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Research Article

RELAP5/MOD3.3 Code Validation with P Abnormal Event

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Abstract

Measured plant data from various abnormal events are of great i study was to validate the RELAP5/MOD3.3 Patch 03 computer cod Nuclear Power Plant (NPP) on April 10, 2005. The event analyzed reduction sequence when regular periodic testing of the turbine closing caused safety injection signal, followed by reactor trip. Th used. In short term, the calculation agrees very well with the plan when operator actions and special plant systems are modeled. I differently. Finally, the calculated data may be supplemental to pl or the measurement is questionable.

1. Introduction

Usually the validation has been performed using experimental d assessments of best estimate codes using experimental data wer the use of experimental data in nuclear reactor thermal hydrauli hydraulic system codes and scaling issues are concisely described important especially validation matrices of separate effects test

data from NPP can be used, if available, and that the data obtaine
the plant. Typically, real plant data are limited mostly to operatior
other components, resulting in complex plant response [5 - 8]. Hc
geometry; therefore they are of great importance for code val
response to deviations from normal operation.

In this paper an abnormal event, which occurred at Krško Nucle
studied with the RELAP5/MOD3.3 Patch 03 computer code [9]. Fo
Krško NPP was used. This is a full two-loop plant model including
system. The limitations of the delivered model for this transient w
turbine only and that no auxiliary systems consuming steam after
very important for the behavior of the secondary pressure and c
dictate the operation of the control and safety systems. The ana
(2000 MWt) with new steam generators and cycle 21 settings,
refuelling in September 2004.

A malfunction occurred during a power reduction sequence when
performed. This caused plant trip, while all the safety systems res
event caused no hazard to the environment or plant staff and di
analysis was to analyze the transient and compare the results with

The analysis was divided into five phases. The first four phases w
the first phase steady state at 100% power level was demonstra
from 100% to 91.72% level. In the third phase one cycle of
simulated in order to obtain as close as possible initial conditions.
verified by comparing calculated initial conditions with plant data
transient start. Finally, in the last phase the transient was anal
stopped at that time.

2. Input Model, Event, and Analysis Scenario Descri

For the abnormal event analysis the RELAP5/MOD3.3 Patch 03 co
basic RELAP5/MOD3.3 thermal-hydraulic model uses six equations
conservation equations, and two energy conservation equations
empirical correlations. For more details the reader is referred to [9

2.1. RELAP5 Input Model Description

To perform the analysis, Krško NPP has provided the qualified b
deck," which has been used for several analyses, including ref
verification [10 - 12]. The simplified scheme of the Krško NPP no
plant model, delivered by Krško NPP, has been used for the a
replacement steam generators type SG 72 W/D4-2. The analysis w
MWt) with new steam generators (SGs) and cycle 21 settings,
refuelling in September 2004.

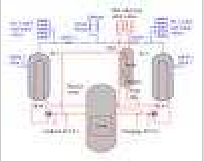

Figure 1: Krško NPP simplified scheme.

The model consists of 469 control volumes, 497 junctions, and 3
Modelled are important components as the reactor vessel, pressuri
spray lines and spray valves, pressurizer power operated relief
includes hot leg, primary side of steam generator by inlet an
representing the U-tube bundle, intermediate leg and cold le
symmetrical except for the pressurizer surge line and chemica
(charging and letdown). Modeled is emergency cooling system (E
accumulators, and low-pressure injection system (LPIS).

The parts of the steam generator secondary side are represented
and steam dome. Main steamlines have main steam isolation val
valve and steam dump flow are regulated by corresponding logic
MFW pump, which is modelled as time-dependent junction. Auxiliar

Besides, a considerable number of control variables and gener
protection, monitoring, and simplified control systems used only
plant control systems: rod control system, pressurizer pressure
steam generator level control system, and steam dump.

The plant protection systems defined using trip logic include rea
steamline isolation, main feedwater isolation, and auxiliary feedwa

2.2. Event Description

The Krško NPP technical specifications required that the turbine
operable at least once per 31 days by cycling each of the high pr
least one complete cycle from the running position. The test pro
turbine (and by this reactor power) must be reduced below 92%
test of turbine governor and stop valves is performed.

