DESIGN OF NEURO-FUZZY NETWORK FOR TEMPERATURE CONTROL OF FURNACE

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Submitted by

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled "Design of Neuro-Fuzzy network for Temperature Control of Furnace", in partial fulfilment of the requirements for the award of degree of Master of Engineering in Electronic Instrumentation & Control Department of Thapar University, Patiala , is an authentic record of my own work carried out under the supervision of Dr. Gagandeep Kaur, Assistant professor, EIED.

The matter presented in the thesis has not been submitted for the award of any other degree of this or any other university.

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ABSTRACT

The design of an advanced control methodology for professional nuclear reactor has been done. This design will increase complexity and reduces the risk factor as nuclear reactor uses highly explosive and radioactive elements as a fuel and required a very highly precise and accurate control at real time. To achieve the control in this process combination of neural and fuzzy logic is used which provide autonomous control to heating and cooling of the reactor.

The system accepts the weights from user which are to be loaded into artificial neural network nodes. When reactor is turned ON. The hardware that is installed in reactor senses the temperature with the help of temperature sensor, and process the measured data to a high speed microcontroller unit. The instant temperature readings are then passed to the computer system located in monitoring office far away from reactor. Reactors coolant and heating controls are also connected to microcontroller unit within the reactor. This system developed can support n number of reactors at a time i.e it can provide temperature measurement for multiple reactors simultaneously and can effectively control them.

Application software is programmed on computer system which receives updated data from reactors microcontroller unit and display current temperature in it. It gets set limit values initially from user and whenever incoming temperature matches or crosses the set limits then it fires the various outputs according to values set to provide amount of coolant and designs to turn the control of reactor automatically. Soul of this application software is artificial intelligence which is provided by concepts of fuzzy sets or rules based expert systems of artificial neural networks.

Intelligence of this application software is to drive nuclear reactor in a smart and control way by itself. It totally eliminates human interaction with controls of reactor. It itself decides that what amount of coolant is needed at which temperature range. This application software is developed of fuzzy logic and artificial neural network nodes technology base and the control system results in security and precise control system.

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LIST OF ABBREVIATIONS

ANN	Artificial neural network
FL	Fuzzy logic
NR	Nuclear reactor
PHWR	Pressurised heavy water reactor
MSR	Molten salt reactor
AL	Artificial intelligence
LWR	Light water reactor
U-235	Uranium
LMCR	Liquid metal cooled reactor
OMR	Organically moderated reactor
RPV	Reactor pressure vessel
BWR	Boiling water reactor
PWR	Pressurised water reactor
GSR	Gas cooled reactor
AGCR	Advanced Gas cooled reactor
LMFBR	Liquid metal fast breeder reactor
IFR	Integral fast reactor
HTGCR	High temperature gas cooled reactor
BARC	Bhabha atomic research centre
AHWR	Advanced heavy water reactor
FBTR	Fast breeder test reactor
CAESAR	Clean and environmentally safe advanced reactor
SSTAR	Small, sealed, transportable, autonomous reactor

X_j	Input signal
W_{kj}	Synaptic Weights
U_k	Linear Combiner Output
b_k	Bias
f	Activation Function
y_k	Output Signal
VB	Visual Basic

CHAPTER 1

LITERATURE SURVEY

This system is going to introducing the concept of nuclear reactor temperature control in three different modes using artificial intelligence. Nuclear reactor is that part of nuclear power plant where fission chain reaction is made to occur and where fission energy is liberated in the form of heat for operating power conversion equipment. The core of the reactor consists of an assemblage of fuel elements, moderator, control rods and coolant. Reactor core have a shape approximating to a right circular cylinder with a diameter ranging from 0.5m to 15m. The fuel elements are made of plates or rods of uranium metal. These plates or rods are usually clod in a thin sheath of stainless steel as zirconium or aluminium to provide corrosion resistance and retention of radioactivity also in some cases it provides structural support. Enough space is provided between individual plates and rods to allow free passage of the coolant. Nuclear reactors are used as research tools. Nuclear reactors are employed as systems for producing radioactive isotopes and most prominently as energy sources for nuclear power plants. Nuclear reactors are many types which are classified by their use, phase of fuel, coolant, generation types of power producing reactors, types of nuclear reaction, and moderate materials to cool reactors. [12]

The system which is going to design is an advancement or add-on to the controls of professional nuclear reactors. This system is design to work in three modes out of it two modes are concerned with artificial intelligence. This used the combination of artificial neural network and fuzzy logic to provide autonomous control to heating and cooling controls of reactor.

The system accepts the weights from user those are to be loaded into nodes of ANN. Thus it turned on the reactor. The hardware that is installed in reactor senses the temperature by help of temperature sensor, and hand it up to a high speed MCU hands over the temperature reading to computer system located in monitoring office far away from reactor. Reactors coolant and heating controls are also connected to MCU in reactor itself. This system can support n number of reactors at a time.

Application software is programmed on computer system which receives updated data from reactors MCU and display current temperature in it. It gets set limit values initially from user and whenever incoming temperature matches or crosses the set limits then it fires the various outputs according to values set to provide amount of coolant and designs to turn the control of reactor automatically. Soul of this application software is artificial intelligence which is provided by concepts of fuzzy sets or rules based expert systems of ANNs.

Intelligence of this application software is to drive nuclear reactor in a smart and control way by itself. It totally eliminates human interaction with controls of reactor. It itself decides that what amount of coolant is needed at which temperature range.

This application software is made up of fuzzy logic and ANN nodes. It is equipped with three modes which are following

- Manual Mode
- Semi – auto Mode
- Intelligent Mode

In manual mode to monitor the temperature of a reactor and have turn ON/OFF the reactor from this application software manually. In semi- auto mode temperature sensor provide weights to ANN's nodes in software which then intelligently controls reactor according to provide weights.

In intelligent mode nodes are already provided with weights. It controls the reactor in fully smart way and removes users interference

1.1 LITERATURE REVIEW

Advancement of technology in the field of nuclear power generation will increase the complexity and risk factors because the nuclear power generation plant and nuclear reactors use highly explosive and radioactive elements as fuel required elements as fuel and required a very highly precise and accurate controlling at real time. Many researches in the past decade have been carried out to on line and offline control of nuclear reactor temperature a few of these are summarised as follow

Vinit. T et al. presents a real time operation based intelligent system which uses an artificial neural network which will control the system with high accuracy and operate the complete system at hard real time. It basically contains sensors and control value software tool and height speed computer system for performing the actions according to requirement. [36]

Chao-c et al. developed new approach for wide-range optimal reactor temperature control using diagonal recurrent neural networks (DR) with adaptive learning rate scheme is presented. The drawback of the usual feed forward neural network (FNN) is that it is a static mapping and requires a large number of neurons and takes a long training time. The usual fixed learning rate based on empirical trial and error scheme is slow and does not guarantee convergence. The DR is for dynamic mapping and requires much fewer numbers of neurons and weights, and thus converges faster than FNN. A dynamic back propagation algorithm coupled with adaptive learning rate guarantees even faster convergence. The DR controller described here includes both a neuro controller and a neuro identifier. A reference model which incorporates an optimal control law with improved reactor temperature response is used for training of the neuro controller and neuro identifier. Rapid convergence of this DR"-based control system is demonstrated when applied to improve reactor temperature performance**.** [4]

M.Sepielli. et al. Proved an activity is aimed at intelligent processing of the data obtained by reactor measurements through soft-computing models based on neural networks (NN). A first application is made for CRDM rod position validation and a second one is devoted to the fuel temperature prediction. Both use the NN-based algorithms working on real data coming from sensors. The bias between real and calculated values is used to train the NNs for improving the performance in the further experiments. [14]

Hussein.A et al. has developed state feedback assisted classical (SFAC) control has to improve temperature response performance of nuclear reactors via modifying the embedded classical controller reference signal. This is done by means of an outermost state feedback controller. Linear quadratic Gaussian with loop transfer recovery (LQG/LTR) at the plant output seems a good candidate for the state feedback loop of SFAC structure but it ends up in a closed loop system with tightly controlled power. To pay more attention to temperature responses, it presents the results of using LQG/LTR at the plant input in SFAC structure. We impose a minor change for considering, to some extent the variation of system poles (and hence its speed) due to linearization of the nonlinear plant in equilibrium conditions other than the design power. The results are compared to an existing LQG controller with LTR at the plant output. Sensitivity of dominant closed loop poles and nonlinear simulations are used for demonstration and comparison**.** [11]

Benedito.D et at. Approach to artificial neural networks based on the design of task-specific networks and on biological models of a neuron with multiple synapses developed by Baptista, Cabral and Soares was extended to accommodate external perturbations. The learning algorithm of this artificial neural network is an unsupervised training method based on the processes of habituation, sensitization and classical conditioning of human reflexes. This new development is applied to the control of the fluid temperature at any point in a natural circulation loop. The learning and the action processes were implemented in a computer program. The thermal-hydraulics processes were also simulated. The natural circulation loop simulation model is based on physical equations and on experimentally identified parameters. The results show that besides the excellent learning capability and generalization the new improvements are suitable to accommodate external perturbations so that the network is able to maintain the controlled variable within allowable limits even in the presence of strong perturbations. [10]

Rashmi.N et al. Developed real time simulation of process models which in heavy demand in the present day industrial scenario especially in Nuclear Power Plant scenario. Nuclear core being the most important and critical component in the Nuclear reactor, the primary concern is towards safe and efficient operation of the reactor by adopting better techniques for monitoring and control of the reactor. Effort is on a global level to develop and build a Training Simulator, covering all the reactor subsystems to impart comprehensive training to Nuclear Power Plant operators. This paper describes about the importance of Core Temperature Monitoring System for Prototype Fast Breeder Reactor (PFBR) real time modeling and simulation of core temperature monitoring system, the basic requirements and methodologies adopted for modeling and simulation. The simulation includes run time calculation for all the fuel subassemblies (SA) outlet temperature and plugging or flow blockage of fuel subassembly for Equilibrium core. Equilibrium core is the state where fuel Subassemblies in the core has burnt for a definite period of time. The code calculates the individual subassembly outlet temperature according to flow and power fraction for that SA mean core outlet temperature and rise in mean core outlet temperature. At the time of flow blockage of a subassembly, the deviation in individual subassembly outlet temperature increases over its expected value and if it crosses its threshold, the SCRAM signal is initiated i.e. reactor comes to shutdown state automatically. The paper also discusses about the Integration of Core Temperature Monitoring logic model to the Simulator Environment and the integrated testing with simulator. [27]

Gilbert.s. et al. researched nuclear power plant designs involve the transmission of heat from the core of a nuclear reactor to the boiler of a steam plant by a gas or liquid coolant. A primary function of the power plant control system is to control the temperature of this coolant to provide the desired heat transfer rates and temperature levels in the boiler and reactor. The control system must also prevent transient excusions in the coolant temperature from exceeding the material and structural limitations of the power plant. Major obstacles to the control of transient excursions in coolant temperature are (l) the tendency of these temperature variations to be recirculated in the closed coolant loop (2) the long transport lags associated with the coolant circulation, and (3) the large inherent time lags of thermometers measuring the coolant temperature. [1]

Haipeng.Li et al. proved Issues in the operation and control of the multi-modular nuclear power plant is complicated. The high temperature gas cooled reactor pebble-bed module (HTR-PM) plant with two modules will be built as a demonstration plant in China. To investigate the operation and control characteristics of the plant, a simplified dynamic model is developed and mathematically formulated based upon the fundamental conversation of mass, energy and momentum. The model is implemented in a personal computer to simulate the power increase process of the HTR-PM operation. The open loop operation with no controller is first simulated and the results show that the essential parameter steam temperature varies drastically with time, which is not allowable in the normal operation. According to the preliminary control strategy of the HTR-PM a simple steam temperature controller is proposed. The controller is of Proportional-type with a time lag. The closed loop operation with a steam temperature controller is then implemented and the simulation results show that the steam temperature and also other parameters are all well controlled in the allowable range. [18]

J.humberto et al. Present a solution to the minimization problem of the transient time to accomplish the switching between different levels of power in a nuclear research reactor satisfying the inverse period constraint and avoiding to use any physical model of the plant. The strategy here proposed consists of two stages. First the optimal trajectory which satisfies the constraint is calculated 00-line second. A control law based on a generalized Hopfield neural network is employed to assure that the reactor power follows this optimal trajectory. [22]

