Load Forecasting in Power Reactors Using Neural Approach

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Abstract- In this paper Artificial Neural Network (ANN) has been introduced to solve Nuclear Power Plant operation complexity. To make power & load matching because of changing load operations of Nuclear Power Plant, it needs to know the precise value of the reactor power to make accurate & timely adjustment. But it is hard to acquire the precise value of the reactor power through measurement of reactor power based on physical or empirical model which leads to uncertainty in the instrument. Reactor power prediction was made in several cases through developing BP Neural network and preprocessing of input data of network. The results indicate that not only the disadvantage of uncertainty in measurement is overcome but also the reactor power can be properly predicted in some cases of partial data lack. The prediction of power output from Self Powered Neuron Detector (SPND) in Liquid Zone Control Compartment (LZC) of nuclear reactors are important in online global power measurement in a large Pressurized Heavy Water Reactor (PHWR).Noisy measured data from SPNDs have been smoothened out with the help of ARMA (Auto Regressive Moving Average) filter and then the smoothened data is used as an input for neural networks for training purpose.

Keywords –Nuclear Power Reactors, Neural Networks, Load Forecasting, SPND, ARMA

I. INTRODUCTION

The instrumentation and control (I&C) systems of a nuclear power plant (NPP) provide accurate and appropriate information and permit judicious action during both normal and abnormal operation when properly planned, designed, constructed and maintained. Under normal operating conditions they provide automatic control, both of the main plant and of many ancillary systems. The I&C safety systems protect the plant from the consequences. Load forecasting is very paramount to the operation transmission and distribution electricity utilities. It enhances the reliable planning, construction and management of the power systems. In Self-Powered Neutron Detectors (SPNDs), the interactions of neutrons and atomic nuclei are used to produce a current which is proportional to the neutron influence rate (flux). To model as a stochastic process, Auto -Regressive Moving Average (ARMA) models should be used. In earlier studies, it was difficult to implement ARMA modeling in real - time because of limitations in the speed of computers. Other studies have demonstrated that ARMA modeling, if equipped with an appropriate recursive estimator, can perform real time machining error modeling and control with good accuracy and minimum computational load. This data is used as input to neural network. ANN is well suited for the plant dynamic analysis because it has several properties like learning, adaptability, generalizability which outperform the other artificial intelligence techniques. ANN can work efficiently where non-linear functions are used and for evaluating the physical parameters at transient conditions with the help of powerful algorithms like back propagation algorithm. The main advantage of ANN is that it can perform interpolation accurately which is of interest of not depending on the process. It is a fast and efficient technique as compared to conventional methods.

II. NUCLEAR POWER REACTORS

A power reactor is a facility that makes electricity by the continuous splitting of uranium atoms (i.e., a nuclear reaction). This facility is often referred to as a nuclear power plant. A nuclear reactor is a device to initiate and control a sustained nuclear chain reaction. The most common use of nuclear reactors is for the generation of electric energy and for the propulsion of ships.

The nuclear reactor is the heart of the plant. In its central part, the reactor core's heat is generated by controlled nuclear fission. With this heat, a coolant is heated as it is pumped through the reactor and thereby removes the energy from the reactor. Heat from nuclear fission is used to raise steam, which runs through turbines, which in turn powers either ship's propellers or electrical generators. Since nuclear fission creates radioactivity, the reactor core is surrounded by a protective shield. This containment absorbs radiation and prevents radioactive material from being released into the environment. In addition, many reactors are equipped with a dome of concrete to protect the reactor against both internal casualties and external impacts.

In nuclear power plants, different types of reactors, nuclear fuels, and cooling circuits and moderators are used. Nuclear plant instrumentation can generally be classified into the following four categories:

• Nuclear: instruments that measure nuclear processes or reactor power, such as neutron flux density.
• Process: instruments that measure non-nuclear processes such as reactor pressure, coolant or pressurizes level, steam flow, coolant temperature and flow, containment pressure, etc.
• Radiation monitoring: instruments that measure radiation n, for example, in monitoring radiation in steam lines, gas effluents, and radiation at the plant site.
• Special: Instruments encompassing all other applications, such as for measuring vibration, hydrogen concentration, water conductivity and boric ac id concentration or meteorological, seismic, or failed fuel detection applications (IAEA, 1999).

