THE POSSIBILITY OF THE APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) BASED ON NEURAL NETWORK FOR THE IDENTIFICATION OF ACCIDENTS IN VVER-1000 NPP

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Abstract: In this paper the architecture of the developing system, main features of its building, including training and checking of neural networks are presented. In particular, the problems of a database forming for identification of various stages of an accident on the base of its modeling with system code are considered. Database was formed on the base of the 2 and 4 types of different "LOCA" accidents for nuclear power plant with VVER-1000 reactor taking into account its stochastic properties. In addition, the task of searching the optimal structure of the neural network is also presented and discussed. The developing approach is illustrated on the base of calculations for accidents with the VVER-1000 reactor.

Keywords: *accident identification, system codes, neural networks, VVER, LOCA, genetic algorithm*

1. INTRODUCTION

The problem of the diagnostic of accidents on a nuclear power plant (NPP) is important because accident processes have nonlinear, non-monotonic, multidimensional and stochastic characteristics. As well there are uncertainties in its forecasting on the base of the best-estimated system codes. All these problems can strongly impede the identification of the accident beginning and its progression. Therefore control of an accident can be very problematical.

Existing systems of operator support in a NPP normally are based only on determination of a pre-accident situation and identification of the monitoring parameters deviating from their nominal values. However for application of the effective measures for the accident control it is necessary to have an efficient system which should identify type of the accident and support a NPP operator and a crisis center during the accident progression.

For solution of this problem, in the proposed method the realization of the approach of the accident identification on the base of AI (in this research work: AI is neural networks) is presented. In the method developing by authors a joint and harmonic application of new methods of information technologies (IT) and as well classical one are applied. In particular, in the offered approach along with neural network the methods for forecasting the NPP behavior during an accident on the base of the system codes of the RELAP5 type were used.

2. ACCIDENT IDENTIFICATION SYSTEM BASEB ON NEURAL NETWORK

The considered problem can be presented as follows. In the process of the NPP operation the monitoring of parameters $\mathbf{Y=\{Y_i, i=1,\ldots, k\}}$ depending on time $\mathbf{t}$: $\mathbf{Y(t)}$ can be completed. These are physical parameters (for instance on the entrance of core: temperature, pressure etc.), conditions of equipment (on/off) and so on. As well a set of possible accidents happening in the NPP can be specified as $\mathbf{A=\{A_i, i=1,\ldots,n\}}$. Then let the accident $\mathbf{A_i}$ begins at time $\mathbf{t_0}$. From $\mathbf{t_0}$ and during the interval $\mathbf{\Delta t}$ the $\mathbf{m}$ observations of $\mathbf{Y(t)}$ exist – the set $\mathbf{Y_{Ai}=\{Y_{ji}, j=1,\ldots, m\}}$. The main task is in the determination of a mapping between realization of the set $\mathbf{Y_A \rightarrow Y_{Ai}}$ and particular item of the set $\mathbf{A}$, i.e. in the mapping $\mathbf{Y_{Ai} \rightarrow A_i}$. This link can be established on the base of an analysis of the NPP's dynamic during the accident with help of best estimate codes of the RELAP5 type. Let some system codes will be $\mathbf{C}$. For each element of $\mathbf{A_i}$ of the set $\mathbf{A}$, the $\mathbf{m}$ values of $\mathbf{Y(t)}$ for a time interval from accident beginning $\mathbf{\Delta t}$: $\mathbf{A_i \rightarrow C \rightarrow Y_{Aic}=\{Y_{jic}, j=1,\ldots, m\}}$

can be evaluated. The identification task is in automation of the correlation $\mathbf{Y_{Ai}}$ and $\mathbf{Y_{Aic}}$ (real and modeled via a system code) and determination of appropriate element is $\mathbf{A_i \in A}$.

The above mentioned system codes of the RELAP5 type model processes with some uncertainty $\mathbf{\Delta Y_{Ai}=Y_{Aic}-Y_{Ai}}$, which is random and has appropriate distribution function $\mathbf{F_{Ai}}$. This should be taken into account in the determination of the $\mathbf{A_i}$. As well some parameters of the NPP model have pure stochastic nature. For example it could be reactor operational power, temperature of coolant in the safety system, failures of the equipment and so on. All this give stochastic influence on $\mathbf{\Delta Y_{Ai}}$ and $\mathbf{F_{Ai}}$.