S.R Patra. et al. Developed Sodium temperature estimation in Intermediate Heat Exchanger is very significant for nuclear power generation in fast breeder test reactor (FBTR). Hence accurate evaluation of sodium temperature is a major concern both in case of offline and online operation of nuclear power plant (NPP). This paper addresses the training of artificial neural network model to precisely estimate the sodium temperature of Sodium-Sodium (Na-Na) Intermediate Heat exchanger and studying its behaviour at transient conditions. Severely unbalanced flow conditions in addition to steady state condition are investigated to generate sufficient number of dataset. Based on the in house data gathered from Quadratic Upstream Interpolation for Convective Kinetics code (QUICK) a three layer neural network model is developed for training and subsequent validation. The back propagation (BP) algorithm is used for training the network. Further a model based on Radial Basis Function (RBF) neural network is developed and trained and the results are compared with standard back propagation algorithm. From the comparison studies it is found that the network trained with RBF converges faster than BP network. Training and testing results show the successful modelling of plant dynamics of the reactor with improved accuracy. ANN can be an alternative to the conventional model as it predicts the physical parameters without much complex calculations as used in conventional model. [38]

Isizoh A. N. et al. Design Fuzzy logic technique is an innovative technology used in designing solutions for multi-parameter and non-linear control models for the definition of a control strategy. As a result it delivers solutions faster than the conventional control design techniques. This paper thus presents a fuzzy logic based-temperature control system which consists of a microcontroller, temperature sensor, and operational amplifier Analogue to Digital Converter, display interface circuit and output interface circuit. It contains a design approach that uses fuzzy logic technique to achieve a controlled temperature output function. [39]

A. Aeenmehr et al. It represents temperature control of a batch tank in a glass factory is investigated. In a turbo generator system a large amount of energy is wasted as thermal energy at the exhaust. Therefore use of Combined Heat and Power (CHP) systems is highly under attention. In this work a turbo-generator system and a glass factory are considered as a CHP system. Since the hot exhaust gas has emissions which have a bad effect on the quality of molten glass, therefore the hot exhaust must be used indirectly in melting glass process, so a rotary regenerator is proposed to transfer gas turbine exhaust heat to the inlet air of the glass melting furnace. It is assumed that turbo-generator is operated at full load condition and gas turbine exhaust is directed into rotary regenerator to transfer gas turbine exhaust heat to inlet air of glass furnace. By controlling the speed of the rotary regenerator the amount of exchanged energy is controlled. An adaptive control strategy as Neuro- PID controller is proposed. The simulation results depict the capabilities of the proposed controller in different working states. [21]

J.Hemberto.P et al. Proved basic control problem in a nuclear research reactor consists of increasing or decreasing the neutron power from a certain level R0 to a new desired level R1 and maintains the reactor stable at the new power level. For security reasons this task must be performed in such a way that during the power ascent the instantaneous period of the reactor must always be greater than or equal to a lower limit value. In this problem avoiding the difficulties associated with the physical modeling of the nuclear process it propose to use an indirect adaptive control scheme in which a single layer second order differential neural network achieves the on-line identification based only on three variables the external reactivity the fuel temperature and the neutron power. The mathematical model provided by this identification process is employed to accomplish the control action in two stages. During the transient stage, the controller objective is to maintain the plant on a constant period. Once the desired power is reached the control action is switched to a regulation stage. This identifier-controller is tested by simulation. Instead of the real plant, an eighth order physical model of a

TRIGA reactor considered as a black box is used. The results show a good performance of the suggested approach. [22]

M.H.Syed et al. Demonstrates that Nuclear Reactors (NR) are large in scale and complex, they are expected to be operated with high levels of reliability and safety. Hence to increase plant safeties to achieve maintain system stability and assure satisfactory in order to meet the increasing demands for automated system and to detect and diagnose system failures and malfunctions. When a plant malfunction occurs a great data influx is occurred. It proposes a support system based on neuro fuzzy approach conjunction with Genetic Algorithm that assist alarming and diagnosis system. Throughout this framework Neuro-fuzzy fault diagnosis system is employed to diagnosis the fault of nuclear reactors. Hence to overcome weak points of both neuro learning and linguistic based approaches by which the integrated system will inherit the strength of both approaches and to optimize the Neuro-fuzzy outcomes using Genetic Algorithm resulting to show the efficiency is obtained by GA is greater and the inaccurate information of the alarming system also compared with Neuro-fuzzy diagnosis system. [40]

Keith.E et al. Developed that Economic constraints are driving the electric power industry to seek improved methods for monitoring, control, and diagnostics. To increase plant availability various techniques have been implemented in industry to assess equipment condition to prevent system inoperability. The availability of a large number of measured signals and additional component information and the increasing number of signal processing options to analyze sampled data motivate the assimilation of such diverse information into a plant wide condition monitor. The use of fuzzy logic is described herein for the purpose of performing the decision making regarding the system status and the possible need for component maintenance. Fuzzy-logic-based diagnostic monitoring is applied to data acquired from instrumentation within operating facilities. [37]

Tomonobu.S et al. Presents a speed control system for ultrasonic motors by PI (proportional and integral) control which has auto-tuning structure based on fuzzy reasoning realized by neural network. The speed characteristics of ultrasonic motor vary with temperature and applied load torque therefore adjusting the control gains of PI controller is necessary in order to obtain fine speed control performance. The proposed control scheme can incorporate the operator's knowledge in speed controller using fuzzy reasoning furthermore it can compensate the speed characteristic variations of the motor by online learning. The usefulness and validity of the proposed control scheme is examined by experiments. [6]

Serhat.Y et al. Proved a programmable logic controllers are microprocessor based control systems which manage a machine or an industrial foundation by means of change of situations and a program edited before. Basically a PLC is composed of a microprocessor. A power supply and input output units. Beside these units mentioned above some certain units were developed which respond to requirement of faster and more effective processing in industrial controlling systems. These special units as high speed counters, heat controllers and pH controllers increase the controlling performance of PLCs. Application of fuzzy logic theory in control systems proved to be superior to the conventional control systems. Fumy logic controllers can infer coherent results in uncertain conditions when it is necessary to control a complex system which is impossible to model using mathematical ways. In this paper, fuzzy control applications on PLCs are investigated under twocaptions first of which is the applicability of a special unit to PLCs were investigated which is controlled by a software that performs fuzzy logic processes, by means of improvement on a real industrial control system and the other is realization of fuzzy control algorithms by basic PLC instructions. [9]

Vasilis.T et al. Developed the dynamic and controlled operation of an integrated natural gas fuel processor system (FPS) a proton exchange membrane fuel cell (PEM-FC) and a catalytic burner (CB). The FC provides power based on the electrochemical reaction of hydrogen. The FPS generates the hydrogen from natural gas through catalytic partial oxidation (CPOX) and the CB provides the energy for preheating the FPS inlet flows by burning any excess hydrogen from the FC exhaust. The coupling of these three systems poses a challenging optimization and control problem. Optimization is performed to generate the air and fuel flow intake set points to the FPS for various load levels. The optimal flow set points are used in a static feed forward map that ensures maximum efficiency at steady state. Linear quadratic techniques are then used to develop a controller to mitigate hydrogen starvation in the fuel cell and regulate CPOX reactor temperatures. We show in simulations that the designed observer-based feedback controller which relies on temperature measurements of two reactors, speeds up the transient response fourfold as compared to the baseline when the static feed forward controller is employed. [15]

Zhang.S et al. Demonstrate that the greenhouse is a complex system. There is strong coupling relationship among its environmental factors in side greenhouse. So it’s difficult to get satisfying effect by using conventional control methods. Based on the characteristics of the greenhouse a new fuzzy neural network controller was proposed to create a proper condition for crop growth. The genetic algorithm was used to train the architecture of fuzzy neural network controller, which was adopted in the greenhouse. Finally the simulations with Matlab about this system were done. The result was that the speed and precision of the system were improved. The overshoot was reduced also. And the greenhouse system with this fuzzy neural network based genetic algorithm had such features as responding quickly smooth transition. [16]

1.2 OBJECTIVE OF THESIS WORK

The objective of thesis work is summarized as follow

i. Control of temperature of nuclear reactor in visual basic

ii. Speed control of coolant by applying PWM in visual basic model

iii. Design of artificial neural network for adaptive control of temperature

iv. Temperature control of nuclear reactor by ANN at different speeds by applying ANN in visual basics

v. Comparison between results obtained for temperature control of nuclear reactor at three different modes manual, semi-auto and intelligent

vi. Interfacing between hardware and software through RS232

1.3 ORGANIZATION OF THESIS

Chapter 1	Summarizes the overview of research work and organization of thesis
Chapter 2	Introduction of nuclear reactor
Chapter 3	Introduction of artificial neural network (ANN) its feed forward structure and learning algorithm
Chapter 4	case study
Chapter 5	Presents the conclusions drawn also outlines the possible avenues for future works

CHAPTER 2

NUCLEAR REACTOR

2.1 NUCLEAR REACTOR

Nuclear power is such a source of energy which can be utilized for the betterment of mankind. The generation of electricity from this nuclear power is one of the wonderful example of effective utilization of this energy which in the development of society. The development of nuclear reactor is helping to generate electricity. 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 is appreciated.

The nuclear reactor is the heart of the nuclear power 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 which then removes the energy from the reactor. Heat from nuclear fission is used to raise steam which runs through turbines. It in turns 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. The reactors are equipped with a dome of concrete to protect the reactor internal casualties and external impacts. The power of nuclear fission and fusion which actually occurs to convert nuclear energy into electrical energy is explained here for understanding. [12]

2.2 NUCLEAR FISSION

Fission is the process that occurs when a neutron collides with the nucleus of certain of the heavy atoms, causing the original nucleus to split into two or more unequal fragments which carries off most of the energy of fission as kinetic energy. This process is accompanied by the emission of neutrons and gamma rays.

The fission fragments that result from the fission process are radioactive. They decay by emission of beta particles, gamma rays and few alpha particles and neutrons. The neutrons that are emitted after fission decay by some of fission fragments are called delayed neutrons. These are very important as they help to control the chain reaction.

Requirements of fission process

i. The neutrons emitted in fission must have adequate energy to cause fission of another nuclei

ii. The produced number of neutrons must be able not only to sustain the fission process but also to increase the rate of fission. Certain loss of neutrons during the process is also to be accounted

iii. The process must be following by the liberation of energy

iv. It must be possible to control the rate of energy liberated

Since the chain reaction requires that one neutron from each fission cause fission reaction. There are several processes competing for the neutrons produced. These processes are non-fission capture in the fuel material, capture in the fuel container and core structure material, moderator and coolant and leakage of neutrons from core. To permit a chain reaction to take place it is necessary to design a system in which after accounting for all neutrons losses due to non-fission absorption and leakage there is still at least one neutron to produce fission reaction. The minimum quantity of fuel required for any specific reactor system is called the critical mass and the size associated with this mass is called critical size. Natural uranium contains 0.7% of fission isotopes U^{235}. Since U^{238} makes up a balance absorb neutrons a nuclear reactor which will sustain a chain reaction with natural uranium requires a large critical mass and the use of moderators and materials of construction which have very low absorption cross section. To reduce the critical mass required and permit more flexibility in material and design choice uranium fuel is frequently enriched with U^{235} content thereby increasing the fraction of neutrons captures that occurs in $U^{235}$and cause fission. [12]

2.3 NUCLEAR FUSION

Nuclear fusion is the process of combining or fusing two lighter nuclei into a stable and heavier nuclide. When the mass of the product nucleus is less than the masses of the two nuclei which are fused then large amount of energy is released. Several reactions between nuclei of low mass numbers have been brought by accelerating one or the other nucleus in a suitable manner. These are often fusion processes accompanied by as of much significance for the utilisation of nuclear energy. To have practical value nuclear fusion reactions must occur in such a manner as to make them self-sustaining i.e more energy must be released than is consumed in initiated the reaction. It is thought that energy liberated in the sun other stars of the main sequence type is due to the nuclear fusion reactions occurring to the very high stellar temperature of 30 million ºk such processes are called thermonuclear reactions because they are temperature dependent. [12]

2.4 HEAT GENERATED BY REACTOR CORE

Heat is generated by the nuclear reactor after nuclear fission or fusion. The energy is liberated in the form of heat after a nuclear reaction for operating power conversion. Thus reactor core generates heat in a number of ways

i. The kinetic energy of fission products is converted to thermal energy when these nuclei collide with nearby atoms
ii. The reactor absorbs some of the gamma rays produced during fission and converts their energy converted into heat
iii. Heat is produced by the radioactive decay of fission products and materials that have been activated by neutron absorption. This decay heat-source will remain for some time even after the reactor is shut down

A kilogram of uranium-235 (U-235) converted via nuclear processes releases approximately three million times more energy than a kilogram of coal burned conventionally 7.2×10^{13}joules per kilogram of uranium-235 versus 2.4×10^{7} joules per kilogram of coal. [35]