The variety of I&C components and applications notwithstanding, temperature, pressure, level, flow, and neutron flux remain the most important and safety-critical measurements for the control and safety protection of nuclear reactors. The heart of each of these measurements is the sensor itself--the most important component in an instrument channel and the one that usually resides in the harsh environment of the field (Hashemian, 2007).
Despite the accelerating advances in I &C technology the basic mechanism of measurement used by these sensors has not changed significantly since the earliest nuclear plants. Today, temperature, pressure, level, flow, and neutron flux are still primarily measured using convention al sensors such as resistance temperature detectors (RTDs), thermocouples, capacitance cells, bellows, force-balance sensors, and conventional neutron detectors although some advances have been made in developing new neutron detectors for nuclear power plants.

The control and safety of nuclear power plants depend above all on temperature and pressure (including differential pressure to measure level and flow) instrumentation—the two most ubiquitous instrument types in a typical nuclear power plant process. In pressurized water reactor (PWR) plants, RTDs are the main sensors for primary system temperature measurement. RTDs are thermal devices that contain a resistance element referred to as the sensing element. Two groups of RTDs are typically used in nuclear power plants: direct immersion (or wet-type) and thermo well mounted (or well-type). The resistance of the sensing element changes with temperature, and therefore by measuring the resistance, one can indirectly determine the temperature. The number of RTDs in a nuclear power plant depends on the plant design an d its thermal hydraulic requirements. For example, PWR plants have up to 60 safety-related RTDs while heavy water reactors have several hundred RTDs. Pressure transmitters are the next most common I&C component. A pressure transmitter may be viewed as a combination of two systems: a mechanical system and an electronic system. The pressure transmitter's mechanical system contains an elastic sensing element (diaphragm, bellows, Bourdon tube, etc.) that flexes in response to pressure applied. The movement of this sensing element is detected using a displacement sensor and converted into an electrical signal that is proportional to the pressure. Typically, two types of pressure transmitters are used in most nuclear power plants for safety -related pressure measurements. These are referred to as motion -balance and force-balance, depending on how the movement of the sensing element is converted into an electrical signal. A nuclear power plant generally contains about 400 to 1200 pressure and differential pressure transmitters to measure the process pressure, level, and flow in its primary and secondary cooling systems. The specific number of transmitters used in a plant usually depends on the type and design of the plant. For example, the number of transmitters used in PWRs depends on the number of reactor coolant loops.

