Experience in using computer technologies for university training of future NPP personnel based on “University-Enterprise” program

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Abstract

This paper considers aspects of a program for training future nuclear power plant personnel developed by the NPP Department of Ivanovo State Power Engineering University jointly with the Kalinin NPP. The program components include application of computer modeling and simulation in the university-based studies and the “8th term” project for studies in the nuclear plant environment. During the 8th term, students acquire practical skills in carrying out shop-floor operations and undergo training at the plant’s training center where examinations are also taken. The university-based studies include computer modeling for numerical experiments in kinetics of water-cooled water-moderated nuclear reactors in the Mathcad environment. Processes are simulated using the VVER-1000 unit computer and full-scale simulators.

Software packages and procedural guides have been developed for mathematical modeling of reactor transients; simulation programs and procedures for the computer and full-scale simulators of neutron experiments and plant startup/shutdown operations have also been developed. Integrated training systems contribute to promoting occupational mentality and form an efficient tool for the personal development of future staff, so most attention in the use of simulators is given to the effects of individual qualities on the level of success achieved at the given stage of training. For illustration, a mathematical model is described and results from numerical experiments to study the reactor xenon stability are presented. Integrated implementation of the described training programs makes it possible to cut practically by half the period for the university graduates to adapt themselves to plant environment as confirmed by reports from the leaders of respective departments. Copyright © 2016, National Research Nuclear University MEPhI (Moscow Engineering Physics Institute). Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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Introduction

Implementing the existing program for the large-scale development of nuclear power in Russia requires training of highly skilled staff with an in-depth insight into the neutron and thermal-physical processes taking place during the nuclear reactor operation under any conditions. It is directly at the nuclear plant that a university graduate reaches an excellence as an operating staff member, still, however, it is possible to reduce considerably the period of his or her training thanks to the extensive use of computer technologies in the university studies and the continuous cooperation between the university and the industry in the process of training.

“University-Enterprise” program

Since 1985, a “University-Enterprise” program has been under way for training of future nuclear power plant personnel as part of a contract between Ivanovo State Power Engineering University (ISPEU) and the Kalinin NPP (KNPP), a component of which is the 8th-term training of students immediately in the plant environment. The basis for the project introduction was the fact that the KNPP construction required a large number of specialist staff for the plant startup and operation in accordance with nuclear and radiation safety requirements. Due to the lack of enough well-trained operating personnel for the unit control rooms, the project’s
objective was defined as cutting the time for the newcomers to adapt themselves to the plant environment. ISPEU, one of the leading higher educational establishments in the field of personnel training for power industry, was placed in charge of the project. During the 8th term, students undergo a course of training at KNPP’s training center to acquire a practical experience in carrying out floor-shop operations with taking examinations in such subjects as “Nuclear Reactors”, “NPP Turbines”, “NPP Power Equipment”, “Safety of Living”, “Environmental Protection”, and “Human Engineering” [1]. The results of practical training are allowed for in updating the university’s educational program with much training time devoted to computer modeling and simulation. The latter is based on a full-scale simulator (FSS) of an NPP unit with the VVER-1000 reactor handed over to ISUPE by KNPP and a computerized functional analytical simulator (FAS) which is identical to the FSS and is a software product from Western Services Co. Ltd.

## Computer software used as part of the “University-Enterprise” program

Computer technologies are commonly known to be highly effective in university training of future nuclear power plant personnel [2–4]. The training technology the university makes use of, involving the use of computer modeling and simulation, consists of three interlinked components. Component 1 is a computer-aided laboratory course in kinetics of water-cooled water-moderated reactors, component 2 deals with FAS-based simulation of the reactor neutron measurements, and component 3 places emphasis on drills in control of processes based on the FAT and the FSS.

