

# A Novel Analysis on Application of Neural Support on Nuclear Reactor Control Process Monitoring

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## Abstract

**Objectives:** The aim of the present work is to study the application of ANN model on a complex system such as Nuclear Reactor and their adaptation for the early prediction of abnormal behaviour. **Methods:** Safe and reliable operation of reactor depends upon many parameters and many physical barriers at different layers. Application of ANN model on reactor control process monitoring requires many training samples and effective method for implementation. It requires the identification of possible occurrences of events and mapping of the each event the relevant parameters. Attention on the selection of parameters related to each of the IEs is paramount. **Findings:** Finding the cause for the transient events is important in every plant and the ANN model trained for all possible transient events is useful for incident analysis as well as avoid reoccurrence of the faults. **Applications/Improvement:** In order to provide heuristics as well as neural support for the similar NPP, collaborate entire NPP database under one roof with the help of cloud computing. History maintenance for future analysis and knowledge sharing will be feasible. However, the end result shall be confirmed with human verification for final decision.

**Keywords:** Cloud Computing, IE, Pattern Recognition, Rule Based System, SVM, Transients

## 1. Introduction

Safe and reliable operation of Nuclear Reactor requires continuous monitoring of many plant parameters. The major capabilities and advantages of ANN leads as decision support systems for continuous monitoring of plant parameters.

Application of Neural Networks as an information processing technology in nuclear power plants has its own significance, specifically in the field in which knowledge expertise is required. The state of art technology in neural network shall be adapted in continuous process monitoring of critical parameters and enable the early prediction of their malfunction. The algorithms like back propagation, gradient descent and MSE-mean squared error are widely used for effective learning in feed forward networks.

## 2. Artificial Neural Networks

Artificial Neural Network (ANN) is described as network of number of elements called neurons. The functionality

of these elements is identical to that of human brain. It was inspired from brain modelling studies. Solutions to the simple problems can be obtained easily by with NN models. However, the complex problems with multiple objectives are cumbersome with NN model as there was limitation on processing and storing capabilities. Brain provides solution to the several complex problems by simultaneous usage of various parts of the brain. ANN is parallel, distributive structure and does transformation on the inputs and convey meaningful outputs.

The important factor in adapting a Neural Network expert system approach is the availability of training examples; more the available training examples the better. If there is noise in the training examples or redundancy is present, suitable methods are required to be adapted to minimize noisy data.

### 2.1 Multilayer Perceptrons

Multilayer Perceptrons (MLP) is the simplest connectionist model capable of representing any Boolean function

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and for approximating many common functions to arbitrary precision. MLP is most commonly used ANN model comprised of many layers which are categorized as input, intermediate layer and output layer. ANN model with multiple hidden layers is used to solve complex problems. However the ANN model with one hidden layer is used frequently. Back propagation algorithm used in MLP models. The inputs are fed at input layer. They pass through the intermediate hidden layer to generate the outputs at the output layer. If there is any difference between the measured and expected result, it will be sent as a feedback to adjust the weights at end of each iteration. This process is iterated such that the difference between the measured outputs and expected results, represented as Mean Square Error (MSE), shall reach the minimum probable value.

## 2.2 Learning Process

The important phase in Neural Network is learning. Learning process basically learns from training samples over number of iterations and become more knowledgeable about the system. The goodness of training data will be reflected in terms of its performance on a large set. A good training data would be the one that has no mislabelled instances and has high Intra-Category Diversity for each category.

In<sup>1</sup> in her paper developed an ANN model for Intermediate Heat Exchanger (IHX) of Nuclear Reactor. IHX is a circuit imposed between primary loop and secondary loop for heat transfer. In that paper, it is demonstrated that it is possible to reduce mean square error by adjusting the attributes like number of hidden layers, learning rate and number of iterations.

In<sup>2</sup> developed a system to predict a pressure drop in heat exchanger using ANN. In that system, Sigmoid transfer function is used as the activation function for the hidden layer and nearly about 10 hidden layers are applied to approach regression coefficient close to one.

## 3. Transient Events

The nuclear power plant experiences many transients at several occasions while operation. These transients may be due to transient behaviour of the components or disturbances in process support systems.

One of the event namely fuel criticality which may occur due to loss of pressure control and cooling malfunction. This event makes the reactor unstable. Hema K.<sup>3</sup> in her paper had adapted CFD Model to analyse the pressure dis-

tributions and flow patterns in the assembly. To investigate loss of pressure control on Nuclear Reactor, ANN model is used to provide support to plant operators at an incipient stage. The model was well trained with associated process parameters pertaining to these conditions.