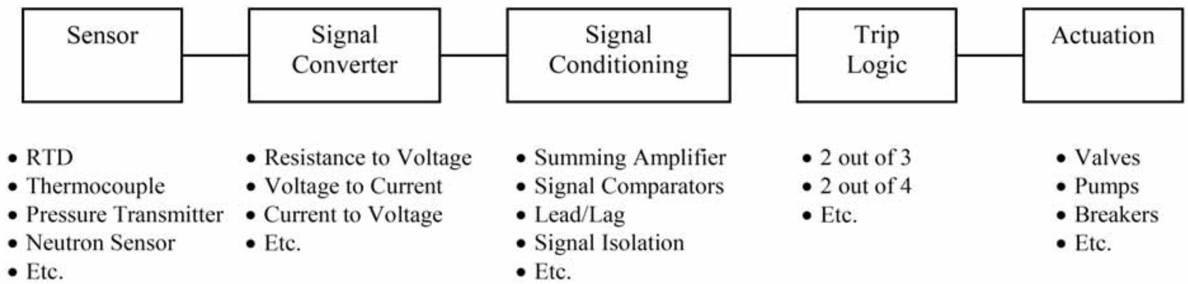


Fig1.Process Instrumentation Channel in Nuclear Power plants

A. Controlled Fission

A nuclear reactor operates by the controlled fission of ^{235}U. Fission occurs at a slow steady rate, rather than suddenly in a fraction of a second, as in a bomb. Fission produces heat, and this heat is used to generate electricity, in the same way that the heat of burning oil or coal generates electricity in a conventional power plant. Continuous operation depends on each fission producing neutrons for the next fissions. But we do not look for the multiplying effect. Rather, after each fission we want to produce, on the average, one additional neutron to initiate fission. In that way the process doesn't grow rapidly, but continues at a constant rate.

Operation

The presence of large amounts of ^{238}U in the reactor imposes important constraints on the reactor's design. As neutrons collide with the ^{238}U nuclei there is a growing chance of them being absorbed (producing ^{239}U). There will eventually be so much absorption, that not enough neutrons will remain to initiate further fissions, and to maintain the reactor in operation. On the other hand, when neutrons strike a ^{235}U nucleus, there is a high probability that they will be absorbed, and produce the unstable ^{236}U, which then fissions. This probability is greater if the neutron is moving relatively slowly.

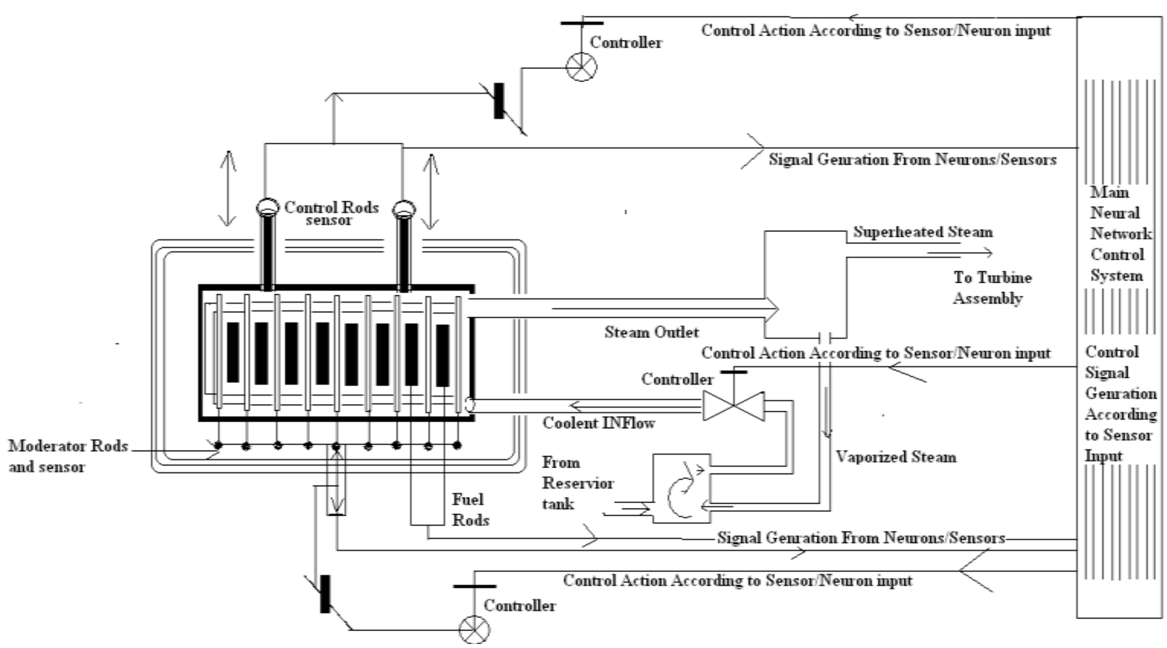


Fig 2. Nuclear Power Reactor Operation

B. Adaptive Neural Network

An adaptive neural network is a system that processes information and makes adjustments to the network when necessary. Such networks can be found in computer systems or in organic life forms. They are used to interpret large amounts of complex information and are the basis of modern artificial intelligence technology. A man-made adaptive neural network, also called an artificial neural network, is modeled after the naturally occurring neural networks in the brains of humans and animals. They work using a series of information-gathering sensors — the neurons — that are interpreted by a central processing unit. These connections can alter and change the way they interact with the central processing unit based on their own evaluation of how to most efficiently carry out their functions.