2.5 NUCLEAR REACTOR COOLANTS

The function of coolant is to remove the intense heat produce in the reactor. Usually water but sometimes a gas or a liquid metal or molten salt is circulated past the reactor core to absorb the heat that it generates. The heat is carried away from the reactor to generate steam. Most reactor systems employ a cooling system that is physically separated from the water that will be boiled to produce pressurized steam for the turbines like the pressurized water reactor. But in some reactors the water for the steam turbines is boiled directly by the reactor core for example the boiling water reactor. [12]

The desirable characteristics for reactor coolant are

i. Low parasite capture
ii. Low melting point
iii. High boiling point
iv. Chemical and radiation stability
v. Low viscosity
vi. Non-toxicity
vii. Non-corrosiveness
viii. Minimum induced activity like low energy emissions
ix. High specific heat which provides reduces pumping power and thermal stress
x. High density which reduces physical plant size and pumping power

2.6 REACTIVITY CONTROL

Nuclear poison is also called neutron absorber. It is a substance with large neutron absorption cress section in nuclear reactor. Absorbing neutrons is normally an undesirable effect. Neutron absorbing materials are called poisons. Control rods that are made of a neutron poison are used to absorb neutrons. Absorbing more neutrons in a control rod means that there are fewer neutrons available to cause fission that pushing the control rod deeper into the reactor will reduce its power output and extracting the control rod will increase it. At initial stage of control in all nuclear reactors a process of delayed neutrons emission by a number of neutron-rich fission isotopes is an important physical process. These delayed neutrons account for about 0.65% of the total neutrons produced in fission with the remainder termed prompt neutron released immediately upon fission. The fission products which produce delayed neutrons have half-lives for their decay by neutron emission that ranges from milliseconds to as long as several minute. Reactor is kept in the zone of chain reactivity where delayed neutrons are required to achieve a critical mass state which provides time for mechanical devices or human operators to have time to control a chain reaction in real time otherwise the time between achievement of criticality and nuclear meltdown as a result of an exponential power surge from the normal nuclear chain reaction would be too short to allow for intervention. [5]

In some reactors the coolant also acts as a neutron moderator. A moderator increases the power of the reactor by causing the fast neutrons that are released from fission to lose energy and become thermal neutrons. Thermal neutrons are more likely than fast neutrons to cause fission so more neutron moderation means more power output from the reactors. If the coolant is a moderator then temperature changes can affect the density of the coolant or moderator and therefore change power output. A higher temperature coolant would be less dense and therefore a less effective moderator. In other reactors the coolant acts as a poison by absorbing neutrons in the same way that the control rods do. In these reactors power output can be increased by heating the coolant which makes it a less dense poison. Nuclear reactors generally have automatic and manual systems to scram the reactor in an emergency shutdown. These systems insert large amounts of poison often boron in the form of boric acid into the reactor to shut the fission reaction down if unsafe conditions are detected or anticipated. Reactors used in nuclear marine propulsion especially nuclear submarine often cannot be run at continuous power around the clock in the same way that land based power reactors are normally run and in addition often need to have a very long core life without refuelling. For this reason many designs use highly enriched uranium but incorporate burnable neutron poison directly into the fuel rods. This allows the reactor to be constructed with a high excess of fissionable material which is nevertheless made relatively safer early in the reactors fuel burn cycle by the presence of the neutron-absorbing material which is later replaced by naturally produced long lived neutron poisons far longer lived than xenon-135 which gradually accumulate over the fuel load's operating life. [5]

2.7 NUCLEAR REACTOR TYPES

Nuclear reactors are classified by several methods

i. Classification by type of nuclear reaction

ii. Classification by moderator material

iii. Classification by coolant

iv. Classification by generation

v. Classification by phase of fuel

vi. Classification by use

2.7.1 Classification by type of nuclear reaction

i. **Nuclear fission**

All commercial power reactors are based on nuclear fission. Nuclear reactors generally use uranium and its product plutonium as nuclear fuel though a thorium fuel cycle is also possible. Fission reactors can be divided roughly into two classes depending on the energy of the neutrons that sustain the fission chain reaction. [17]

a. Thermal reactors use slowed or thermal neutrons. Almost all current reactors are of this type. These contain neutron moderator materials that slow neutrons until their neutron temperature is thermalized that is until their kinetic energy approaches the average kinetic energy of the surrounding particles. Thermal neutrons have a far higher cross section probability of fissioning the fissile nuclei uranium-235plutonium-239 and plutonium-241 and a relatively lower probability of neutron capture by uranium-238 (U-238) compared to the faster neutrons that originally result from fission which allows use of low-enriched uranium or even natural uranium fuel. The moderator is often also the coolant, usually water under high pressure to increase the boiling point. These are surrounded by a reactor vessel instrumentation to monitor and control the reactor, radiation shielding, and a containment building.

b. Fast neutron reactors use fast neutrons to cause fission in their fuel. They do not have a neutron moderator and use less-moderating coolants. Maintaining a chain reaction requires the fuel to be more highly enriched in fissile material about 20% or more due to the relatively lower probability of fission versus capture by U-238. Fast reactors have the potential to produce less transuranic waste because all actinides are fissionable with fast neutrons but they are more difficult to build and more expensive to operate. Overall fast reactors are less common than thermal reactors in most applications. Some early power stations were fast reactors as are some Russian naval propulsion units. Construction of prototypes is continuing

ii. Nuclear fusion

Fusion power is an experimental technology, generally with hydrogen as fuel. While not suitable for power production, Farnsworth-Hirsch fusors are used to produce neutron radiation.

2.7.2 CLASSIFICATION BY MODERATOR

In a nuclear reactor the function of a moderator is given below

i. To slow down the neutrons from the high velocities and hence high energy, which they have no being released from the fission process. Neutrons are slow down most effectively in scattering collisions with nuclei of the light elements, such as hydrogen, graphite and beryllium etc.

ii. To slow down the neutrons but not absorb them.

Moderates function is to absorb the part of kinetic energy of the neutrons. The neutrons collide directly with moderator and thus slow down. No ideal moderator is available in nature or has been produced artificially. The light weight nuclei materials are not suited at all as a moderator because they do not possess the property of absorption of neutrons. [12]

Classification of nuclear reactor by moderators

i. **Graphite moderated reactors**

A Graphite Reactor is a nuclear reactor that uses carbon as a neutron moderator which allows un-enriched uranium to be used as nuclear fuel. The most famous would be the one that blew up causing the chemobyl disaster. There are several types of graphite moderated nuclear reactor that have been used in commercial electricity generation

ii. Water moderated reactors

Water moderated reactor is further divided into two types

a. **Heavy water reactors.**

A pressurized heavy water reactor (PHWR) is a nuclear power reactor using unenriched natural uranium as fuel. PHWR uses heavy water coolant and moderator i.e. deuterium oxide D_2O. The heavy water coolant is kept under pressure allowing it to be heated to higher temperatures without boiling much as in a PWR. While heavy water is significantly more expensive than ordinary light water. It yields greatly enhanced neutron economy thereby allowing the reactor to operate without fuel enrichment facilities and generally enhancing the ability of the reactor to efficiently make use of alternate fuel cycle.

b. **Light water moderated reactors** (LWRs)

Light water reactors use ordinary water as moderate and coolant for light water moderated reactors. At operating temperature if the temperature of the water increases then its density drops and fewer neutrons passing through it are slowed enough to trigger further reactions. That negative feedback stabilizes the reaction rate. Graphite and heavy water reactors tend to be more thoroughly thermalized than light water reactors. Due to the extra thermalization, these types can use natural uranium or unenriched as a fuel.

iii. **Light element moderated reactors**

These are further divided into two types reactors are moderated by lithium or beryllium.

a. **Molten salt reactor**

Molten salt reactors are moderated by a light elements such as lithium or beryllium, which are constituents of the coolant or fuel matrix salts LiF and BeF_2. A molten salt reactor is a class of nuclear fission reactors in which the primary coolant or even the fuel itself is a molten salt mixture. MSRs run at higher temperatures than water cooled reactors for higher thermodynamic efficiency while operating at low vapor pressure. Operating at near atmospheric pressures reduces the mechanical stress endured by the system and thus simplifying aspects of reactor design and improving safety. It should be possible to construct and operate molten salt reactors more cheaply than coal power plants. The nuclear fuel may be solid or dissolved in the coolant itself. In many designs the nuclear fuel is dissolved in the molten fluoride salt coolant as uranium tetra fluoride (UF_4). The fluid becomes critical in a graphite core which serves as the moderator. Solid fuel designs rely on ceramic fuel dispersed in a graphite matrix with the molten salt providing low pressure and high temperature cooling. The salts are much more efficient than compressed Helium for removing heat from the core. Thus it reduces the need for pumping, piping and reducing the size of the core. [28]

b. **Liquid metal cooled reactor**

Liquid metal cooled reactors are one whose coolant is a mixture of Lead and Bismuth. It may use BeO as a moderator. A liquid metal cooled nuclear reactor LMC is an advanced type of nuclear reactor where the primary coolant is a liquid metal. Liquid metal cooled reactors were first adapted for nuclear submarine use but have also been extensively studied for power generation applications. They have advantages because the reactor doesn't need to be kept under pressure as they allow a much higher power density than traditional coolants. Disadvantages include difficulties associated with inspection and repair of a reactor immersed in opaque molten metal, and depending on the choice of metal, corrosion and/ production of radioactive activation

iv. Organically moderated reactors (OMR) use biphenyl and terphenyl as moderator and coolant.

2.7.3 CLASSIFICATION BY COOLANT

In thermal nuclear reactors the coolant acts as a moderator that must slow down the neutrons before they can be efficiently absorbed by the fuel. [7]

i. **Water cooled reactor**

There are 104 operating reactors in the United States. Of these 69 are pressurized water reactors (PWR) and 35 are boiling water reactors.

a. **Pressurised water reactor**

Most commercial PWRs and naval reactors use pressurizers. During normal operation a pressurizer is partially filled with water and a steam bubble is maintained above it by heating the water with submerged heaters. The pressurizer is connected to the primary reactor pressure vessel (RPV) and the pressurizer bubble which provides an expansion space for changes in water volume in the reactor. This arrangement also provides a means of pressure control for the reactor by increasing or decreasing the steam pressure in the pressurizer using the pressurizer heaters.

b. **Pressurised heavy water reactors**

Pressurised heavy water reactors are a subset of pressurized water reactors by sharing the use of a pressurized and isolated heat transport loop but using heavy water as coolant and moderator for the greater neutron economies it offers.

ii. **Boiling water reactor**

Boiling type reactor is characterized by boiling water around the fuel rods in the lower portion of a primary reactor pressure vessel. A boiling water reactor uses ^{235}U enriched as uranium dioxide as its fuel. The fuel is assembled into rods that are submerged in water and housed in a steel vessel. The nuclear fission causes the water to boil so as to generating steam. This generated steam flows through pipes into turbines. The turbines are driven by the steam and this process generates electricity. During normal operation, pressure is controlled by the amount of steam flowing from the reactor pressure vessel to the turbine.

a. **Pool type reactor**

It is also called swimming pool reactors because reactor core is located near the bottom of a large pool of highly purified water approximately 20 feet deep. The core consists of a rectangular assembly of plate type fuel elements. Each plate of aluminium uranium alloy is clad with aluminium. There are about 10 to 20 plates in each element. The water acts as neutron moderator or cooling agent and radiation shield. The layer of water directly above the reactor core shields the radiation so that complete operators may work above the reactor safely. This design has two major advantages the reactor is easily accessible and the whole primary cooling system *i.e.* the pool water is under normal pressure. This avoids the high temperatures and great pressures of nuclear power plant. Pool reactors are used as a source of neutrons for process heat but not for electrical generation.

iii. **Liquid metal cooled reactor**

In liquid metal cooled reactor water is used as moderator. Water cannot be used as a coolant in a fast reactor. Liquid metal coolants have included sodium, NaK, lead, lead bismuth eutectic and in early reactors mercury

- **Mercury**

  Clementine was the very first liquid metal cooled nuclear reactor and used mercury coolant thought to be the obvious choice since it is liquid at room temperature. However because of disadvantages including high toxicity and high vapor pressure even at room temperature. At low boiling point it produces noxious fumes. But when heated at relatively low thermal conductivity and a high neutron cross section it has fallen out of favor.

- **Sodium and NaK**

  Sodium and NaK don't corrode steel to any significant degree. These are compatible with many nuclear fuels which allows for a wide choice of structural materials. However ignite spontaneously on contact with air and react violently with water to produce hydrogen gas. This was the case at the Monju nuclear power plant in a 1995 accident and fire. Neutron activation of sodium also causes these liquids to become intensely radioactive during operation though the half life is short and therefore their radioactivity doesn't pose an additional disposal concern.