### 3.1 Initiating Events (IE)

Normally, the process monitoring systems are equipped with self diagnostics feature to monitor the proper functioning of the system. In some conditions like equipment malfunction, the system has to initiate safety action to avoid an abnormal state i.e. undesired condition. During such a situation, generally referred as an Initiating Event (IE), the plant personnel have to do many data analysis to find out the root cause of the event. The plant diagnostic system is used to identify critical unsafe situations and to give the plant operators appropriate data to carry out the corrective actions. Therefore, by properly identifying the process critical parameters, its associated parameters and their value ranges, IEs can be distinguished. To tackle this problem, a number of pattern recognition techniques can be utilized. Artificial Neural Network is referred as Black Box modelling since it need to know little about the process itself, it shall be constructed and trained with a set of samples from the process<sup>4</sup>.<sup>5</sup>In his paper, adapted ANN model for effective event identification. Similarly,<sup>6</sup>teamed up to develop a single ANN that can recognize nearly eight nuclear power plant transient events. The developed and trained ANN is able to correctly classify about eight events.

In the Nuclear Reactor, controlling techniques are applied in such a way that they should respond in real time. In Reactor Control Process monitoring system, system should monitor and responds to the abnormal situation in real time. However, each of the process method takes a considerable amount of time to handle the situation. The time taken by the process to respond for the situation is known as dead time. This dead time should be as low as possible. However, the process methods should respond in real time.<sup>7</sup>In his paper, more concerned about the real time capabilities which add deterministic feature to the system. With real time feature, system shall be controlled at hard real time with high accuracy.

### 3.2 Classification

For effective classification of transient events, it is mandatory to anticipate all possible transient scenarios

and effectively apply for training. Mostly, feed forward type of network is applied to estimate the severity level of the transients. The occurrence of simultaneous multiple component faults is very difficult to detect and identify, since the possibility of one component fault partially or completely cancelling out the effect of another on the measured plant signals. Every transient event needs to be explicitly represented when NNs are used for the classification of transients.

### 3.3 Pattern Recognition

Pattern Recognition Techniques are employed to detect the failure at incipient stage in Nuclear Reactor components. Classification will have a unique label for each set of inputs. For the given input, label shall be assigned. This method is adapted for earlier detection of control rod variations in Phenix Reactor. Control rod is the most important part of the Nuclear Reactor which is used to control the fission chain reaction. It needs the continuous monitoring of its operation.

### 3.4 Support Vector Machine (SVM)

Support Vector Machine (SVM) method adapted for pattern recognition. It is a binary classification method. Faults have to be identified and classified based on their severity.<sup>8</sup> Worked on the classification of various faults in nuclear power plant using Support Vector Machine (SVM). In his paper, he improved SVM using Genetic Algorithm to determine the optimal value of parameters to assure higher predictive accuracy and generalization ability.

### 3.5 Spatio Temporal Network (STN)

It is also noted that simply watching the trends of some parameters, it is difficult to identify some important critical components like reactor vessel.<sup>9</sup> Used the method called Spatio Temporal Network (STN) to deal directly with spatial and temporal aspects of input parameters and identify the time-varying critical situation. It may be very difficult, however, for operators to identify a reactor vessel failure simply by watching the temporal trends of some parameters since it is very difficult to anticipate such conditions. Therefore, a method is proposed to identify Pressurized Water Reactor (PWR) vessel failure for major incident using Spatio Temporal Network (STN). The spatial and temporal aspects of input are handled by STN and can identify a time-varying problem.

### 3.6 Resilient Back Propagation

Resilient back Propagation algorithm (RPROP) is a local adaptive learning method used in feed forward Neural Networks to perform supervised batch learning. The algorithm is to eliminate the harmful influence of the size of the partial derivative. RPROP modifies the size of the weight step taken adaptively, and does not take into account the magnitude of the gradient as got from a particular weight, but considers only the sign. This allows for the adaptation of the step size and ignoring the size of the gradient interference<sup>10</sup>.

<sup>11</sup>Noted in his paper that ANN model resembles database model when it is required to provide more sets of solutions well in advance. In complex systems, the computational effort in the training of the network consists of the calculation of the training set. Whenever, there is a need for the identification of the similar pattern to any new sample pattern, ANN model requires reconfiguration of associated parameters in their pattern recognition system.