There are two main ways an adaptive neural network "learns": supervised learning and unsupervised learning. Supervised learning requires a human counterpart who instructs the network on how to interpret and interact with various inputs. The purpose of this style of learning is to ensure that there are no errors in the methods that the adaptive neural network uses to process information, and to reinforce the desired actions of the network.

Non-supervised learning relies on the central processing unit interacting with its environment and making its own decisions on how it should operate based on its original programming. To do this it organizes and reorganizes the information it receives and makes predictions about what the results of changing this data could be. A network can either learn online or offline. Online learning means that network learns while it is also performing tasks. Offline learning requires the network to learn separately from acting. Currently there are four main tasks that are performed by adaptive neural networks. They all deal with processing and interpreting patterns. First, there is clustering, where the network examines a number of patterns and groups related patterns into clusters.

A second task that an adaptive neural network may perform is recognizing and interpreting a pattern, such as written or spoken words. In doing this, it may attempt to understand completely unknown patterns based on its understanding of related patterns. Providing an estimate of the value of a function is the third main task, and is often used in science or engineering. The fourth main task that an adaptive neural network may perform is to make predictions of what will occur in the future if changes are made to certain data models.

An artificial neural network is a form of artificial intelligence and its most modern uses involve advanced robotic technology. It is more commonly used by data analysts, since their jobs deal with interpreting and sorting through large amounts of information. An artificial neural network can help an analyst organize her data, conduct research, and test possible changes to her company’s products and services. As technology becomes more advanced, applications of neural networks will become more common.

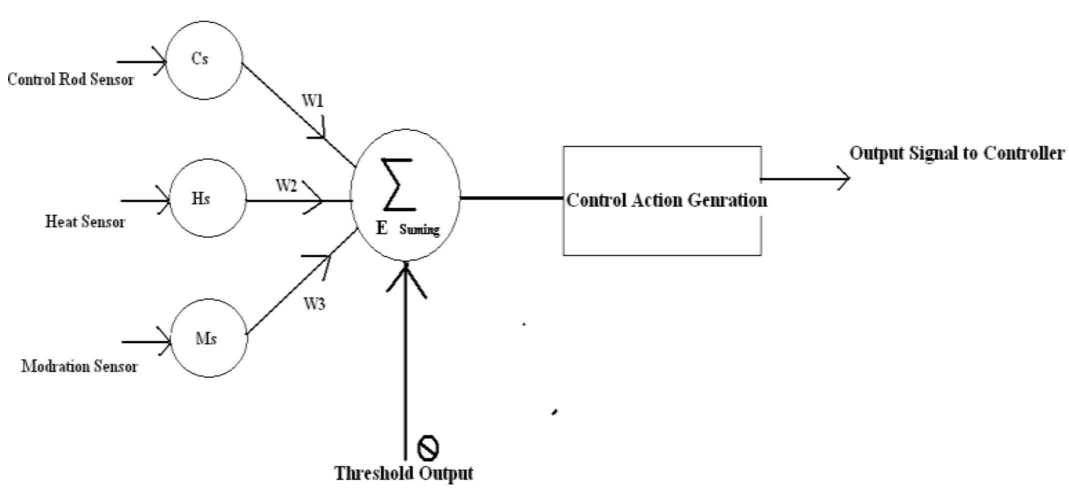


Fig 3. Neural Network Approach

In this system we are creating a neural network using various signals those are generated by the various sensors (heat, moderation, coolant flow) during the continuous process of nuclear reactor. The signals that are flowing in the reactor process defined in neural network are mainly used to control the reactor process to get the optimized output. Here we are also considering that each sensor is a neuron signal generator according to the condition and each generated signal is an neural signal and this neural signal is then feed to the main neural network control system where all the actions are defined for each and every condition and the proper action is been takes place according to the arrived condition that will feed to the control value those are controlling the coolant flow ,Control rods, moderation rods, because of the presence of the neural network the complete process is balanced and all the necessary actions should be taken place at on hard real time so that there is no human errors or any time delay is involved in the process.