- **Lead**

  Lead has excellent neutron properties reflection with low absorption and is a very potent radiation shield against gamma rays. The higher boiling point of lead provides safety advantages as it can cool the reactor efficiently even if it reaches several hundred degrees Celsius above normal operating conditions. However because lead has a high melting point and a high vapor pressure it is tricky to refuel and service a lead cooled reactor. The melting point can be lowered by alloying the lead with bismuth but lead bismuth eutectic is highly corrosive to most metals used for structural materials.

Coolant	Melting point	Boiling point
Sodium	97.72°C, (207.9°F)	883°C, (1621°F)
NaK	-11°C, (12°F)	785°C, (1445°F)
mercury	-38.83°C, (-37.89°F)	356.73°C (674.11°F)
Lead	327.46 °C, (621.43 °F)	1749 °C, (3180 °F)

Table 2.1 Liquid metal coolants

a. Sodium cooled reactor

In sodium cooled fast reactor is a Generation IV reactor project to design an advanced fast neutron reactor. It builds on two closely related existing projects the LMFBR and the Integral Fast Reactor with the objective of producing a fast spectrum sodium cooled reactor. The reactors are intended for use in nuclear power plant to produce nuclear power from nuclear fuel.

b. Lead cooled fast reactor

The lead cooled fast reactor is a nuclear reactor that features a fast neutron spectrum molten lead or lead bismuth eutectic coolant. Options include a range of plant ratings including a number of 50 to 150 megawatts electric units featuring long life and pre manufactured cores. Plans include modular arrangements rated at 300 to 400 MWe and a large monolithic plant rated at 1,200 MWe. The fuel is metal or nitride based containing fertile uranium and transuranics. The LFR is cooled by natural convection with a reactor outlet coolant temperature of 550 °C. It is possibly ranging over 800 °C with advanced materials. Temperatures higher than 830 °C are high enough to support thermochemical production of hydrogen. [25]

iv. **Gas cooled reactor**

Gas cooled reactor are cooled by a circulating inert gas often helium in high-temperature designs. Carbon dioxide has been used in past British and French nuclear power plants. Nitrogen has also been used. Utilization of the heat varies depending on the reactor. Some reactors run hot enough that the gas can directly power a gas turbine. Older designs usually run the gas through a heat exchanger to make steam for a steam turbine. [28]

v. **Molten Salt Reactors**

Molten salt reactor is cooled by circulating a molten salt typically a eutectic mixture of fluoride salts such as FLiBe. In a typical MSR the coolant is also used as a matrix in which the fissile material is dissolved.

2.7.4 CLASSIFICATION BY GENERATION

i. Generation I reactor early prototypes research reactors are non-commercial power producing reactors
ii. Generation II reactor most current nuclear power plants 1965-1996
iii. Generation III reactor evolutionary improvements of existing designs 1996 now
iv. Generation IV reactor technologies still under development unknown start date possibly 2030. [19]

2.7.5 CLASSIFICATION BY PHASE OF FUEL

i. Solid fueled
ii. Fluid fueled
    a. Aqueous homogeneous reactor
    b. Molten salt reactor

iii. Gas fueled [5]

2.7.6 CLASSIFICATION BY USE

i. Electricity
   a. Nuclear power plants including small modular reactors

ii. Propulsion
   a. Nuclear marine propulsion
   b. Various proposed forms of rocket propulsion

iii. Other uses of heat
   a. Desalination
   b. Heat for domestic and industrial heating
   c. Hydrogen production for use in a hydrogen economy

iv. Production reactors for transmutation of elements
   a. Breeder reactors are capable of producing more fissile material than they consume during the fission chain reaction by converting fertile U-238 to Pu-239 or Th-232 to U-233. Thus a uranium breeder reactor once running can be re-fueled with natural or even depleted uranium and a thorium breeder reactor can be refueled with thorium however at an initial stock of fissile material is required.
   b. Creating various radioactive isotopes such as americium for use in smoke detectors and cobalt-60, molybdenum-99 and others used for imaging and medical treatment.
   c. Production of materials for nuclear weapons such as weapons grade plutonium

v. Providing a source of neutron radiation and positron radiation

vi. Research reactor

Typically reactors used for research and training materials testing or the production of radioisotopes for medicine and industry. These are smaller than power reactors or those propelling ships and many are on university campuses. There are about 280 such reactors operating in 56 countries. Some operate with high enriched uranium fuel and international efforts are underway to substitute low enriched fuel. [30]

2.8 CURRENT TECHNOLOGIES OF NUCLEAR REACTOR

i. **Pressurised water reactor**

These reactors use a pressure vessel to contain the nuclear fuel, control rods, moderator, and coolant. They are cooled and moderated by high pressure liquid water. The hot radioactive water that leaves the pressure vessel is looped through a steam generator, which in turn heats a secondary non-radioactive loop of water to steam that can run turbines. They are the majority of current reactors. Diadlo canyon is a thermal neutron reactor design the newest of which are the VVER-1200 Advanced pressurised water reactor and the European pressurised reactor. United states of naval reactors are of this type.

ii. **Boiling water reactor**

A BWR is like a PWR without the steam generator. A boiling water reactor is cooled and moderated by water like a PWR but at a lower pressure it allows the water to boil inside the pressure vessel producing the steam that runs the turbines. Unlike a PWR there is no primary and secondary loop. The thermal efficiency of these reactors can be higher and they can be simpler and even potentially more stable and safe. Laguna Verde nuclear power plant is a thermal neutron reactor design the newest of which the advanced boiling water reactor and the Economic simplified boiling water reactor.

iii. **Pressurised heavy water reactor**

These reactors are heavy water cooled and moderated Pressurized water reactors. Instead of using a single large pressure vessel as in a PWR the fuel is contained in hundreds of pressure tubes. These reactors are fueled with natural uranium and are thermal neutron reactor designs. PHWRs can be refueled while at full power which makes them very efficient in their use of uranium. The canadian-deuterian-uranium Qinshan Nuclear Power Plant is an example of pressurised heavy water reactor.

iv. **High power channel reactor**

High power channel reactor is built to produce plutonium as well as power. Reaktor bolshoy moschnosti kanalniy (RBMKs) is an example of this reactor in which water cooled with a graphite moderator. RBMKs are in some respects similar to CANDU in that they are refuelable during power operation and employ a pressure tube design instead of a PWR-style pressure vessel. However unlike CANDU they are very unstable and large which makes containment buildings for them expensive. A series of critical safety flaws have also been identified with the RBMK design though some of these were corrected following the Chernobyl disaster. Their main attraction is their use of light water and unenriched uranium. Despite these safety improvements RBMK reactors are still considered one of the most dangerous reactor designs in use. RBMK reactors were deployed only in the former Soviet Union.

v. **Gas Cooled Reactor and Advanced Gas Cooled Reactor**

These are generally graphite moderated and CO_2 cooled. Gas cooled reactors and advanced gas cooled reactors can have a high thermal efficiency compared with PWRs due to higher operating temperatures. There are a number of operating reactors of this design mostly in the United Kingdom where the concept was developed. Older designs i.e. Magnox stations are either shut down or will be in the near future. However, the AGCRs have an anticipated life of a further 10 to 20 years. The Torness nuclear power station is a thermal neutron reactor design. Its decommissioning costs can be high due to large volume of reactor core.

vi. **Liquid Metal Fast Breeder Reactor**

Liquid metal fast breeder reactor is cooled by liquid metal totally unmoderated and produces more fuel than it consumes. They are said to breed fuel because they produce fissionable fuel during operation because of neutron capture. These reactors can function much like a PWR in terms of efficiency do not require much high pressure containment and as the liquid metal does not need to be kept at high pressure even at very high temperatures. BN-350 and BN-600 in USSR and Superphénix in France were a reactor of this type, as was Fermi-I in the United States. The Monju reactor in Japan suffered a sodium leak in

1995 and was restarted in May 2010. All of them use liquid sodium. These reactors are fast neutron not thermal neutron designs. [29]

2.9. FUTURE AND DEVELOPMENT TECHNOLOGIES OF ADVANCED REACTOR

i. More than a dozen advanced reactor designs are in various stages of development. Some are evolutionary from the PWR,BWR and PHWR designs above some are more radical departures. The former include the Advanced Boiling Water Reactor (ABWR) two of which are now operating with others under construction and the planned passively safe Economic Simplified Boiling Water Reactor (ESBWR) and AP1000 units.

ii. The Integral Fast Reactor (IFR) was built tested and evaluated during the 1980s and then retired under the Clinton administration in the 1990s due to nuclear non-proliferation policies of the administration. Recycling spent fuel is the core of its design and it therefore produces only a fraction of the waste of current reactors.

iii. The Pebble Bed Reactor and a High Temperature Gas Cooled Reactor (HTGCR) is designed so high temperatures reduce power output by Doppler broadening of the fuels neutron cross section. It uses ceramic fuels so as to safe operating temperatures exceed the power reduction temperature range. Most designs are cooled by inert helium. Helium is not subject to steam explosions it resists neutron absorption leading to radioactivity and does not dissolve contaminants that can become radioactive. Typical designs have more layers up to 7 of passive containment than light water reactors usually 3. A unique feature that may aid safety is that the fuel balls actually form the cores mechanism and are replaced one by one as they age. The design of the fuel makes fuel reprocessing expensive.

iv. The Small, sealed, transportable, autonomous reactor (SSTAR) is being primarily researched and developed in the US intended as a fast breeder reactor that is passively safe and could be remotely shut down in case the suspicion arises that it is being tampered with.

v. The Clean And Environmentally Safe Advanced Reactor (CAESAR) is a nuclear reactor concept that uses steam as a moderator this design is still in development.

vi. The Hydrogen Moderated Self-regulating Nuclear Power Module (HPM) is a reactor design emanating from the Los Alamos National Laboratory that uses uranium hydride as fuel.

vii. Subcritical reactors are designed to be safer and more stable but pose a number of engineering and economic difficulties. One example is the Energy amplifier.

viii. Thorium based reactors. It is possible to convert Thorium-232 into U-233 in reactors specially designed for the purpose. In this way thorium is more plentiful than uranium. It can be used to breed U-233 nuclear fuel. U-233 is also believed to have favourable nuclear properties as compared to traditionally used U-235 including better neutron economy and lower production of long lived transuranic waste.

a. Advanced Heavy Water Reactor (AHWR)

   A proposed heavy water moderated nuclear power reactor that will be the next generation design of the PHWR type. Under development in the Bhabha Atomic Research Centre (BARC) India.

b. KAMINI

   A unique reactor using Uranium-233 isotope for fuel. Built in India by BARC and Indira Gandhi Center for Atomic Research (IGCAR).

c. India is also planning to build fast breeder reactors using the thorium Uranium-233 fuel cycle. The (FBTR) Fast Breeder Test Reactor in operation at Kalpakkam (India) uses Plutonium as a fuel and liquid sodium as a coolant. [29]

2.10. NUCLEAR FUEL CYCLE

This fuel cycle is the simplest and the most economic fuel cycle today. There are six Major steps

i. **Uranium mining and milling**.

Uranium is the starting fuel for all fuel cycles. Uranium mining and milling is similar to the mining and milling of copper, zinc, and other metals. Uranium is often found with copper, phosphates, and other minerals and thus a co-product of other mining operations. About 200 tons of natural uranium is mined to fuel a 1000-MW(e) light water reactor for one year.

ii. **Uranium conversion and enrichment.**

The uranium is chemically purified. Uranium contains two major isotopes: uranium-235 and uranium-238. Uranium-235 is the initial fissile fuel for nuclear reactors. Natural uranium contains 0.7% uranium-235. In the uranium enrichment process, natural uranium is separated into an enriched uranium product containing 3 to 5% uranium-235 and ≥95% uranium-238 that becomes LWR fuel and depleted uranium that contains 0.3% uranium-235 and 99.7% uranium-238. There will be 10 to 20 times as much depleted uranium as product.

iii. **Fuel fabrication.**

The enriched uranium is converted into uranium dioxide and fabricated into nuclear fuel. An LWR requires 20 tons of fuel per year.

iv. **Light water reactor**.