An in-depth study into neutron processes is based on numerical experiments conducted as part of an in-house computer software package [5,6]. Mathematical models encompass the cold and hot reactor kinetics. They make it possible to analyze the role of delayed neutrons, the fuel and coolant temperature effects on the nature of transients, fuel burnup, the reactor xenon and samarium poisoning, as well as xenon oscillations and the reactor xenon stability. Mathematical models are based on a system of stiff nonlinear differential equations integrated using the respective Mathcad algorithms. The use of this environment makes the process of modeling highly graphic and convenient for numerical experimentation while allowing students to manipulate with different input parameters, assess their role and undertake a research of their own. When transients are modeled, attention is given to the problem of closing the system of differential equations, which is not just a mathematical problem but is also of a practical importance allowing conditions to be formulated for analyzing the operation of interacting components of the unit’s process circuit. Besides, students learn to be able to consider interlinked transients in components not only based on numerical experiments but also using a qualitative analysis of differential equations without solving them.

The second component deals with the reactor neutron measurements based on the FAT simulator [7]. It should be noted that reactor measurements are not quite adequately covered by the existing university programs and respective guides. However, a nuclear reactor can be safely started up and further operated only when its neutron performance is known as exactly as required by nuclear safety and core thermal reliability regulations. Familiarization with and mastering of the physical experimentation technology during education is one of the most important tasks in training of personnel who will be in charge of nuclear reactor control.

The closing component is FAT- and FSS-based simulation of the VVER-1000 NPP unit processes, specifically the unit startup and shutdown [8]. The guidance for this component has been developed based on the plant’s model stepwise startup/shutdown program with regard for the standard list of startup/shutdown operations, as well as the procedures for and the sequence of these. This training component makes it possible for students not only to study the action of the unit components but also to explore the interlinking among them, solidify and systematize theoretical knowledge, and acquire primary skills in operating complex facilities.

Simulator training promotes the formation of occupational mentality and is an effective tool for the personal development of future staff and is an aid for the improvement of occupationally important traits. Therefore, FSS-based simulation of startup/shutdown operations includes investigations to identify the individual and personal qualities that define the degree of success achieved in performing simulator tasks. Personal qualities are a component of competences that has an effect on the rate and efficiency of their formation. Students with different simulator work efficiencies exhibit a greatly differing extent to which their personal qualities are pronounced. Analyzing these qualities makes it possible to evolve the guidance aspect of training based both on integrated solutions and on individual recommendations to trainees.

### A study into the xenon stability of a water-cooled water-moderated reactor

For illustration, we shall consider a computer realization of a mathematical model for excitation and suppression of axial xenon oscillations in a nuclear reactor allowing students to explore this challenging and operationally important problem. Large nuclear reactors operating with a high neutron flux are known to have a potential for a highly hazardous effect that manifests itself in the occurrence of xenon oscillations and waves. Xenon oscillations are conditionally divided into azimuthal, radial and axial oscillations. Experiments show that only axial oscillations are what matters to a VVER reactor and so measures need to be taken to suppress them. This phenomenon is caused by the positive reactor reactivity feedback with respect to the xenon component. If an oscillation resulting in a growth in the neutron flux occurs in any core region, this will lead to extra xenon burnup, a further neutron flux growth and a local energy release. Unless this oscillation is suppressed by the reactor control members, the process will progress with a potential of a severe accident involving fuel assembly damage as the result of linear and bulk
heat load limits being exceeded therein. An integral action of the control system will cause the neutron flux to decrease throughout the reactor core. The xenon concentration across the core, excluding locally, will start to grow. It will decrease for some time more in the non-uniformity region and will start to grow thereafter. Such control system and reactor interaction will lead to the region with a variable xenon concentration to move within the core with a period of about one day. Temperature and power reactivity effects will have a stabilizing effect on the xenon oscillations (waves).