The analysis of the existing IT and taking into account conditions described above determines that for the automatic mapping values $\mathbf{Y_{Aic}}$ and $\mathbf{Y_{Ai}}$ as in the beginning of the accident and in its progression the system of artificial intelligence (AI) is most fitting. In particular it is neural network (NN) [1]. Another aspect connected with an uncertainty of calculation results of best estimate codes $\mathbf{\Delta Y_{Ai}}$ and their probabilistic characteristics $\mathbf{F_{Ai}}$, can be estimated on base of the uncertainty analysis, for instance in [2,3]. The algorithm of the identification system is presented in Fig. 1.

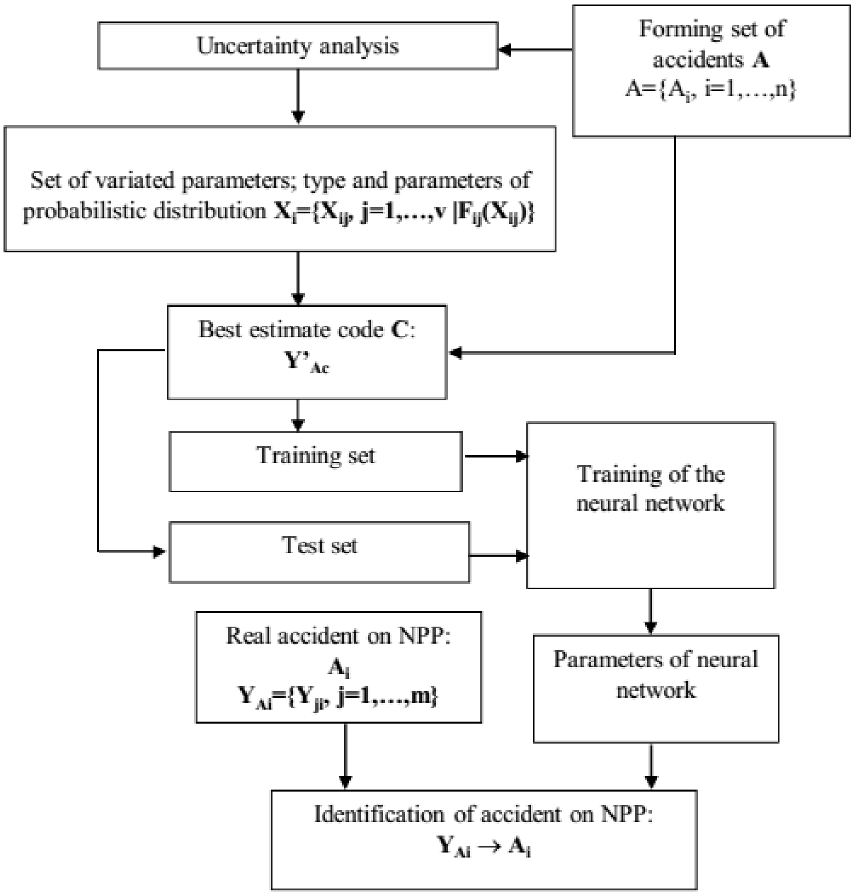

Fig. 1. Architecture of the identification system with using of the neural network

The important part of this approach is the application of IT based on NN. In such approach a right choice of NN's architecture and appropriate training procedures are important questions. The organizing of the NN's training is based on independently forming of two sets of data. First one is for training of the NN and second one is for final test (Fig. 1). The training on an algorithm of back propagation with adaptive correction is implemented.

The training and testing sets are formed on the base of modeling of accidents via the best estimate codes of the RELAP5 type. To define possible uncertainties of modeling via codes and uncertainties of aleatory kind, methods of uncertainty (UA) and sensitivity analysis (SA) can be used [2,3,5]. Different approaches to UA exist. For complex codes of the RELAP5 type and sufficient amount of parameters the methods based on the Monte Carlo (MC) approach are the best.