In the first step the turbine power is reduced until governor val
reduced for another 7% until the nuclear power is less than or eq
changed from sequential to single mode of operation. The positio
equal 35% of opening. On the opposite, the power should be addit

In the second step of testing turbine valves, the allowed maximur
of opening. To fulfil this, “valve position limit display” button
position limit.” Then the valve position limit is raised to 160% a
closed and then opened to its initial value. When all valves are t
value at test start (less than or equal 35% of opening). When lov
below “flow demand” value. On the opposite, the governor valve
event these really happened. The valves were closing for 5 second
12 seconds, and after that the position starts to increase to 14%,
indicate that the operator sets the valve position limit below flow d
turbine flow. This resulted in reactor trip in next 2 seconds or le
each 2 seconds). Setting the valve position limit below the flow d
noticed decreased electrical power output he tried to correct the se
aware of the steam dump operating. The increased steam flow de
steam generator pressure drop, therefore the SI signal was gene
reactor trip signal was generated followed by turbine trip. SI sig
delay.

The measured data were available for 1878 seconds and were sa

seconds represent the steady state while at 54 seconds the gover
transient started. Therefore, it was assumed that governor val
transient start time ($t = 0$). The remaining data up to 1878 seconds

2.3. Analysis Scenario Description

The RELAP5/MOD3.3 Patch 03 analysis was divided into two pai
closing and opening of governor valve was simulated. The purpos
initial conditions as close as possible to the plant initial conditions
shown in Table 1. In the first phase, steady state at 100% power
power was reduced from 100% to 91.72% level and steady stat
phase, one cycle of turbine governor valve closing and opening wa
initial conditions. In total, there are four turbine governor valves.
when governor control valve is fully closed. When the governor v
for the third phase, the steady state was demonstrated. When a
component was replaced by valve component this caused some ti
calculation with valve component was performed in the fourth pha
plant condition because of replacing time dependent junction. Th
which were available for 53 seconds before the transient start. By
controls to achieve steady-state condition at 91.72% level. It shou
governor valve, the position of other three governor valves is a
constant. Also, the plant data were not available at 100% power
The novel feature of the above approach is that the initial conditi
that is, opening and closing the turbine governor valve.

Table 1: Subdivision of analysis.

In the second part, which is the fifth phase, the transient leading
reactor trip was simulated. The time zero was denoted for the tra
from −4000 seconds to 0 second, while the transient was analyzed

3. Results

Figure 2 shows the results for part 1 analysis, while Figures 2 an
analysis. In part 1 analysis, the power was reduced from nominal
and opening of turbine governor valve was simulated. In part 2
reactor trip at 91.72% power level, and associated operator action

Figure 2: Achieving steady state at 91.72%: (
PRZ pressure, (d) SG 1 pressure.

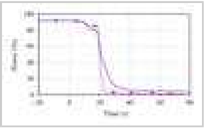

Figure 3: Transient with reactor trip—sho
temperature, (c) PRZ pressure, (d) PRZ level
steam flow, (h) SG 2 steam flow.

3.1. Part 1 Analysis—Achieving Steady State at 91.72% Lev

Figure 2 shows some important calculated variables during sin
explains how initial condition at 91.72% power level was ob
calculation”) are shown in the time interval (−4000 seconds -
(labelled “NPP measurement”) were available for interval (−5
scheme was such that flow was reduced from nominal value 10
turbine valve test initial conditions. Then the simulation of closing
without operating other turbine governor valves. This caused rod i
minutes were assumed for 25% power reduction from 91.72% po
less than 5% of nominal power per minute load reduction. In thi
When the VALVE component was introduced back into the inp
introduced which quickly stabilizes during the fourth phase.

The obtained initial conditions are shown in Table 2. The first two c
The third column shows average value of plant measured initial co
(−53 seconds - 0 second) because the measured values were s
second was chosen as start of reactor trip transient. For this time
the fourth column, which in some cases differ from average stead
accuracy for the measured channels. The design accuracy can b
accuracy is lower as time drift and environmental effect should b
columns steady-state values at the end of the second, the third, a
are given calculated initial conditions after initial power reduction
in the seventh initial conditions after rods withdrawal (at time -
conditions at the time of transient start ($t=0$). When comparing t
conditions, with the exception of feedwater flow for loop 2, all valu

Table 2: Initial conditions for reactor trip trans

Please note that for power reduction, the turbine flow was mod
linear flow decrease and increase can be prescribed. The benefit o
plant would respond to linear power decrease, what would be very
is not linear with the steam flow). It should be noted, that this
tactics for achieving steady-state conditions. The nonlinear clos
component too, but it would require more time as 5%/minute c
Another steady state had to be calculated when TMDPJUN compone
turbine governor valves.