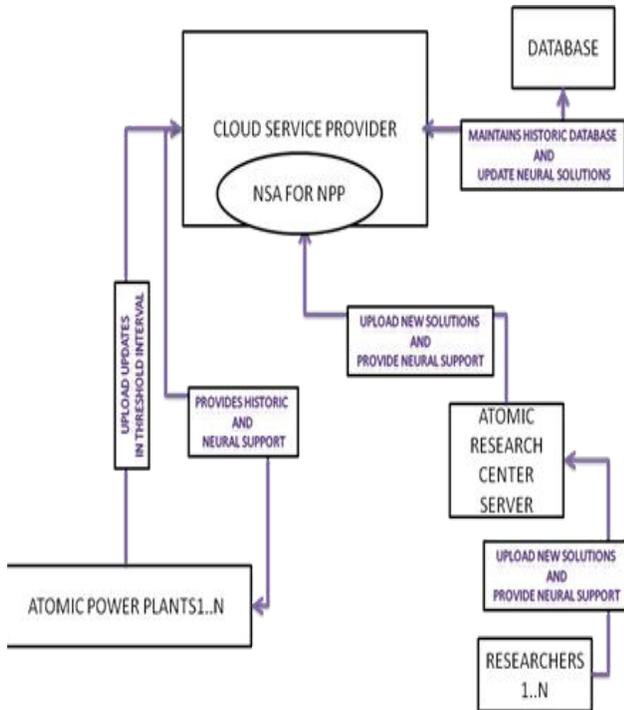
### 3.7 Rule Based System

The simplest form of ANN which is commonly used in the industry is rule-based system. It is a way of encoding a human expert's knowledge into a fairly automated system. The main advantage of using this method is that the human expert's knowledge becomes available to wide range of people and also capture the expertise of an expert in the field and the knowledge we acquire is never lost. It is mainly used to develop software that will provide a solution to a problem instead of a human expert. It consists of rule-base (permanent data), an inference engine (process) and working memory. Knowledge is stored as rules in the rule-base and rules are of the form of IF some condition THEN some action. Inference engine applies the rules to working memory.

A rule based system for classifying Loss of Coolant Accidents [LOCA]<sup>12</sup>. LOCA is a deviation from normal operation state which can occur in extreme rare condition. The rule based system classified the LOCA break size and directs it to one of 15 ANNs which predict the time to core uncover, lower support plate failure and containment building failure in terms of operating environment.

## 4. Application of Cloud Storage for Nuclear Data

When we collect all NPP database under a cloud storage for history storage and future reference as shown in Figure 1,



**Figure 1.** Application of cloud storage for nuclear data.

following survey has been carried out on security issues. In this context, the current report surveys the research outcomes stemming from European and National projects and discusses how to address the complete SLA lifecycle. The report also contains of recommendations for the on-going policy work on SLAs of the cloud Select Industry Group (SIG). Regarding intrusion detection in the cloud, proposed an efficient multi-threaded cloud IDS, administered and monitored by a third party ID monitoring service, which can provide alert reports to cloud user and expert advice for cloud service provider.

## 5. Analysis

In this paper, detailed literature analysis on application of different ANN techniques for reactor process monitoring is done. In Nuclear Reactor, control rod is used to perform the nuclear fission chain reaction in a controlled manner. It is an important shutdown mechanism ensures the safe and reliable operation of Nuclear Reactor. If there is any variation in the control rod position due to ageing or swelling, it has to be identified at an incipient stage. For this important application, the literature analysis emphasis one of the ANN technique named pattern recognition shall be applied. Similarly, event identification is

an important process during the occurrence of transient events. It is very essential to find out the root cause since the event can occur due to the transient behavior of equipment or instruments. The literature analysis emphasis that there should be an effective event identification system which consists of all possible transient events and their related critical parameters to map the initiating events. This is very important since it can effectively map the initiating events and also capable of recording the repeated occurrence of similar events which needs suitable corrective action to avoid recurrence.

## 6. Conclusion

Application of different ANN models to the various fields of nuclear power plant reveals that the early predication of abnormal behaviour of the components like control rod variations, reactor vessel failure, incident due to LOCA or pressure drop will be made possible. The major concern on the development of ANN model for the NPP is the event identification, selection of important parameters and its associated parameters for each event. Mapping of the selected parameters to the events and then training the model perfectly. Development of ANN model emphasizes the importance of training and significance of training samples. If it is possible to gather the entire NPP database under one roof with the help of cloud computing, we can provide heuristics as well as neural support for all NPP. However they collaborate software with human verification for final decision. Through this, we can overcome 85% of the problems. Also, it offers the advantages like history maintenance for future analysis, knowledge sharing, taking necessary precautions, immediate support and solutions for the new type of problems.

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