Numerical experiments to model xenon oscillations are based on a system of two similar coupled reactors with an equal energy release and contacting ends. This system of reactors is a model of one reactor divided vertically into two identical halves. The exchange of neutron fluxes between these reactors is through the neutron leakage via the contacting ends. The probability of a leakage is determined by the following expression:

\[ P = 1 - \exp\left(-B^2M^2\right) = B^2M^2, \]

where \( B^2 \) is the geometrical parameter, and \( M^2 \) is the neutron migration area. The neutron exchange time is a preset parameter varied in the course of the experiment the threshold value of which can be estimated from the following formula:

\[ \tau_{ex} = H^2/(v \cdot D), \]

where \( H \) is the height of the reactor half; and \( D \), and \( v \) are respectively the coefficient of diffusion and the velocity of thermal neutrons.

Xenon oscillations between the reactor’s upper and lower halves are excited through the excitation of one reactor half by an oscillation introduced into it in the form of a reactivity leap, while the suppression of the introduced oscillation is modeled by boron regulation acting on both reactor halves. The consideration is based on a “pointwise” model of the reactor in a two-temperature approximation for fuel and coolant with the xenon birth and death equations added to it. Since the transient is slow, no delayed neutrons affect it in any way, and these may be neglected whatsoever, that is, all neutrons may be treated as instantaneous or a single-group approximation may be used. In the investigated model, the axial xenon oscillations were suppressed through a temperature reactivity effect and by reducing the time of the neutron flux exchange between the coupled reactors. The non-uniformity of the axial power distribution is characterized by axial offset (AO) which is understood as the ratio of the difference in the energy release between the reactor’s lower and upper halves to the sum thereof found prior to the oscillation occurrence:

\[ AO = (W_l - W_u)/(W_l + W_u), \]

The parameters representative of the VVER-1000 reactor are used as the initial data. The representative values of time scales for some of the processes are in a range of \(10^{-4}\) s to several days, so the system of equations under consideration represents a class of stiff differential equations, and respective algorithms have been used to integrate them.

Based on the presented numerical experiments, curves are plotted by students to define the boundary between the xenon

stability and the reactor instability. Oscillations are growing in the xenon instability region and fading in the stability region. The transition from one region to the other is characterized by sustained oscillations. Fig. 1 presents representative dependences of the temperature reactivity effect on the reactor power which define the reactor xenon instability region for different values of the time of the neutron flux exchange between the reactors. Initially, the curve rise results from the destabilizing impact of the xenon concentration growth due to iodine decay, and further a stabilizing impact of the reactivity effect manifests itself. We shall note that if the time of the neutron flux exchange between the reactors will turn out to be of the order of magnitude of the instantaneous neutron generation lifetime, no xenon oscillations occur whatsoever.

To conclude this study, the numerical experiment results are compared against the full-scale test results and the results from a theoretical research into the reactor xenon stability as part of excitation theory. Thus, for the conditions of modeling used, the reactor half power jump in the course of a transient was 200 MW, the overheating of fuel elements was 27°, the greatest offset value was 17.8%, the oscillation period was 27.7 h and the fading time constant was 52.5 h. These results are in a satisfactory agreement with the experimental data obtained in full-scale experiments on operating reactor facilities [9]. The suppression of the reactor xenon instability thanks to the power reactivity effect, calculated in the framework of excitation theory, agrees satisfactorily with the respective temperature effect found using the above model [10].

**Conclusion**

At the present time, a “University-Enterprise” program is being implemented at ISPEU for students majoring in “Nuclear Plants: Design, Operation and Engineering”
The annual admission for this training course is 40 students. The computer technologies developed by us and described above have been introduced into the whole range of subjects and are used as the basis for students’ research training and graduation papers. The share of job-related subjects which involve mathematical modeling and simulation amounts to more than 35%. For some of the courses, such as “Kinetics of Nuclear Reactors”, “Reactor Measurements”, “NPP Operating Modes and Operation”, and “Testing and Adjustment of NPP Equipment”, the number of training hours allocated for modeling and simulation reaches 90% of the entire education time.

Therefore, the experience gained in using computer technologies as part of the “university-industry” program implemented jointly with the Kalinin NPP provides for a beneficial effect in training future NPP personnel. As reported by the leaders of respective plant departments, this leads to the time for the university graduates to adapt themselves to the real plant environment cut by a third or even by half.

References