3. CALCULATIONS ON DEVELOPMENT OF THE PROPOSED METHOD

The training and testing of a workability of the proposed method for accident identification on the base of models of RELAP5 code [4] for the NPP with the reactor type of VVER-1000/V320 was completed.

On the first stage (i) of the method application it is necessary to form a set of identified accidents **- A**. Types of LOCA accidents with variation of its localization – cold or hot leg were chosen. On next step (ii), for forming the training and testing sets the UA should be used. In the current work results of [3,5] have been used.

General amount of uncertain parameters is 173, however it isn’t necessary to take into account all of them for the tuning of the identification system. Only parameters with maximum influence on safety of the NPP should be used. Therefore, results of the SA should be used. On base of [5], in the tuning of the identification system the most influential parameters have been chosen. However even in such simplification by taking into account the nodalization of the NPP, the final amount of parameters for the uncertainty modeling was 64.

Right choice of monitoring parameters is another important task. In this work the following 34 parameters were used:

- Pressure on inlet and outlet of the core;
- Pressure of the secondary system on steam generators (SG);
- Mass flow rate on the loops;
- Temperature on the exit of the core;
- Reactor power;
- Mass flow of the fast pressure reduction system (into the atmosphere);
- Mass flow of the fast pressure reduction system (into the condenser);
- Pressures in cold leg and hot leg of the primary system;
- Coolant level in the pressurizer;
- Coolant level in the SG.

4. DETERMINATION OF THE NN OPTIMAL PARAMETERS AND THE WORKABILITY DEMONSTRATION OF THE IDENTIFICATION SYSTEM FOR 2 AND 4 TYPES OF LOCA ACCIDENTS

The choice of optimal parameters of the NN is an important problem. This problem is solved in blocks “Training of the neural network” and “Parameter of the neural network” (see in in Fig. 1). These are amount of hidden layers and neurons per layer. If the amount of neurons is huge then the overtraining of NN can be occurred or a bad forecasting in reverse case. For illustration, the dependence of the NN training quality (average probability of the error on the testing set) from the amount of neurons in hidden layer was calculated (see in Fig. 2). It is easy to note that some optimums in the neuron amount exist, after which the further increasing of the neuron amount doesn’t improve quality of the NN. This can be connected to the NN’s overtraining.

An especial software program for processing of NN was developed, which can complete in automatic mode the finding of optimal parameters of NN, its training and identification of an accident. Two algorithms of the NN’s optimal structure finding have been realized. The first method uses sequential iteration for all existing combination of neurons in hidden layers.

However, this approach will not be effective in case of presence of several hidden layers and wide variation of the neurons amount per layer. Also from Fig. 2 it is possible to note that local and global optimal points exist. For a solution of such problems a method of the NN optimal structure searching on the base of the application of an algorithm for global optimum search was developed. In particular, the genetic algorithm (GA) was used. GA is based on the computer modeling of the biological evolution for finding the global optimum [6]. It is successfully used for the optimizing complex technical systems. The example of calculations for NN of optimal structure on the base of the GA is presented in Fig. 3.