The reason why simple power reduction scheme was not performe
that in the case of just lowering the power to 91.72% by insert
power and turbine power some initial conditions are different fr
Figures 2(b) and 2(d)). The reason is the deadband in the t
temperature and the auctioneered average reactor coolant system
stop to move in and start to move out is 1.4 K. Such a difference
side too (1 K temperature change corresponds to 0.125 MPa pre

Due to rod movement, the reactor power changes as it is shown i
modelled as a linear function of turbine flow. The RCS average tem
when power was decreased but increased in the initial 150 second
delay caused by a combination of loop transport time, resistance
instrument processing time (see Figure 2(b)). Then the tempera

value. Same phenomenon repeated at the beginning of the third When power is increased the opposite happened. The temperatu −1530 seconds (the turbine governor valve starts to open at −170

Proportional heaters compensate the pressurizer pressure duri pressure initially increases and then returns to its nominal value, (c)). Finally, the steam generator 1 pressure shown in Figure 2 decreasing during turbine valve opening. When the turbine val direction and stabilizes at certain value depending on the value of

3.2. Part 2 Analysis – Transient with Reactor Trip

The time sequence of main events during the transient is shown in on the measured data of plant variables. The measured data show 5 seconds from 35.5% to 12.2% position, and then stabilized for 14% (opening caused by operator), there was full closure of turbi was tripped. The reason for the reactor trip was low steamline pressure signal resulted from the turbine flow increase. As at 15 seconds was already 14.1% it was assumed that operator starts t On SI signal also main feedwater isolation and main steamline actuated, and letdown and charging are isolated.

Table 3: Time sequence of main events durinc

It should be noted that the sequence of events was determined plots; therefore the values are rounded to seconds. For example, exact time of reactor trip could not be determined because delay ir

To obtain the correct time sequence of events in short term, it wa closure and subsequent opening of turbine governor valve. How t generators number 1 and 2, is shown in Figures 3(g) and 3(h), calculations depends on the position of turbine valves and SG P closed at 20 seconds while the SG PORVs open at 27 seconds. Af than in the plant. From the measured data, it could be conclu governor valve closure. In the RELAP5 model these systems w differences.

Figure 3(a) shows the power drop when the reactor is tripped. The the neutron flux. After reactor shutdown, only a part of decay hea spontaneous fission neutrons. Decay heat comes also from other actinides. Therefore, the measured neutron flux is lower than disagreement with the calculation. The decay heat is simulated w correctly this decay.

The RCS average temperature is shown in Figure 3(b). After trar until reactor is tripped in 17 seconds. Then the temperature is a side injection) and the secondary heat sink.

In Figure 3(c) is shown pressurizer pressure. The initial pressure rapidly increasing until the pressurizer sprays are actuated. It can reduce the pressure increase before reactor trip. When the re decreased. Initial agreement is very good including peak pressure calculated pressure shows repressurization of the primary systen and measured steam flows (see Figures 3(g) and 3(h)). It should governor valve was simulated till 17 seconds when the valve close measured data, the steam flows start to drop at 21 seconds. In caused SG pressure increase what deteriorated cooling of the pr when secondary side cooling was re-established by SG PORV op decrease again. In addition, some cooling on the primary side calculation the injection started in 50 seconds. No adjustment injection, SG PORV operation, and steam flows.

The steam generator pressure was calculated very well as shown governor valve closure and the second peak due to the turbine tri valves, the SG pressure after first peak started to decrease; the pressure. The second peak caused the SG PORV valve opening.

The steam generator levels also agree well initially as shown in F main feedwater isolation. The closure of the turbine valves and cor in the steam pressure increase (see Figure 3(e)), which had instrumentation. On SI signal with 25 seconds delay, the AFW ir filling the steam generators. Following the main feedwater isolatio feedwater and released steam. However, it was observed that ir when SG PORV 1 is operated, the calculated level is higher than tl could be in the RELAP5 input model; the damping of the oscillatin in the steam generators is underpredicted.

In the long term, the secondary pressure dictates the transient p used in the calculation to simulate the operation of AFW pumps. T flow was modeled also as indicated by the measured data (see Fig such that after the main steamline isolation after the turbine tı system. The steam in the steam generators is generated based Figure 4(h), it can be seen that the measured value of steam generated steam for one steam generator (label “calculation limit a way to obtain as much as possible good agreement of SG press physically feasible, but it is not known if it was so in the reality. Without assuming any steam flow after reactor trip or assuming would be overpredicted (requiring SG PORV opening) or underpre calculated variables are in excellent agreement with the measurec of power range channel is based on the neutron flux as already n than the calculated power based on the decay heat (Figure 4(a)). 4(e)) also the RCS average temperature (Figure 4(b)) and SG lev discrepancy in the pressurizer pressure and level (Figures 4(c) ar different from the measured data. It was decided not to tune the operated approx. 5 minutes). Later, the primary system is filled by

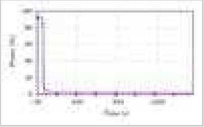

Figure 4: Transient with reactor trip—long ter (c) PRZ pressure, (d) PRZ level, (e) SG 1 pres SG2 steam flow.

