Ultimate design and testing TPTS-based control systems with using full-scaled physical models of nuclear power plants

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Abstract. Radiation degradation rate of base current in SiGe HBTs was experimentally investigated using X-ray irradiation source with Cu anode at room and low temperatures. The dependences of base and collector current on the emitter-base voltage of the transistors were measured during radiation impact and presented for different total dose levels and irradiation conditions.

1. Introduction
Development of I&C for Nuclear Power Plants is complicated by difficult of processes, count of signals and equipment. One else difficulty is requirements to equipment of I&C. Russian design power plants used TPTS equipment produced by VNIIA, which certificated by ISTEC (all classes of protection IEC 61226).

Equipment of VNIIA is 90% I&C of nuclear power plants. Design of all of these parts of I&C is a task of a few big project institutes (JSC Atomenergoproject, JSC Atomproject etc.). These institutes are participated to process of design for all lifecycle. It produces concept project which contains algorithms which will be programs for microcontrollers. One else concept project contains description of electricity connection and requirements to reliability. It’s main task of project because it influents on count of equipment for I&C (count of microcontrollers) and its location on power plants. I&C for «Belarussian» NPP (is the most modern NPP of Russian design) involves over than 3500 TPTS controllers, which resolve different types of tasks of control systems. Such difficult distributed control systems need special methods for development and testing.

2. Experimental equipment
For programming of TPTS controllers used special program which name is GET-R1. Developer can create not trivial logic which can involve function of reliability and diversity and these algorithms can be translated into «machine» code (STEP code) and loaded into controller by this program. GET-R1 certificated by international institutes and can be used on NPPs.

Specialists of cathedra №2 of MEPPh developed special programming module (SimuNT) which was involved into GET-R1 for testing and modeling algorithms with using full-scaled model of power plants.

Full-scaled model of power plants is integrated information system which includes models of neutron kinetics, thermal hydraulics and model of power electricity. All of these models are integrated by special information system which name is ENICAD. This program lets create full-scale models with over than 3*106 variables. Full-scale model is used in simulators for NPP and testing algorithms of I&C.
Programming module SimuNT lets create special testing scripts on language Python to estimate reliability of control systems and algorithms. These scripts can imitate inputs (or even states of inner memory cells) of TPTS based algorithms or model inputs (for example, output value of pressure sensor) according to technology instructions. Script estimate state of equipment (get data from full-scaled model) and estimate state of controllers after imitation. An automatic rollback hardware or model changes happens in the end of script execution.

Scripts can be executed with full-scaled model (Model testing). And the same scripts can be executed with real hardware (Hardware testing). Exist opportunity to execute package of scripts for testing all controllers and algorithms. Diagram functionality of script engine is presented in Fig.1.

![Diagram functionality of script engine](image)

**Figure 1.** Diagram functionality of script engine

PyTest used for script engine. This framework allows create scripts with using special syntax. User can split tests on independent parts (it’s the main part of unit module testing) with using this syntax, verify scripts in convenient IDE (PyCharm, Sublime, Visual Studio and others) and debug script. Python allow create template of scripts with using library Mako or create report in convenient format with using special python libraries.

Bellow example of the script is presented in Fig.2.

```python
#!/usr/bin/env python
# -*- coding: utf-8 -*-

from udps_client import *
import time

cli = TClient()

#allow test rewrite memory
cli.fs = 1

#Imitate 0.012 MPa of process function
cli["20KUB50CP001_MID"] = 0.012;

#Pause 1 sec
time.sleep(1);

#Check switch off equipment
if not cli["20KUB50API081_XB01"]:
    raise Exception("Not switch off 20KUB50API081");

#Rollback rewrite memory
cli.clear_force()
```

**Figure 2.** Example of testing script
This script allows check control function, which used in technology of NPP. It’s technology protection of equipment (pump).

Script tests send messages with using UDP protocol to SimuNT module. SimuNT can be connected with full-scaled model of NPP. Library ZeroMQ is used for such connection. ZeroMQ is cross-platform, multithreaded library and can be used in supercomputers (full-scaled models is executed on such machines often).

SimuNT uses LLC protocol and hardware specific library for connection with TPTS controllers. Library uses certified crypto functions for protection. Crypto protection is the main part of script engine, because these scripts can be executed in any time of NPP lifecycle, even when power plants on 100% energy efficiency. This technology can be used for any NPP hardware of I&C. And it can be a standard of hardware testing for modern NPP. Example of using this testing system – is verification of algorithms control systems

BRU-A in the technological system of steam pipes of fresh steam. Verification was done by JSC Atomenergoproject with Modeling and Simulators Design Department of VNIIAES. Technology system with BRU-A equipment used in algorithms of safety system.

In the course of the work on the assessment of control loops, the work of the BRU-A was checked during emergency cooling of the reactor.

BRU-A is necessary to ensure the reliability of the steam pipe system and protects against bursting when the pressure is exceeded. When this event occurs, the steam from the steam pipeline is discharged into the atmosphere. The operation of the BRU-A is an emergency mode, because the BRU-K, PGI-PG units can cope with excess pressure, which allow to preserve the "working medium" and not lose the efficiency of the reactor installation.

For the NPP-2006 project, the emergency setpoint of the operation of the BRU-A is 6.8 MPa. After this pressure is reached, the surplus of steam is released into the atmosphere and the BRU-A enters the pressure maintenance level at 6.57 ± 0.1 MPa. To test the technological algorithms, a process model was developed that described the pressure dependence in the steam pipeline from the position of the BRU-A.

3. Experimental results and discussion
The verification program included simulating perturbations in the steam pipeline and checking the control algorithms. The mathematical model of the BRU-A regulator is presented below in Fig.3.

![Figure 3. Structural diagram of the regulator BRU-A](image-url)

The total signal is fed to the relay element: P – current pressure in the steam pipeline, MPa; Ps – setting pressure, MPa; kx – feedback gain by valve position, MPa/%; X – valve position, %; Uc – correction signal in the circuit of the three-position relay element, MPa.
The developed testing algorithms simulate an input disturbance of 6.81 MPa and show the process of maintaining pressure at the level of 6.57 MPa. The test results are presented below. The results allow to conclude that the main regulatory criteria are satisfied.

![Graph showing pressure and valve position over time](image)

**Figure 4.** The process of maintaining the pressure in the GHG with the help of BRU-A at a pressure excess of more than 6.8 MPa

### 4. Conclusion

After the static testing of the task for automation, the controllers are programmed. The test scripts are connected to the equipment and simulate control actions, as well as on the model of the task for automation. The same execution of the results on the equipment and on the model allows to conclude that the validation procedure of the control system has been performed.

### References

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