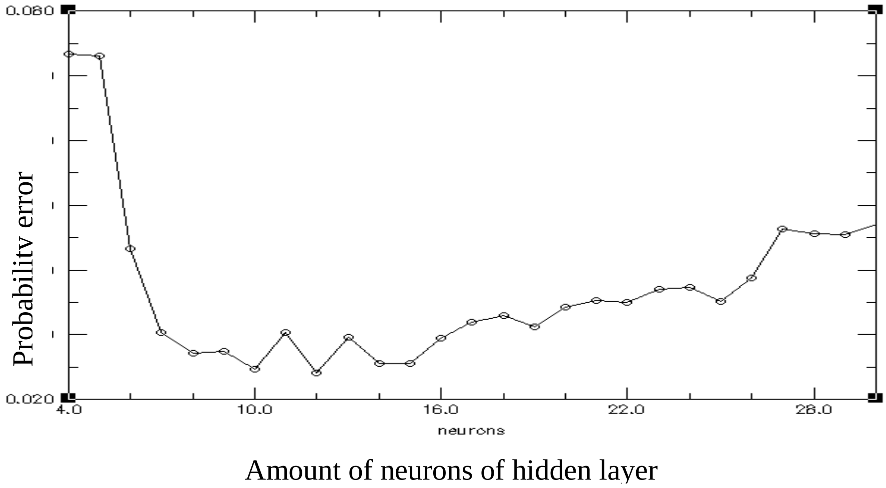

Fig. 2. Dependence of probability of error in the identification of an accident from amount of hidden layer neurons for a set of 4 accidents of the LOCA type with break size from 30 to 40 mm for cold and hot legs

There was the NN with two hidden layers and the appropriate variation of neurons amounts in intervals of 20÷100 and 1÷100. The amount of possible combinations is 8000 variants. On Fig. 3 approximated surfaces of a normed error of the training in dependence from the amount of neurons variation by layers with different variants of training algorithm implementation are presented. In GA2 the training rate was constant. In GA3 it was adaptive. From the Fig. 3, it is obvious that the dependence is non-monotonic and an application of standard optimization methods will be ineffective. The GA is capable to find the global optimum for sufficient fewer amounts of steps – about 30÷50 in the comparison to 8000 possible combinations.

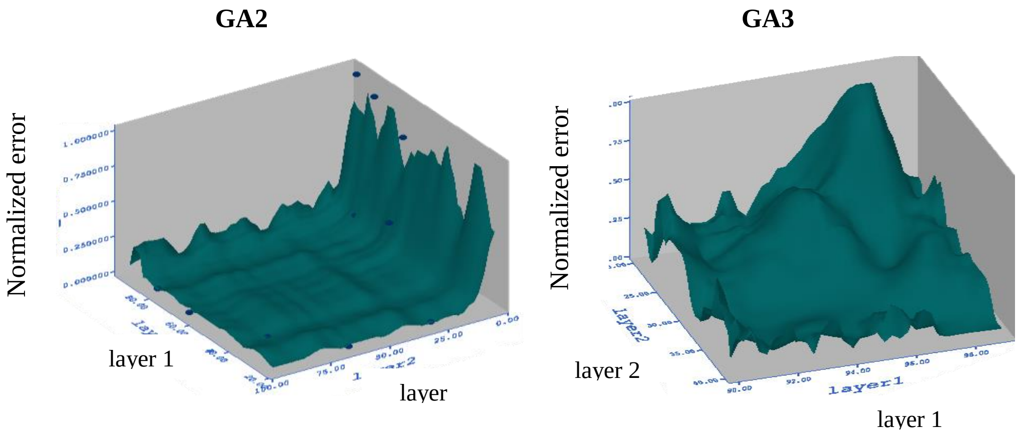

Fig. 3. Approximated surfaces for normed error in dependence of neurons variation on layers for variants of training **GA2** and **GA3**

After determination of NN optimal structure, the training of NN should be completed. For this operation the iterative algorithm on the base of steps "training – testing" was developed. On the current stage of research, training and testing of the NN should be completed for verification of identification system possibility on the example of 2 and 4 accidents (see in Table 1). In additional research of capabilities of the system with variation of time point of identification process was used. For this 100 points in time of the accident progression were randomly generated from the beginning of the accident on 100 sec till 2000 sec (during the accident progression).

Two criteria are considered here:

- difficulty of the tuning of the NN;
- criterion of generalizing error – i.e. characterizing of possible error of forecast.

The variation of these criteria were considered for the identification system based on initial events of the LOCA type breaks from cold and hot legs with various sizes (Table 1). The results of calculations are presented in Figs. 4 and 5. For providing comparability between the different identification cases on time points in the calculations, the same identical structure of the NN was used. It is necessary to emphasize that in all calculations the tuning of the NN for the successful identification of the accidents was reached.