All power reactors in the United States are LWR. The initial fuel is uranium-235 that is fissioned to produce heat. The fuel also contains uranium- 238 a fertile non-fuel material. In the nuclear reactor some of it is converted to plutonium-239 and a fissile fuel that is also fissioned to produce heat. The heat is converted into electricity. With a fresh fuel assembly all the energy is from fissioning of uranium-235. When the fuel is discharged from the reactor as SNF about half the energy being generated is from the fissioning of plutonium-239 that was created in the reactor.

v. **Storage of SNF**

It is a typical LWR fuel assembly remains in the reactor for three to four years. upon discharge of the SNF. It contains 0.8% uranium-235, 1% plutonium, 5% fission products, and uranium-238. The SNF is stored for several decades to reduce radioactivity and radioactive decay heat before disposal.

vi. **Waste disposal**

Nuclear fuel cycles are different from fossil fuel cycles because nuclear reactors burn only a fraction of the fuel before the fuel is discharged as SNF. Full burn up of the fuel before discharge is not possible.

a. The reactor produces heat by fissioning uranium-235 or plutonium-239. The resultant fission product ash in high concentrations will shut down the reactor
b. The materials of fuel element construction have a limited endurance in the reactor and limit fuel burn up. Because reactors cannot fully utilize the fissile and fertile materials in a fuel assembly there are many possible fuel cycles.

vii. **LWR partly closed fuel cycle**

The fissile material in LWR SNF can be recycled back into LWRs. The LWR SNF is reprocessed, the plutonium and uranium recovered and the plutonium and some uranium are fabricated into fresh fuel and the resultant transuranic fuel is sent to the LWR. Because of the low fissile content of the LWR SNF recycle of the plutonium reduces uranium fuel demand by only 15% and recycle of the uranium reduces uranium fuel demand by only 10%. The high-level waste (HLW) from reprocessing is stored for several decades to reduce radioactivity and radioactive decay heat before disposal. LWR SNF recycle changes the plutonium isotopes such that the SNF can only be recycled one or two times. The recycle SNF must either wait to go to a repository or could fuel fast reactors. Several countries recycle LWR SNF. [26]

2.11 NUCLEAR POWER PLANT DIFFER FROM FOSSIL FUEL SYSTEM

Nuclear power plant differs from fossil fuel system. Some of the more important considerations that differentiate nuclear fueled plants from fossil fueled plants are listed below

i. Nuclear fuel is charged to a power plant in frequently and has a relatively long life usually measured in months or years, as compared with a continuous fuel-feed requirements for fossil fueled plants
ii. Burned nuclear fuel is radioactive; it requires remote handling and special processing and disposal
iii. Major portion of a nuclear plant are radioactive during and after operation, requiring special precautions for maintenance of much of the plant
iv. Special system designs are required to prevent radioactivity release during normal operations or due to accident
v. Control and instrumentation requirements are strongly influenced by safety requirements and are related to reactor stability, load-following requirement, and the capability of a reactor to increase power output with no additional output
vi. Nuclear fuel is highly processed materials generally used in précised fabricated form, as opposed to fossil fuels, which are essential raw materials used with only minimal rough processing
vii. The use of nuclear fuel does not require combustion air thus obviating thermal stack losses and related problems [12]

2.12 FUELING OF NUCLEAR REACTOR

The amount of energy in the reservoir of nuclear fuel is expressed in terms of full power days which are the number of 24 hour periods a reactor is scheduled for operation at full power output for the generation of heat energy. The number of full power days in a reactor operating cycle between refueling outage times is related to the amount of fissile uranium 235 (U-235) contained in the fuel assemblies at the beginning of the cycle. A higher percentage of U-235 in the core at the beginning of a cycle will permit the reactor to be run for a greater number of full-power days.

At the end of the operating cycle the fuel in some of the assemblies is spent and is discharged and replaced with new fuel assemblies. To determine the life time of a nuclear fuel in reactor poisons are build. Build up of long lived neutron absorbing fission by products impedes the chain reaction before all possible fission taken place. The fraction of the reactors fuel core replaced during refueling is typically one fourth for a boiling water reactor and one third for a pressurized water reactor. The disposition and storage of this spent fuel is one of the most challenging aspects of the operation of a commercial nuclear power plant. This nuclear waste is highly radioactive and its toxicity presents a danger for thousands of years.

The amount of energy extracted from nuclear fuel is called its burn up which is expressed in terms of the heat energy produced per initial unit of fuel weight. Burn up is commonly expressed as megawatt days thermal per metric ton of initial heavy metal. [20]

2.13 SAFETY OF NUCLEAR REACTOR

Nuclear safety covers the actions taken to prevent nuclear and radiation accidents or to limit their consequences. The nuclear power industry has improved the safety and performance of reactors. Nuclear power plant involves radiation leaks, health hazard to workers and community and has negative effect on surrounding forests.

i. Nuclear power plant should be located away from habitation
ii. Quality of construction should be of required standards
iii. Waste water from nuclear power plant should be purified. Thus water purification plant should be of high efficiency and satisfy rigid requirements as regards the volume of radioactivity wastes disposed to buried

iv. An atomic power plant should have an extensive ventilation system. To maintain the concentration of all radioactive impurities in the air below the permissible concentration ventilation is required
v. An exclusion zone of 1.6 km radius around the plant should be provided where no public habitation is permitted
vi. The safety system of plant should be of such as to enable safe shut down of reactor whenever required. Engineered safety features are built into the station so that during normal operation as well as during severe design basis accident the radiation dose at the exclusion zone boundary will be within permissible limits as per internationally accepted values [13]

CHAPTER 3

INTELLIGENT TECHIQUES TO CONTROL TEMPERATURE OF NUCLEAR REACTOR

3.1 INTRODUCTION OF ARTIFICIAL NEURAL NETWORK

An artificial neural network is an information processing technique which is inspired by the biological nervous system i.e. brain for process information. It is made up of a large number of highly interconnected processing elements working to gather to solve specific problems, pattern recognition and classification through a learning process. Artificial neural network are used for solving artificial intelligent problems without creating a model of real biological system. It involves a large number of processors operating in parallel with its own dedicated set of knowledge and it accesses the data to apply control strategy. Neural network is initially trained with large amount of data and relations between different parameters to take control action. Algorithm of neural network depicts the response to an external stimulus which can initiate activity within the limits of its access to external world. [36]

A nuclear reactor is a system that contains and controls sustained nuclear chain reaction. Reactors are used for generating electricity, moving aircraft and submarines, producing medical isotopes for imaging and cancer treatment and also for carrying one in this field. When they absorb neutrons placed into the reactor vessel along with a small neutron source. The neutrons start chain reaction where each atom that splits releases more neutrons that cause other atoms to split. When each time an atom splits it releases large amount of energy in the form of heat. The heat is carried out of the reactor by coolant which is commonly plain water. The coolant heats up and goes off to a turbine to spin a generator or drive shaft. Actively the nuclear reactor is exotic heat sources. Since nuclear fission creates radioactivity so the reactor core is surrounded by a protective shield so that radioactive radiations should not escape to environment. This containment absorbs radiation and prevents radioactive material from being released into the environment. In addition to its many reactors are equipped with a dome of concrete to protect the rector against external impacts. [30]

3.2 SALIENT FEATURES OF ARTIFICIAL NEURAL NETWORK (ANN)

The following characteristics properties of neural network are significant

i. **Non-Linearity**

   Neural networks have great promise in diverse fields because of their theoretical ability to approximate arbitrary non linear mappings. In a neural network the non-linearity is disturbed throughout the network.

ii. **Provide Model Free Environment**

   ANN controllers do not require derivation of the mathematical model of the process. Thus the cumbersome mathematics and the added assumptions which introduce approximations in the model are not needed. ANN model or controller does not require a priori knowledge of the pant dynamics.

iii. **Parallel Distributed Processing**

   Neural network have a highly parallel structure which lends itself immediately to parallel implementation. The basic processing unit in a neural network has a very simple structure. This along with parallel implementation results in very fast overall processing.

iv. **Input Output Mapping**

   A popular exemplar of knowledge of learning called supervised learning involves modification of the synaptic weights of a neural network by applying a set of input output training samples. The network learns from the examples by constructing an input output mapping for a problem at hand.

v. **Learning with Experience**

Neural networks a built in capacity to learn and adapt their synaptic weights to provide changes in the surrounding environment.

vi. **Fault Tolerance**

A neural network implemented in hardware has a potential to be inherently fault tolerant of robust computation in the sense that is performance degrades gracefully under adverse operating conditions.

vii. **Data Fusion**

Neural network can operate simultaneously on both quantitative and qualitative data. The neural network can deal with information that is fuzzy probabilistic noisy and inconsistent.

viii. **Hardware implementation**

Not only can the network be implemented in parallel but also dedicated VLSI implementations are being introduced recently. This brings additional speed and increases the scale of neural networks which can be implemented.

ix. **Multivariable Systems**

Neural network naturally process many inputs and have many outputs. Thus it is readily applicable to multivariable system. [2]

3.3 ARTIFICIAL NEURAL NETWORKS (ANN) MODEL

A biological neuron consists of three principle components dendrites, cell body and axon as shown in figure 3.1. The tree like structure is called dendrites. They are receptive networks of nerve fibres that carry electrical signal into cell body. The cell body effectively sums and thresholds these incoming signals. The signal long fibre called axons. The point where an axon of one cell and from the cell body is carried out to other neurons by the single dendrite of another cell are in contact is called synapses. [30]

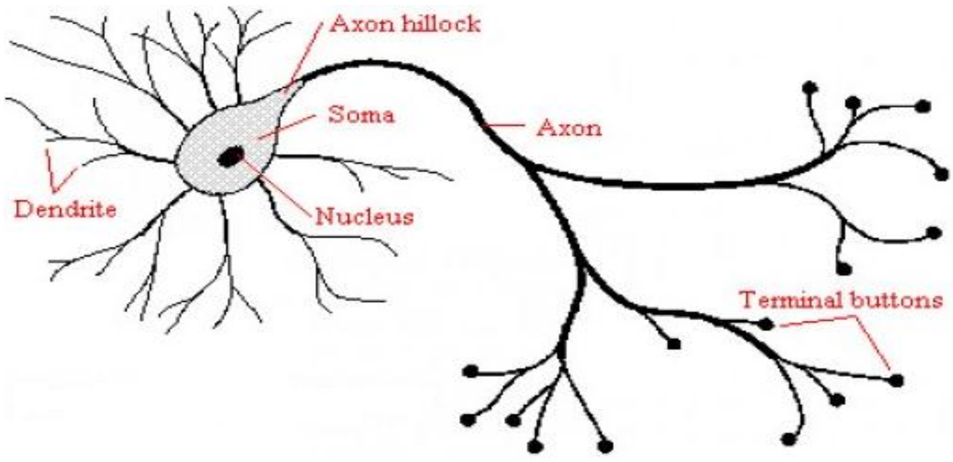


Fig.3.1 Schematic of biological neurons

Artificial neural networks are neither as powerful as biological neurons in the brain nor are complex. Biological and artificial neural networks have two basic similarities between them

1 Biological and artificial neural networks are simple computing devices that are highly interconnected.

2 The connections between the neurons determine the function of the network. The neuron model in Figure 3.2 includes an external applied bias which is denoted by b_x.

$$W_{k0} = b_k \text{ (bias)} \qquad (3.1)$$

The bias has an effect of increasing and decreasing the net input of the activation function that depends on whether it is positive or negative respectively. [3]

$$u_k = \sum_{j=1}^{m} W_{kj} X_j \quad \& Y_k = f(u_k + b_k) \qquad (3.2)$$

X_j is input signal

W_{kj} is synaptic weights

U_k is linear combiner output

b_k is bias

f is activation function

y_k is output signal

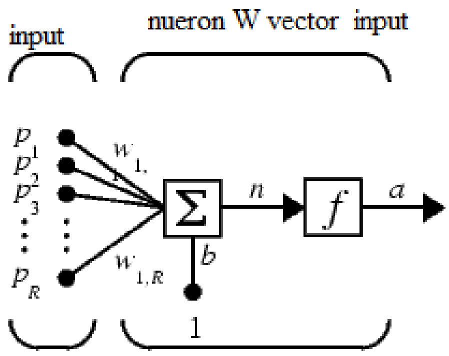


Fig 3.2 Multiple input neurons [31]

The use of bias has the effect of applying an affine transformation to the output of the linear combiner in the model of Figure 3.2 [28]

$$V_k = u_k + b_k \tag{3.3}$$

3.3.1 ARTIFICIAL NEURAL NETWORK ARCHITECTURE

The arrangement of neurons in the layers and the connections between them defines the network architecture. All the neurons in any particular layer perform in a same way. Their behaviour is conditioned by the transfer function and weights. Networks are classified into two based on the number of layers they have

i. single layer
i. Multi-layer networks

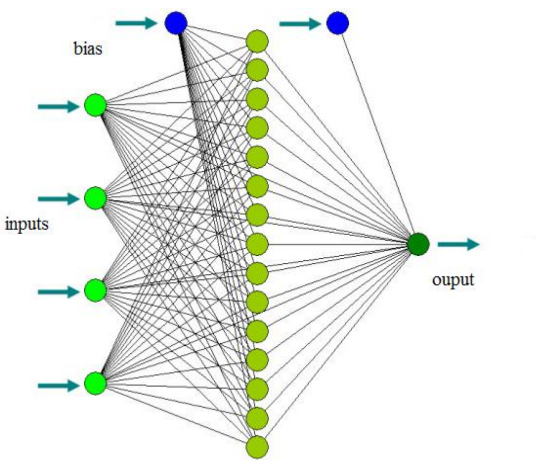


Figure 3.3 shows the architecture of multi-layer network. Single layer networks have an input layer and an output layer. The input layer is not counted while counting the