C. Load Forecasting of Nuclear Power Reactors using Neural Approach

The system that we have defined is mainly to control the three main processes of nuclear reactor.

Moderation Process
In this process the action is taken place because when the fuel is completely filled in the reactor core and reaction process is about to start moderation rods will control the moderation of the neutrons of those are used for bombardment on U-235 nuclei. The moderation rods are also responsible for heat generation speed in the reactor core if the heavy moderation should done in the reactor the whole process will misbalance but the moderation sensor and control will be controlled by the signal generated by moderation sensor. The moderation rods are also used to provide optimized output during the whole process.

Cooling process
In this process the action should be taken place because of generation of heat sensor signals in the reactor core. When the temperature of reactor core is going beyond the subcritical region because of the nuclear reaction process the sensor will generate a signal that will send to the main neural network control system.

Control/Absorption Process
In this process the action is taken place because of signal generated from two sensors that is heat sensor and flow sensor when the reactor heat level is high the moderation is obviously high so the absorption o neutrons is compulsory so the control signals are sent to control rods from neural network system .Secondly when the flow of coolant is there at that time also the control rods are in action for providing optimization output.During the complete process in the reactor and its control system we should take care about some important factors for achieving the real time operation and best performance

Dead Time
It is the time taken by a process control system to control any situation that is generated in the system .The dead time is the complete time of action that is cover the signal generation according to the condition occur during the process and a control signal generated to control that situation .This whole time that we have calculated in this neural network system so that the hard real time operation is achieved every time.

Optimized Output
Optimized output is the main requirement of the nuclear reactor because the cost of the nuclear fuel is very much and it is necessary to get maximum efficiency output from the reactor each and every time for that we are using the concept of CSTR (continuous steer tank reactor)[6] .In which we are considering three conditions .

Case 1:- Minimum Input Minimum Output (Initialization of Process)
Case2:- Balanced Input Balanced Output (Optimized Process)
Case3:- Maximum Input Maximum Output (Critical Region Process)
All the time after initialization of process the neural network will maintain the process in Optimized mode

Multi-layer Perceptron Neural Network Model

The Perceptron is a single layer neural network whose weights and biases could be trained to produce a correct target vector when presented with the corresponding input vector. The training technique used is called the perceptron learning rule. The perceptron generated great interest due to its ability to generalize from its training vectors and work with randomly distributed connections. Perceptrons are especially suited for simple problems in pattern classification.

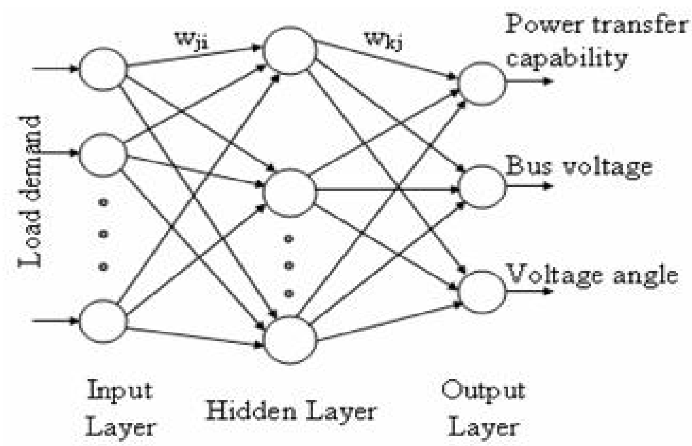


Fig 4. Load Forecasting using Perceptron Neural Model

The network 'learns' by adjusting interconnections between layers. When the network is adequately trained, it is able to generalize relevant output for a set of input data. Learning typically occurs by example through training, where training algorithm iteratively adjust the connection weights (synapses).