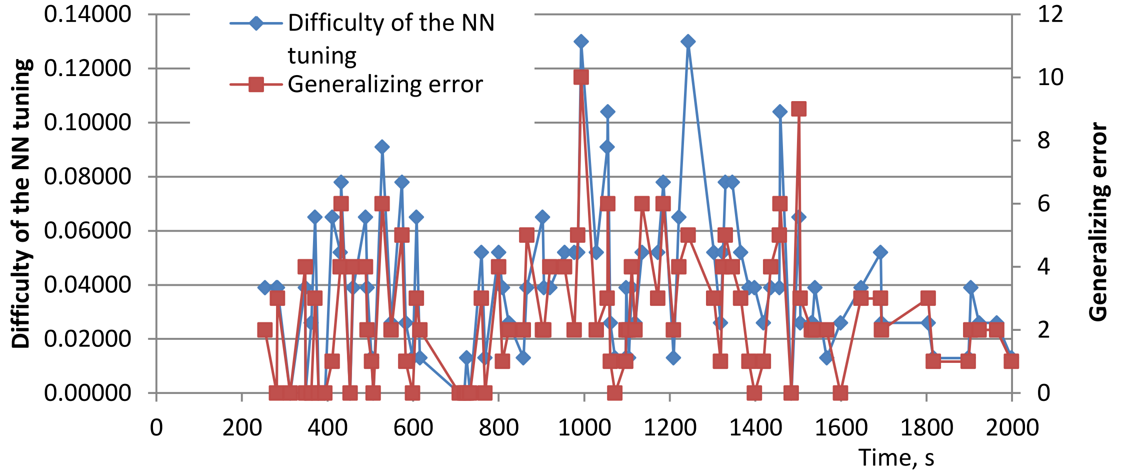

Fig. 4. Variation of the criteria of the NN tuning for different time points for 2 types of accidents

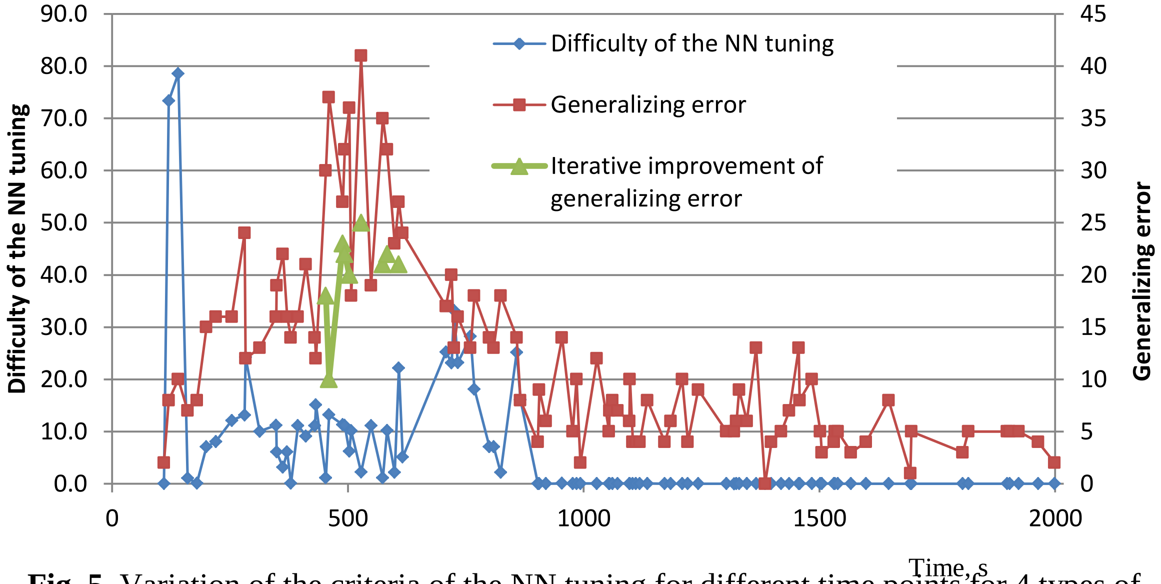

Fig. 5. Variation of the criteria of the NN tuning for different time points for 4 types of accidents