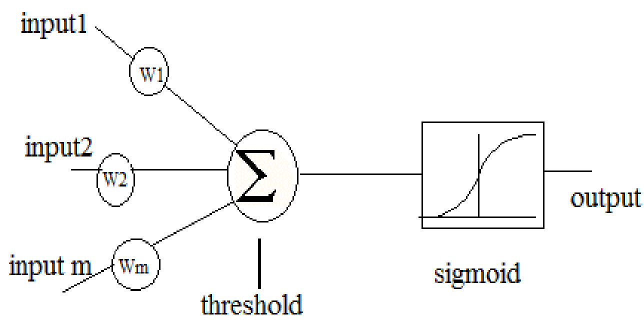


Fig 3.3 Neural network architecture for multilayer and single layer [31]

Number of layers in a network since its only task is to provide input data. Input layer does not perform any calculations. Multi-layer network has several layers which include an input layer, one or more hidden layers and output layer. The hidden layers don't interact directly with external surrounding of the network. The multi-layer shown in Figure 3.3 consists of three layers; two hidden layers and one output connected by three layers of weights. [3]

3.3.2 WEIGHTS AND NETWORK TRAINING

Weights correspond to the strength of a synapse between two neurons of layers. It is also referred to as synaptic weight. Initially the weights are set to either zero or a very small number. Those weights are changed using a learning rule during iterative training process A positive weights represents an excitatory stimulus. While negative weight corresponds to an inhibitory stimulus. A zero weights value indicates as weight matrices *w*. commonly the matrix element wij is used to donate the connecting the output of *i*th neuron to the input of *j*th neuron. Network training is performed by the use of learning algorithms. Network training process can be classified three major types which are as follow [32]

i. **Supervised learning**

In supervised learning, pattern or input vector is provided with an associated target or output vector. The supervised learning can be thought of as learning to adjust the weights and biases of the network in order to move the network outputs closer to the targets. Weights are updated continuously based on the feedback received about the quality of solutions obtained thus far. Supervised learning is used in pattern recognition and regression.

ii. **Unsupervised learning**

Unsupervised learning uses only an input vector. In unsupervised learning weights and biases are modified in response to only network inputs. There are no target outputs available. Unsupervised learning can be used for general estimation of statistical distribution and filtering.

iii. **Reinforced learning**

In reinforced learning for each network input the algorithm is only given a grade. The grade is a measured of network performance over some sequence of inputs. Reinforced learning is used in control problems, games and other sequential decision making tasks. In the present study supervised learning will be utilized with pattern or input and target or output generated using a commercial reservoir simulator

3.3.3 TRANSFER FUNCTIONS

Transfer function scales the response of an artificial neuron to an external stimulus and generates the neuron activation. Transfer function can be either a linear or non-linear function. Any multilayer perceptron using a linear transfer function has an equivalent single-layer network; a non-linear is therefore necessary to gain the advantage of a multi-layer network. [31]

The output (a) of a linear transfer function is equal to its input (n)

$$f(a) = n$$

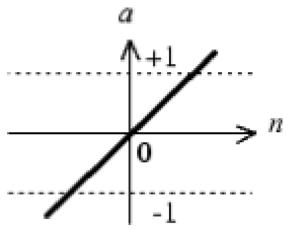


Fig.3.4 Linear transfer function

The purelin transfer function output (a) versus input (n) characteristic of a single input linear neuron with a bias is shown on the right of Figure 3.4. This function applied to the output layer. Purelin transfer function allows the network to produce its output within desire limits without renormalizing them.

Log-sigmoid and hyperbolic tangent sigmoid are the transfer functions employed in multilayer networks. Log-sigmoid transfer function is trained with backpropagation algorithm. Log-sigmoid transfer function takes the input and scales its output to range in between 0 and 1.The output (a) of a log-sigmoid transfer function is calculated according to the expression

$$a = \frac{\mathbf{1}}{\mathbf{1} + \boldsymbol{e}^{-\boldsymbol{n}}}$$

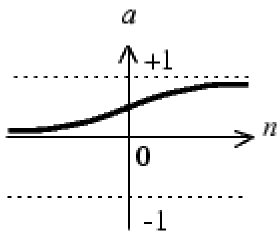
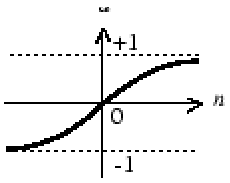


Fig.3.5 Log sigmoid transfer function

Log-sigmoid transfer function is shown in the left of figure 3.5, while the output (a) versus input (p) characteristic of a single-input linear neuron with a bias is shown on the right of figure.3.5

Hyperbolic tangent sigmoid transfer function has an advantage over log-sigmoid transfer function of being able to deal directly with negative numbers. The output (a) of a hyperbolic tangent sigmoid transfer function is calculated according to expression:

$$a = \frac{e^{n} - e^{-n}}{e^{n} + e^{-n}}$$



a=tansig(n)

Fig.3.6 Hyperbolic tangent sigmoid transfer function

In hyperbolic tangent transfer function output (a) versus input (p) characteristics of a single output linear neuron with a bias is shown in figure.3.6

3.4 MULTILAYER FEEDFORWARD NETWORK WITH BACKPROPAGATION

Multilayer feedforward network with backpropagation is the generally used network architecture. Feedforward networks are the simplest artificial neural networks. Feedforward network has no feedback. Backpropagation is the supervised learning method. Multilayer feedforward network is the implementation of the delta rules. The term backpropagation is an abbreviation for backwards propagation of errors. Feedforward network are most benefited when working with backpropagation. Backpropagation adds the components of feedback to the feedforward network. Feedforward networks with backpropagation are easy to implement and it is trained faster than other types of networks. Multilayer feedforward network with backpropagation solve many types of problems correctly. They operate in two steps. First is the feedforward step. In which Input pattern is presented to the input layer and the information is transferred through hidden layers to the output layer.

Transfer function processes the information so as to as move from layer to layer. When transfer function process is taken place backpropagation is used to calculate gradient of the error of the network with respect to the networks modifiable weights. The networks response is compared to the desired output and the error are propagated from output layer to inner layers. The propagated error signal is applied to adjust the network weights. Each intermediate layer receives a portion of total error signal based roughly on the relative contribution to the unit made to the original output. Thus after several iterations of the process the error signal so generated become small. After completing the whole process network is considered trained for intended purpose. Thus it makes it able to predication from a novel set of inputs. [3]

3.4.1 CONVERGENCE AND TRAINING EFFICIENCY

Convergence problem applied to a situation where total error of the current iteration is lower than previous iteration. There can be several causes for the convergence problem. The main reason behind the convergence is the presence of several local minima on the error surface. This problem can be prevented by using momentum parameter. A high momentum parameter can also help to increase speed of convergence. But it is required to take use of high momentum. High momentum may lead to overshooting the actual minimum thus making the network unstable. The optimization method adopted may not guarantee to converge when the system is far away from the local minimum. The learning efficiency can be improved by taking the following measures.

i. using high momentum parameters
ii. using functional links
iii. using fast learning functions

High momentum parameters can improve speed of learning. The functional links used in the input and output layer regularly help the network interpret the data better and thus interpreted data improve the learning efficiency. Training and learning functions are mathematical procedures used to automatically adjust the network weights and biases of a given network. The training network dictates a global algorithm that affects all the networks and biases of a given network. [33]

3.4.2 BACKPROPAGATION WITH FEEDFORWARD NETWORK

Back-propagation has reawakened the scientific and engineering community to the modeling and processing of many quantitative phenomena using neural-networks. The learning algorithm is applied to multilayer feed forward networks consisting of processing elements with continuous differentiable activation functions. Multilayer feedforward networks associated with the back propagation learning algorithm are also called back propagation networks. Given a training set of input-output pairs ($x^{(k)}$, $d^{(k)}$) k=1,2……p the algorithm provides a procedure for changing the weight in back propagation network. Thus changed weights in backpropagation network classify the given input patterns correctly. The bias for this weights update algorithm is simply the gradient-descent as used for simple perceptron with differentiable units.

For a given input-output pair ($x^{(k)}$, $d^{(k)}$) the back-propagation algorithm performs two phases of data flow. In the beginning the input pattern $x^{(k)}$ is propagated from input layer to the output layer. Due to the feedforward flow of data it produces an actual output $y^{(k)}$. Then the error signal computing from the difference between $d^{(k)}$ and $y^{(k)}$ are back-propagated from output layer to the previous layer for them to update its weights. Considered a three layer network as shown in Figure 3.7 to illustrate the details of the back-propagation learning algorithm. Here the network has m processing elements in the input layer. Now it considered l elements in the hidden layer and n processing element in the output layer. Initially considered an input output training pair (x, d) where the superscript k is omitted for notation simplification. [34]

Given an input pattern x, a processing element q in the hidden layer receives a net input as

$$net_q = \sum_{j=1}^{m} v_{qj} x_j \tag{3.4}$$

net_q is net input

q is elements of hidden layer

And produces an output of

$$z_q = a(net_q) = a\left(\sum_{j=1}^{m} v_{qj} x_j\right) \tag{3.5}$$

z_q is an output for q elements in hidden layer

v_{qj} is sum of linear output x for processing element j and bias

The net input for processing element I in the output layer is then

$$net_i = \sum_{q=1}^{l} w_{iq} z_q = \sum_{q=1}^{l} w_{iq} a\left(\sum_{j=1}^{m} v_{qj} x_j\right) \tag{3.6}$$

(3.6)

$$y_i = a(net_i) = a\left[\sum_{q=1}^{l} w_{iq} z_q = \sum_{q=1}^{l} w_{iq} a\left(\sum_{j=1}^{m} v_{qj} x_j\right)\right] \tag{3.7}$$

y_i is the output for processing element i

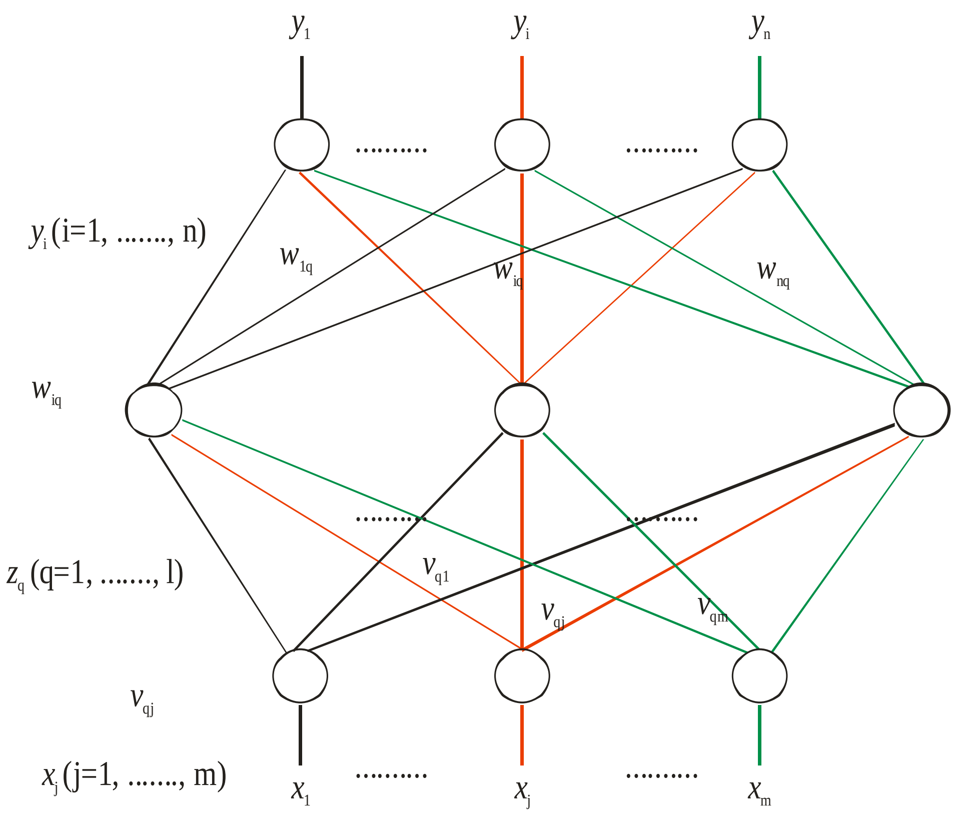


Fig.3.7 Three layer back-propagation network

The above equation indicates the forward propagation of input signal through the layers of neurons till output layer.