Important was the finding that RELAP5 computer code calculatior out that there is some larger steam flow to the gland steam sy: turbine trip, which occurred in the analyzed event. Namely, the RELAP5 input model.

3.3. Quantitative Assessment

The obtained results shown in Figure 4 were quantitatively ass
(FFTBM). Both the original FFTBM [13] and improved FFTBM
quantitative assessment by applying FFTBM was done to confirm
The readers not familiar with FFTBM can refer to references [1, 1
know that lower is the average amplitude (AA), higher is the accu
good calculation. For primary pressure the AA below 0.1 means a
time intervals, the time interval (−20 seconds – 0 second) for ste
long-term (0 second – 1800 seconds) results.

Table 4: Quantitative results for different time

The results for time interval (−20 seconds – 0 second) showed th
confirms the results in Table 2, where it is shown that all variabl
measuring channels. For the short- and long-term calculation th
calculation. When comparing original FFTBM and improved FFTBM
due to the unphysical edge effect (difference between the first
frequency spectrum in the original FFTBM. When edge is present
lower AA in the case of original FFTBM, that is, core power and st
how edge effect could be eliminated by signal mirroring, the reade

4. Conclusions

In this study, plant measured data for abnormal event resultin
validation of the RELAP5/MOD3.3 Patch 03 computer code. The a
an approach by maneuvering the plant was proposed to achieve
turbine governor valve closure with reactor trip and the associated

The calculated initial conditions at 91.72% power level were ac
maneuvering the plant. These results suggest that the input mod
plant. The results of the abnormal event analysis showed good ag
in the short term. This is true also for long term when operator act

The limitation of the plant measured data for code validation is t
Namely, the calculated results showed that the transient evolutio
trip. In the short term, it would be very valuable to have separat
through SG relief valve. This would clarify differences in flow a few
that in the long term the measured data indicate steam flow afte
pressure also RELAP5 computer code calculation suggests some st
it was found out that there is some steam flow to the gland steam
turbine trip, which occurred in the analyzed event. Namely, the
RELAP5 input model. But, the study of maximum steam generated
steam flow was not reliable. Therefore, the steam flow was tuned
the calculated and measured steam generator pressure. In this wa
the plant measured data.

In general, the conclusion is that the RELAP5/MOD3.3 Patch 03 c
event but it requires qualified input model. In the presented stu
steam system is needed to obtain good quantitative agreement. F

the plant measured data when the information is missing or the m

Acknowledgments

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References

1. A. Prošek, F. D'Auria, and B. Mavko, "Review of quantitativ based method (FFTBM)," *Nuclear Engineering and Design*,
2. A. Prošek, F. D'Auria, D. J. Richards, and B. Mavko, "Quant for heavy water reactor calculations," *Nuclear Engineering*
3. F. D'Auria, "The role of experimental database in the valida *International Journal of Heat and Technology*, vol. 21, no. 1
4. A. Petruzzi and F. D'Auria, "Thermal-hydraulic system code procedures," *Science and Technology of Nuclear Installatio*
5. IAEA-TECDOC-1550, in *Proceedings of a Technical Meeting Nuclear Power Plants*, Dubrovnik, Croatia, May 2005.
6. P. Groudev and A. Stefanova, "Validation of RELAP5/MOD3 VVER 440/V230," *Nuclear Engineering and Design*, vol. 23
7. A. Prošek, B. Kvizda, B. Mavko, and T. Kliment, "Quantitati *Nuclear Engineering and Design*, vol. 227, no. 1, pp. 85–96
8. I. Parzer, "RELAP5/MOD3.3 simulation of MSIV closure eve *American Nuclear Society*, vol. 87, pp. 202–203, 2002.
9. Information Systems Laboratories, Inc., Nuclear Safety Anal NUREG/CR-5535 Rev. P3," Rockville, Maryland, Idaho Falls
10. I. Parzar, B. Mavko, and B. Krajnc, "Simulation of a hypoth nuclear power plant," *Journal of Mechanical Engineering*, v
11. A. Prošek, I. Parzer, and B. Krajnc, "Simulation of hypothet modernized nuclear power plant," *Electrotechnical Review*,
12. I. Parzer, "Break model comparison in different RELAP5 ve *Conference Nuclear Energy for New Europe*, pp. 217.1–217 September 2003.
13. F. D'Auria, M. Leonardi, and R. Pochard, "Methodology for t accuracy," in *Proceedings of International Conference on N* Pisa, Italy, May-June 1994.
14. A. Prošek and M. Leskovar, "Improved FFTBM by signal mi *Proceedings of International Congress on Advances in Nucle* Nice, France, May 2007.