D. SPND AND ARMA In Power Monitoring Channel

The main purpose of in-core flux detectors is to measure the neutron flux distribution and reactor power. The detectors are used for flux mapping for in-core fuel management purposes, for control actions and for initiating reactor protection functions in the case of an abnormal event. In order to ensure predictable temperatures and uniform depletion of the fuel installed in a reactor, numerous measures are taken to provide an even distribution of flux throughout the power producing section of the reactor. This shaping, or flattening, of the neutron flux is normally achieved through the use of reflectors that affect the flux profile across the core, or by the installation of poisons to suppress the neutron flux where desired. The last method, although effective at shaping the flux, is the least desirable since it reduces the neutron economy by absorbing the neutrons.

In the BWR, the output power alternately falls and rises due to the generation and disappearance of voids, respectively, which may possibly generate power oscillation whereby the output power of the nuclear reactor oscillates and is amplified. The power monitoring system has a local power range monitor (LPRM) unit that has a plurality of local power channels to obtain local neutron distribution in a nuclear reactor core; an averaged power range monitor (APRM) unit that receives power output signals from the LPRM unit and obtains averaged output power signal of the reactor core as a whole; and an oscillation power range monitor (OPRM) unit that receives the power output signals from the LPRM unit and monitors power oscillation of the reactor core. The output signals from the LPRM unit to the APRM unit and the output signals from the LPRM unit to the OPRM unit are independent.

A unique type of neutron detector that is widely applied for in-core use is the self-powered detector (SPD). These devices incorporate a material chosen for its relatively high cross section for neutron capture leading to subsequent beta or gamma decay. In its simplest form, the detector operates on the basis of directly measuring the beta decay current following capture of the neutrons. This current should then be proportional to the rate at which neutrons are captured in the detector. Because the beta decay current is measured directly, no external bias voltage need be applied to the detector, hence the name self- powered. Another form of the self-powered detector makes use of the gamma rays emitted following neutron capture. Some fraction of these gamma rays will interact to form secondary electrons through the Compton, photoelectric, and pair production mechanisms. The current of the secondary electrons can then be used as the basic detector signal. Nonetheless, the self powered neutron detector (SPND) remains the most common term applied to this family of devices. Compared with other neutron sensors, self-powered detectors have the advantages of small size, low cost, and the relatively simple electronics required in conjunction with their use. Disadvantages stem from the low level of output current produced by the devices, a relatively severe sensitivity of the output current to changes in the neutron energy spectrum, and, for many types, a rather slow response time. Because the signal from a single neutron interaction is at best a single electron, pulse mode operation is impractical and self-powered detectors are always operated in current mode.