Table 1. Considered types of accidents

Amount of accidents in the system	**Types of accidents (A)**	Designation
2	Break from a cold leg - sizes: 30, 40 mm	Cn30, Cn40
4	Break from a cold leg - sizes: 30, 40 mm and a hot leg - sizes: 30,40 mm	Cn30, Cn40 Hn30, Hn40

The comparison of the results has showed that the easier tuning is for 2 types of accident cases and harder for 4 types of accident in the system. The error of generalizing has mainly increased in transition from 2 types of accident cases. Also the criteria have the sufficient variation during the accident progression. On the time interval from the beginning till 200 sec and especial after 1000 sec all criteria are smaller. In the diapason from 200 till 800 sec for 4 of accident cases the sufficient increasing of the criteria exists. This effect depends on how closer monitoring parameters of a NPP are in these time intervals for different types of accidents. The relative high values of the generalizing error can be explained via above-mentioned non-adaptive identical structure of the NN. The improvement can be effectively reached by using of several iterative variants of NN training and as well via the search for the NN optimal structure as was presented above. In Fig. 5 the results of the iterative search for the improvement of the generalized error criterion for the identification system with 4 types of accidents are presented. The search was done for time points with maximum generalizing error. As result of completing 3 to 4 iterations, the variants of error decreasing in approximately two times were found.

5. CONCLUSIONS

In this paper the approach of using the modern information technologies coupling with methods of analysis of accidents based on the best estimate codes, the uncertainty analysis for building the accident identification system is presented. The architecture of the identification system and main steps on its creation are considered.

The especial attention in this paper is paid to questions of the system tuning, choosing the optimal structure of the NN. In framework of this research, identifications of 2 and 4 types of LOCA accidents at various time points were successfully completed. The results of the research have shown practical possibility of the identification system creation for accidents on NPP on the base of the presented approach. This system can be used for support of the NPP operator and as well as for a crisis center.

Regarding to this research, another interesting question is database generation for training and testing the NN on the base of the uncertainty analysis. The standard uncertainty analysis uses the confidence interval but doesn't take into account a risk criterion for analyzing accidents. Therefore, the potential dangerous situation as an accident at the NPP Fukushima can be excluded from consideration and the identification system may recognize it wrong. For solution of such problem, in further researches it is planned to study the possibility to use the Dynamic Probabilistic Safety Assessment (DPSA) methods in additional to the uncertainty analysis in the process of the training of the accident identification system.

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KHẢ NĂNG ỨNG DỤNG TRÍ TUỆ NHÂN TẠO (AI) DỰA TRÊN MẠNG THẦN KINH NHÂN TẠO ĐỂ NHẬN DIỆN CÁC SỰ CỐ NHÀ MÁY ĐIỆN HẠT NHÂN VỚI LÒ VVER-1000

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Tóm tắt: Trong bài báo, cấu trúc của hệ thống đang nghiên cứu, phát triển và các đặc trưng chính của việc xây dựng hệ thống (nhận diện sự cố) bao gồm việc đào tạo và kiểm chứng năng lực của mạng thần kinh nhân tạo được đưa ra. Cụ thể hơn, các vấn đề liên quan đến việc tạo cơ sở dữ liệu phục vụ cho việc xây dựng hệ thống nhận diện các sự cố (ở các giai đoạn khác nhau của quá trình diễn ra sự cố) trên cơ sở mô phỏng bằng các code tính toán đã được xem xét. Ở giai đoạn này của nghiên cứu, cơ sở dữ liệu được xây dựng cho 2 và 4 kiểu sự cố LOCA của nhà máy điện hạt nhân với lò phản ứng VVER-1000 và có tính đến các yếu tố ngẫu nhiên liên quan trong quá trình diễn ra sự cố. Ngoài ra, bài toán tìm kiếm cấu trúc tối ưu của mạng thần kinh nhân tạo cũng được đề cập. Phương pháp đang phát triển được minh họa trên cơ sở tính toán sự cố với lò phản ứng VVER-1000.

Từ khóa: *nhận diện sự cố, code tính toán hệ thống, mạng thần kinh nhân tạo, VVER, LOCA, thuật toán di truyền*