The cost function is defined as

$$E(w) = \frac{1}{2}\sum_{i=1}^{n}(d_i - y_i)^2 = \frac{1}{2}\sum_{i=1}^{n}[d_i - a(net_i)]^2 \tag{3.8}$$

$$= \frac{1}{2}\sum_{i=1}^{n}\left[d_i - a\left(\sum_{q=1}^{l} w_{iq} z_q\right)\right]^2 \tag{3.9}$$

Error signal is propagated back upto input layer and according to the gradient-descent method, the weights in the hidden –to-output connections are updated by

$$\Delta w_{iq} = -\eta \frac{\partial E}{\partial w_{iq}} \tag{3.10}$$

Using equations (3.6)-(3.9) and the chain rule for $\frac{\partial E}{\partial w_{iq}}$ to have

$$\Delta w_{iq} = -\eta\left[\frac{\partial E}{\partial y_i}\right]\left[\frac{\partial y_i}{\partial net_i}\right]\left[\frac{\partial net_1}{\partial w_{iq}}\right] = \eta\left[d_i - y_i\right]\left[a'\left(net_i\right)\right]\left[z_q\right] \stackrel{\Delta}{=} \eta\delta_{oi}z_q \qquad (3.11)$$

Where δ_{oi} is the error signal and its double subscript indicates the *i*th node in the output layer. The error signal is define.

$$\delta_{oi} \stackrel{\Delta}{=} -\left[\frac{\partial E}{\partial y_i}\right]\left[\frac{\partial y_i}{\partial net_i}\right] = \left[d_1 - y_i\right]\left[a'\left(net_1\right)\right] \qquad (3.12)$$

Where net_i is the net input to the processing element *I* of the output layer

For the weight update on the input-to-hidden connections, the weight update link weight connecting processing element j in the input layer to processing element q in the hidden layer

From the equation (3.8) & (3.9) it is clear that each error term $[d_i-y_i]$, i=1,2……….n, is s function of z_p. Evaluating the chain rule to have

$$\Delta v_{qj} = \eta\sum_{i=1}^{n}\left[\left(d_i - y_i\right)a'\left(net_i\right)w_{iq}\right]a'\left(net_q\right)x_j \qquad (3.14)$$

Using equation (3.12) we can rewrite equation (3.14) as

$$\Delta v_{qj} = \eta\sum_{i=1}^{n}\left[d_{oi}w_{wiq}\right]a'\left(net_q\right)x_j = \eta\delta_{hq}x_j \qquad (3.15)$$

Where δ_{hq} the error is signal of processing element q in the hidden layer and is defined as

$$\delta_{hq} \stackrel{\Delta}{=} -\left[\frac{\partial E}{\partial z_q}\right]\left[\frac{\partial z_q}{\partial net_q}\right] = a'\left(net_q\right)\sum_{i=1}^{n}\delta_{oi}w_{iq} \qquad (3.16)$$

Where net_q is the input to the hidden processing element from equation (3.4). The error signal of a processing element in a hidden layer is different from the error signal of a processing element in the output layer, as in eq. (3.12) & (3.16). Because of this difference, the above weight update procedure is called generalised delta learning rule.

3.4.3 BACKPROPAGATION LEARNING ALGORITHM STEPS

Considered a network with Q feed forward layers, q=1,2,……Q and let q_{neti} and q_{yi} denotes the net input and output of the *i*th in the qth layer respectively. The network has m input nodes and n output nodes. Let q_{wij} denots the connection weights from $q\text{-}1_{yj}$ to q_{yi}.[34]

Input

A set of training pairs $\{(x^{(k)}, d^{(k)})\}$ k= 1,2….,p} where input vectors are augmented with the last element as -1, that is $x^{(k)}_{m+1}=-1$.

Step0

Choose ή >0 E_{max}. Initialize the weights to small random values

Step 1

Apply k^{th} input pattern to input layer

$q_{yi}=1_{yi}=x_i^{(k)}$ for all *i*.

Step 2

Propagate signal forward through network using

$$q_{y_i} = a(qnet_i) = a\left(\sum_j q_{wij} q_{yj^{-1}}\right) \tag{3.17}$$

Step 3

Compute the error value and error signal from the output layer

$$E = \frac{1}{2}\sum_{i=1}^{n}\left(d_i^{(k)} - Q_{yi}\right)^2 + E \tag{3.18}$$

$$Q_{\delta i} = \left(d_i^{(k)} - Q_{yi}\right)a'\left(Qnet_i\right) \tag{3.19}$$

Step4

Propagate the errors backward to update weights and compute error signal from preceding layer

$$\Delta q_{wij} = \eta q_{\delta_i^{q-i}} y_j \qquad and \qquad q_{w_{ij}^{new}} = q_{w_{ij}^{old}} + \Delta q w_{ij} \qquad (3.20)$$

$$q^{-1}\delta_i = a'\left(q^{-1}net_i\right)\sum_j q_{wij} q \delta_j \qquad for \qquad q = Q, Q-1, ..., 2 \qquad (3.21)$$

Step 5

Check whether the whole set of training data has been cycled once. If k<p and the k=k+1 and go to step 1 otherwise go to step 6

Step 6

Check whether the current total is acceptable if $E<E_{max}$ then terminate the training process E=0 and output the final weights K=1 and initiate the new training epoch by going through step 1

3.5 MATHEMATICAL APPROACH

Once modeling an artificial functional model from the biological neuron.it must take into account three basic components. Initially the synapses of the biological neuron are modeled as weights. Reminisce that the synapse of the biological neuron is the one which interconnects the neural network and gives the strength of the connection. For an artificial neuron, the weight is a number which represents the synapse. A negative weight reflects an inhibitory connection while positive values designate excitatory connections. The following components of the model represent the actual activity of the neuron cell. All inputs are summed altogether and modified. Here design of neuro-fuzzy network to control the temperature of nuclear reactor with intelligent and semi-auto mode. In it three fuzzy sets are developed to attain the accuracy of the neural network and nuclear reactor.

i. **intelligent mode**

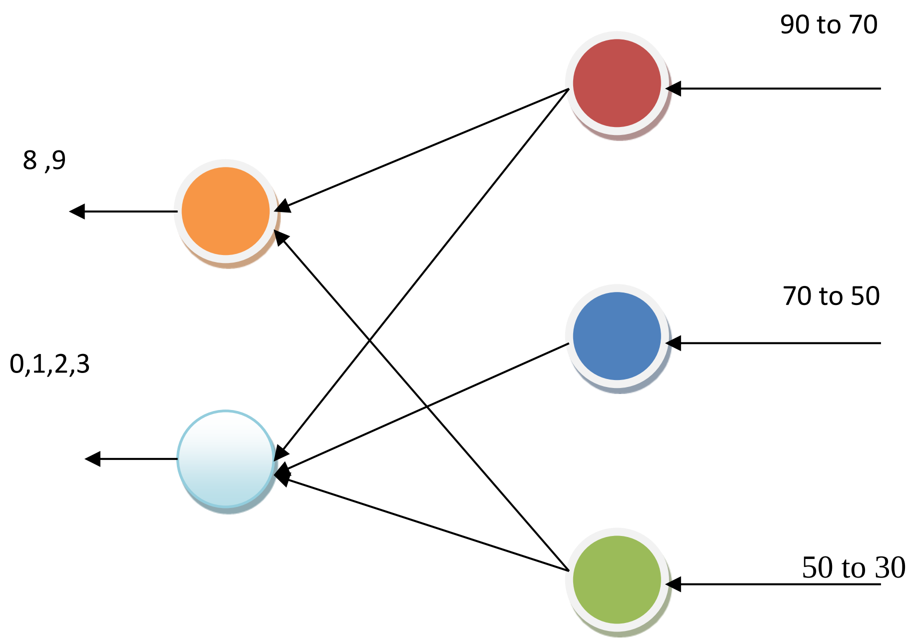


Fig 3.8 Intelligent mode

To control the temperature of nuclear reactor neuro-fuzzy combination is used as explained in figure 3.8 in which three sets are developed in outer layer. It works to control temperature of heater and coolant. RS232 is used to provide connection between hardware and computerised programming. Three set limits are provided to three sets

a. 90 to 70
b. 70 to 50
c. 50 to 30

Weights are provided to these setpoints. Fuzzy logic detects in which limit that weight falls. Thus that input value is provided to any of the three setpoints according to weight. In inner layer two sets are developed that fires output 8,9 or 0,1,2,3 according to the input given like 8,9 is for ON/OFF of furnance if temperature is very high or temperature is very low and 0,1,2,3 is fired if the temperature is in some adjustable limits according to the fuzzy rules.

ii. Semi-auto mode

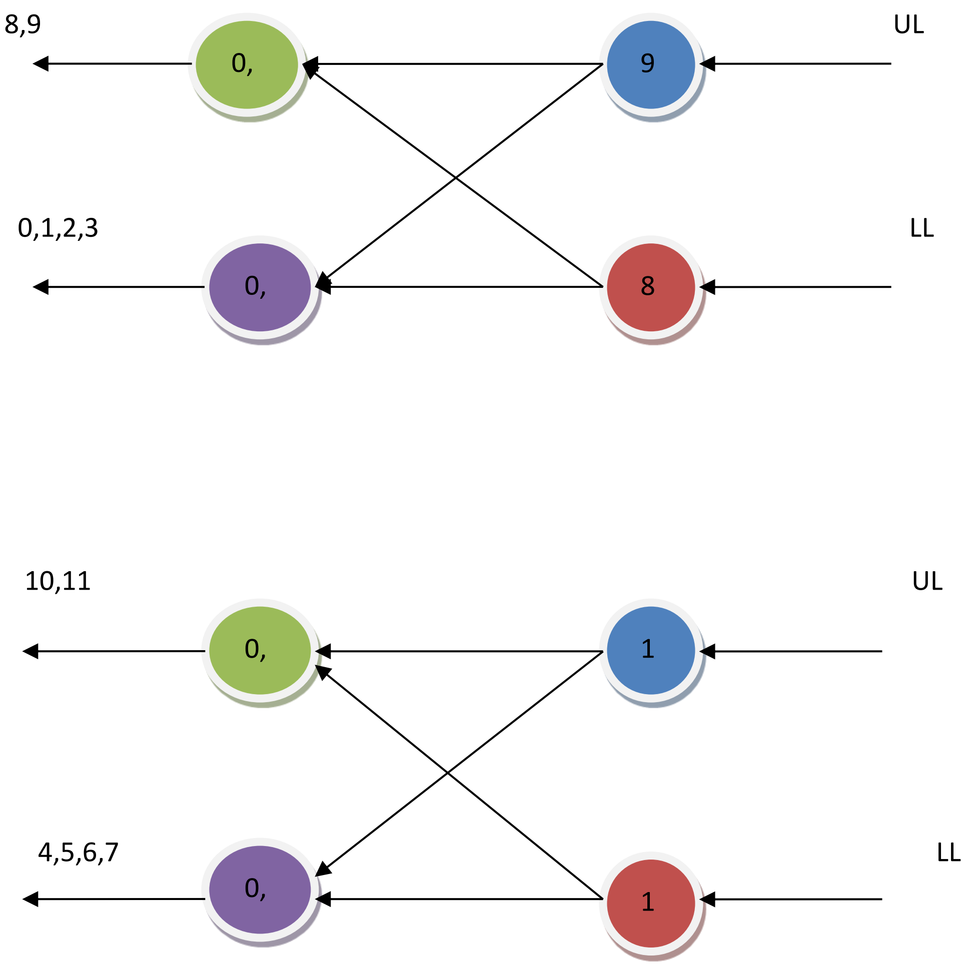


Fig 3.9 Semi- Auto Mode

Figure 3.9 represents for two nuclear reactors working simultaneously. In it two nodes are developed in both inner and outer layer. After receiving data from hardware it starts working. Temperature sensor provides some weights to the fuzzy sets. if input data that it receives from temperature sensor matches or crosses the given weights them coolant start cooling but that also depend upon user that what amount of cooling it requires to came back to its normal state.

