONS

Test facilities are frequently scaled down models of the actual power plant; the scaling can increase the uncertainty of the results of the test facility relative to the reactor performance. In this benchmark based on Kozloduy NPP the scaling is not a factor.

The results provide an integrated evaluation of the complete RELAP5 VVER-1000 model. The comparisons indicate that RELAP5 predicts the test results very well. These results are an important part of the validation of the RELAP5 model developed for Kozloduy NPP.

The overall conclusion is that RELAP5/MOD3.2 is adequate to simulate the transient phenomena occurring in a VVER-1000 for this type of transient MCP failure conditions.