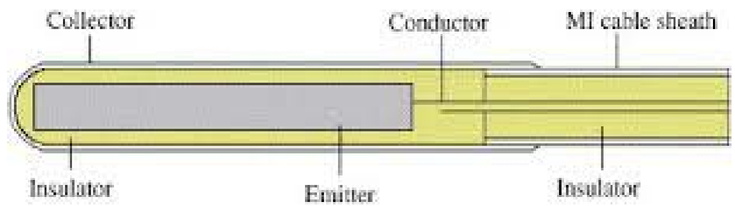
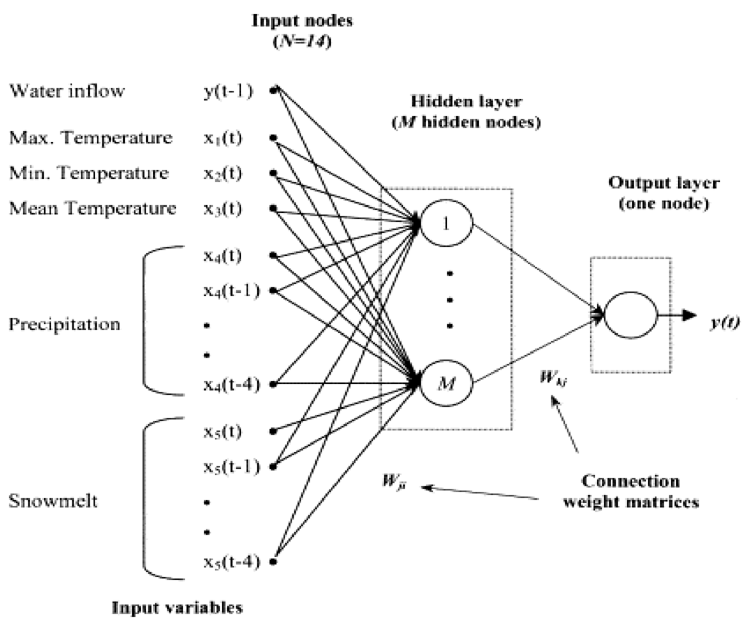
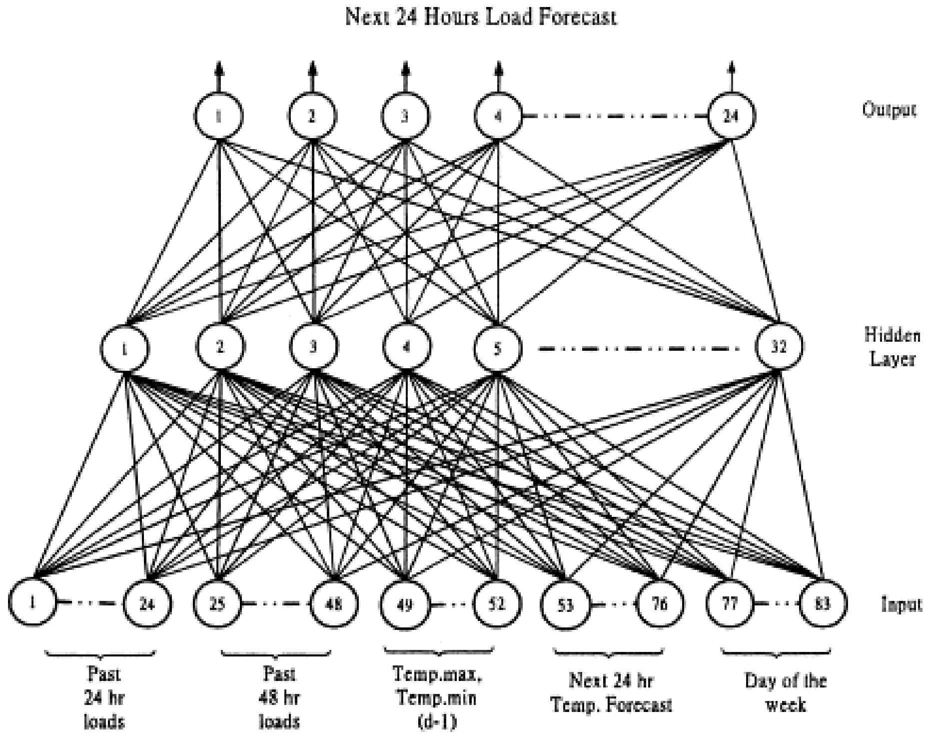
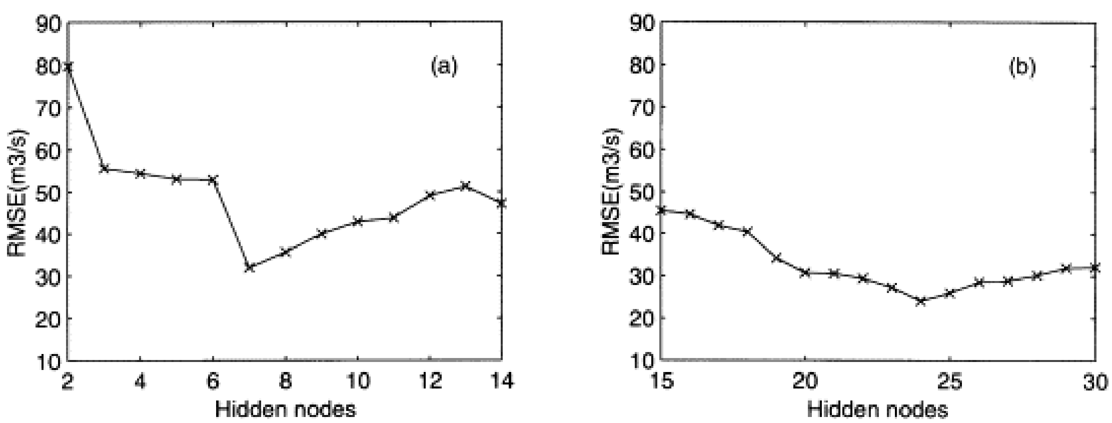


Fig 5.Self Powered Neutron Detector (SPND)

III. EXPERIMENT AND RESULT




Next 24 Hours Load Forecast
Output
Hidden Layer
Input
1
2
3
4
24
5
32
1
24
25
48
49
52
53
76
77
83
Past 24 hr loads
Past 48 hr loads
Temp.max, Temp.min (d-1)
Next 24 hr Temp. Forecast
Day of the week


(a)
(b)
RMSE(m3/s)
Hidden nodes
90
80
70
60
50
40
30
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10
2
4
6
8
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12
14
15
20
25
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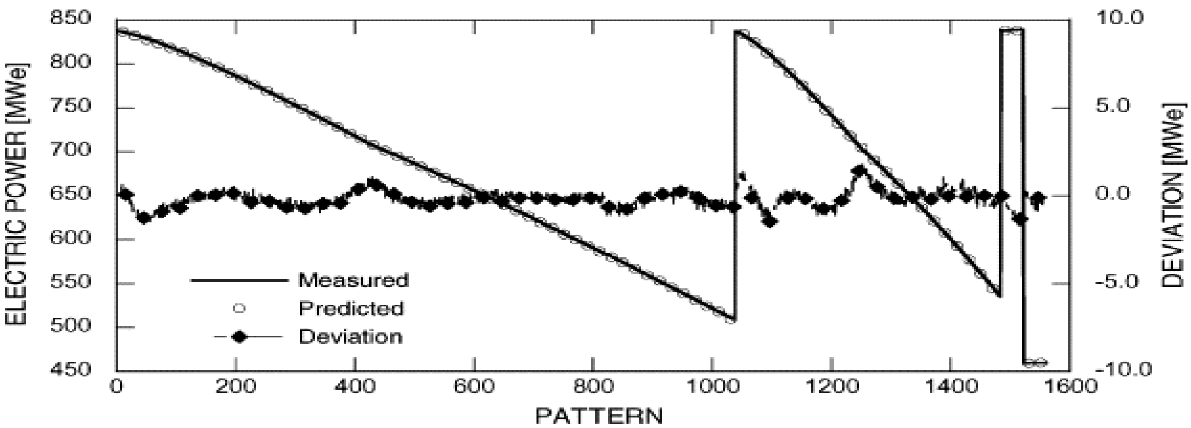

IV.CONCLUSION

ANN models for load forecasting can be extended to heat demand forecasting. Prediction of transient responses, heat rate in nuclear power plants, tuning of power system stabilizers, Control of load frequency, Modeling of dynamic load, Control of load shedding, forecasting and also fault diagnosis can be done with the examined thoroughly with the help of ANN. By establishing the fundamental theory and /or more reliable procedures for neural net design and development Electric power industry can work successfully. Interpolation and Extrapolation based on temperatures are implemented for load forecasting for various weather conditions. Much better results with respect to actual load and removal of regression are expected if load and temperature are highly correlated to each other.Future work can be focused on the online real time predictive systems. Computer aided training simulators should play a very vital part in heat rate with minimum emission and improved performance.

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