3.6 ARTIFICIAL NETWORK MECHANISM

Feed forward adaptive control offers the advantage of fast action without involving any inner closed loops however suffers from the disadvantage of effect of unmeasured disturbances and amount of disturbances. In order to get fast convergence and attain the better solution for a local minimum problem back propagation method is used. Neural network can be trained to perform as a controller by learning an inverse model of plant or as an emulator by indenting the forward model. Among many neural networks learning methods the back-propagation algorithm is most widely used in a wide variety of applications. Using back propagation method various kinds of neuro controllers could be trained in such a way that desired plant output is attained as much as possible

3.7 TEMPERATURE CONTROL TECHNIQUES USING FUZZY LOGIC

Fuzzy logic is widely used in machine controls. Fuzzy logic allows for a generalization of conventional logic and provides for terms between true and false like almost true or partially false. The conventional logic not only makes the logic to be directly processed on computers but must be emulated by special codes. A fuzzy logic based design control system offers flexibility in system design and implementation, Fuzzy logic implementation uses if then logic instead of sophisticated differential equations. Its technology provides room for graphical user interface, which makes it understandable by people who do not have process control backgrounds. Another importance of a fuzzy logic-based control design is the ability to automatically and smoothly adjust the priorities of a number of controlled variables. Ultimately it provides assistance to achieve a process that is stable for a long period of time without a need for intervention. However because of the rule based operation of fuzzy systems. A reasonable number of inputs can be processed and numerous outputs can be generated. Albeit fuzzy logic defines the rule base quickly becomes complex if too many inputs and outputs are chosen for a single implementation until the rules defining their interrelation. Fuzzy logic can control nonlinear systems that would be impossible to model mathematically. This opens door for control system would normally be deemed unfeasible for automation. There are many approaches to implement fuzzy logic systems. But those can be software only hardware only or the combination of software and hardware. Before few years fuzzy logic has been implemented using several technologies to solve real world problems such as image processing, robotics/motion control, pattern recognition, fuzzy database and industrial engineering applications. Fuzzy logic is also spreading applications in the field of telecommunications, particularly in broad band integrated networks which is based on ATM technology. [39]

The considerations to make are that

i. All the rules that apply are invoked using membership functions and truth values obtained from the input to determine the result of the rule.
ii. This result in turn will be mapped into a membership function and truth value controlling the output variable.
iii. These results are combined to give a specific crisp answer ie the actual room temperature through a procedure known as defuzzification.

3.8 FUZZY SETS AND MEMBERSHIPS

The fuzzy sets were made to represent each of the variable's intensities. These sets were associated to the linguistic variables like black and white. Making decisions about processes that contain non-random uncertainty such as uncertainty in natural language has been shown to be less than perfect. It is suggested that set membership is a key to decision making when faced with uncertainty.

The notion of a fuzzy set provides a convenient point of departure of the construction of a conceptual framework which parallels in many respects used in the case of ordinary set but is more general than the latter. It may prove to have a much wider scope of applicabilitys particular in the field of pattern classification and information processing essentially such a framework provides a natural way of dealing with problems in which the source of imprecision in the absence of sharped defined criteria of class membership rather than the presence of random variable. The notion of set membership is centre to the representation of objects within a universe of sets defined on the universe. Classical sets contain objects that satisfy precise properties of membership. Fuzzy sets contain objects that satisfy imprecise properties of membership i.e. membership of an object in a fuzzy set can be approximately. We have exhaustive collection of individual elements x which make up a universe of information X. Further various combinations of these individual elements make up sets say A on the universe. For crisp sets an element x in the universe X is either a member of some crisp set A or not. This binary issue of membership can be represented mathematically with the indicator function. [23]

$$\chi_A(x) = \begin{cases} 1, & x \in A \\ 0, & x \notin A \end{cases}$$

3.9 FUZZY SET OPERATIONS

A fuzzy set operation is an operation on fuzzy sets. These operations are generalization of crisp set operations. There is more than one possible generalization. The most widely used operations are called standard fuzzy set operations. There are three operations fuzzy complements, fuzzy intersections and fuzzy unions. In our research work three fuzzy sets are developed to control the temperature of nuclear reactor within certain limits. [24]

1. First set

   <= (90) and > (70)

   Then the value is 100% is open for coolant purpose
2. Second set

   <= (70) and > (50)

   Then the value is 75% open for coolant purpose
3. Third set

   <= (50) and > (30)

   Then the value is opened to 50% for coolant purpose

3.9.1 FUZZIFICATION

The process of converting a crisp input value to a fuzzy value is called fuzzification.

Fuzzification is the process of decomposing a system input and output into one or more fuzzy sets. The process of fuzzification allows the system inputs and outputs to be expressed in linguistic terms so that rules can be applied in a simple manner to express a complex system. Suppose a simplified implementation for a nuclear reactor system with a temperature sensor. The temperature might be acquired by a microprocessor which has a fuzzy algorithm to process an output to continuously control the opening and closing of a value which keeps the reactor in a good temperature. It can also directly open and close as necessary. The figure illustrates the process of fuzzification of the reactor temperature. There are three fuzzy sets for temperature: COOL, WARM and HOT. Further each fuzzy set operated in five different levels to control the temperature of reactor. Like for 90 to 70˚c range it operates at five levels above 90˚c temperature, at 90˚c temperature, between 90 to 70˚c temperature, at 70˚c temperature and below70˚c temperature. The process follows for others fuzzy sets also.

S.No	FUZZY SETS	FUZZY STATE
1.	90 to 70˚c	HOT
2.	70 to 50˚c	WARM
3.	50 to 30˚c	COOL

Fig.4.1 Fuzzy sets defining temperature

Obtaining the rules empirical if the reactor temperature is good keep the value opening is medium, if it is warm value opening is more and value is fully opening if the room is hot. On the other hand if the temperature is cool % to which value is opened decreased and close the value if it is cold. This is the beauty of fuzzy logic to turn common sense, linguistic descriptions as according to computer controlled system. Therefore it is required to understand how to use some logical operations to build the rules. [25]

3.9.2 DEFUZZIFICATION

After fuzzy reasoning we have a linguistic output variable which needs to be translated into a crisp value. The objective is to derive a single crisp numeric value that best represents the inferred fuzzy values of the linguistic output variable. Defuzzification is such inverse transformation which maps the output from the fuzzy domain back into the crisp domain. Some defuzzification methods tend to produce an integral output considering all the elements of the resulting fuzzy set with the corresponding weights. Other methods take into account just the elements corresponding to the maximum points of the resulting membership functions. The following defuzzification methods are of practical importance [25]

i. **Max membership principle**

   This principle is limited to peak output function. It is also known as height method.

ii. **Centroid method**

   The Centroid method is often referred to as the Center of Gravity method because it computes the centroid of the composite area representing the output fuzzy term. It is most prevalent and physically appealing for all the defuzzification methods.

iii. **weighted average method**

The weighted average method is most frequently used in fuzzy applications. It is the more computationally efficient method. It is restricted to symmetrical output membership function. The weighted average method is formed by weighting each membership function in the output by its respective membership value.

iv. **Mean max membership**

The Mean max membership is used only in some cases where the Center of maximum approach does not work. This occurs whenever the maxima of the membership functions are not unique i.e. the maximum membership can be a plateau rather than a single point

v. **Center of sums**

This is faster than many defuzzification methods. It is not symmetric membership functions. This process involves the algebraic sum of individual output fuzzy set instead of their union. In the center of sums method the weights are area s of the respective membership functions. Whereas in the weighted average method the weights are individual membership values.

vi. **Center of largest area**

The Center of area method is often referred to as the Center of Gravity method because it computes the centroid of the composite area representing the output fuzzy term.

vii. **First or last of maxima**

This method uses the overall output or union of all individual output fuzzy sets to determine the smallest value of the domain with maximized membership degree.

3.10 LINGUISTIC VARIABLES

i. While variables in mathematics regularly take numerical values in fuzzy logic applications. The non-numeric linguistic variables are often used to facilitate the expression of rules and facts.

ii. The linguistic approach abandons the use of a numbers and precise models of reasoning and adopts instead a flexible system of verbal characterization which applies to value of variables and truth tables as well as probabilities of assertion about them. The rationale for this seemingly retrograde step of employing words in place of numbers is that verbal characterizations are intrinsically approximate in nature. Linguistic variables are better suited for description of systems and processes which are as complex and as ill-defined those which relates to human judgment and decision making.

iii. A linguistic variable is a variable whose values are variables rather than numbers. Each linguistic variable is interpreted as a label of fuzzy set in its universe of discourse. In current practice in most applications to control the membership functions of linguistic variables are assumed to be trapezoidal or triangular in shape. The number of linguistic values in the range of three to seven. There is a basic aspect of the concept of linguistic variables which is at heart of its utility. [41]

3.11 ADVANTAGES OF FUZZY LOGIC

i. Use linguistic variables
ii. Allows imprecise inputs
iii. Permits fuzzy thresholds
iv. Reconciles conflicting objectives
v. Rule base or fuzzy sets easily modified
vi. Relates input to output in linguistic terms, easily understood
vii. Cheaper because they are easier to design
viii. Increased robustness
ix. Simplify knowledge acquisition and representation

x. A few rules encompass great complexity
xi. Can achieve less overshoot and oscillations
xii. Allows for rapid prototyping because the system designer doesn't need to know everything about the system before starting

3.12 LIMITATIONS

i. Hard to develop a model from a fuzzy system
ii. Require more fine tuning and simulation before operational

CHAPTER 4

CASE STUDY

4.1 CASE STUDY

A case study of coolant temperature control of nuclear reactor is considered with the interconnection of hardware and software is shown in figure 4.1. In hardware part temperature sensors, analog to digital converters, furnance control, coolant control and microcontroller unit all are interconnected to software part through RS232.

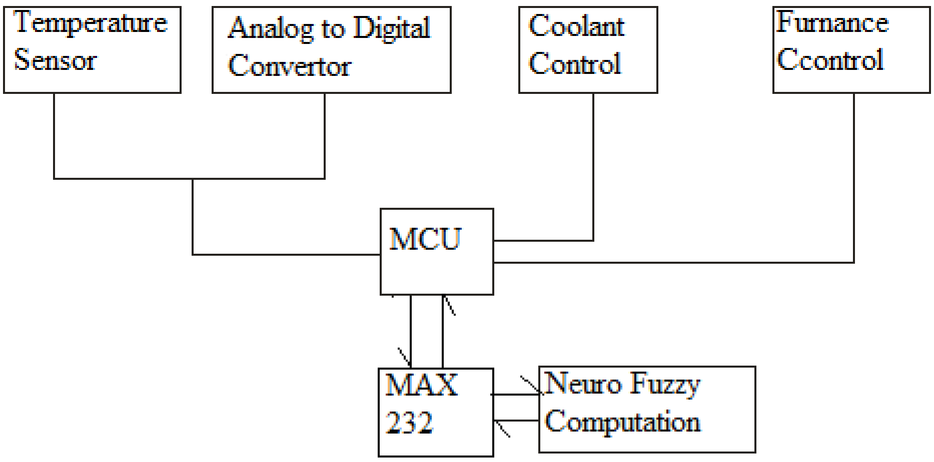


Fig 4.1 Hardware control of one nuclear reactor

This figure shows the working process of temperature sensor, ADC, coolant control, furnance control, RS232 and MCU so as to control the temperature of nuclear reactor.

Temperature sensor

Temperature sensor is used to measure the range of temperature rise or fall while working under normal conditions. Here two nuclear reactors are used simultaneously whereas same scheme can be implemented on 5 nuclear reactors. So two temperature sensors are employed which measure its temperature while nuclear reactor under working.

Analog to digital converter

Here ADC convertor is used to convert the analog signal coming from temperature sensor to digital form and send back to microcontroller unit for further processing. ADC is employed in addition to temperature sensor in both the reactors.

Furnance control

In furnance control temperature is controlled by using neuro fuzzy algorithm is connected to furnance of both nuclear reactors. In it rising temperature is controlled using coolant value. Furnance control is connected to artificial intelligence through RS232. The temperature of furnance varies from 0 to 90˚C. The temperature sensor LM35 is used in it for sensing applications.

Coolant control

In coolant control temperature of nuclear reactor is controlled using neuro fuzzy algorithm. Here in coolant control opening of value that provides coolant is controlled according to the limits that provided to microcontroller unit for temperature control. Normally plane water is used for control applications otherwise different coolants are used for different reactors as sodium is used for fast reactors.

MCU

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. 8051 MCU most available operations are limited to 8 bit. It is used widely in control systems robotics as well as in industries.

Software

In software neuro fuzzy algorithm is used to control the temperature of nuclear reactor. Here in software different schemas are designed for coolant control and furnance control. In software three different modes are designed intelligent mode, semi-auto mode and manual mode. Further three schemas are developed for these three modes.

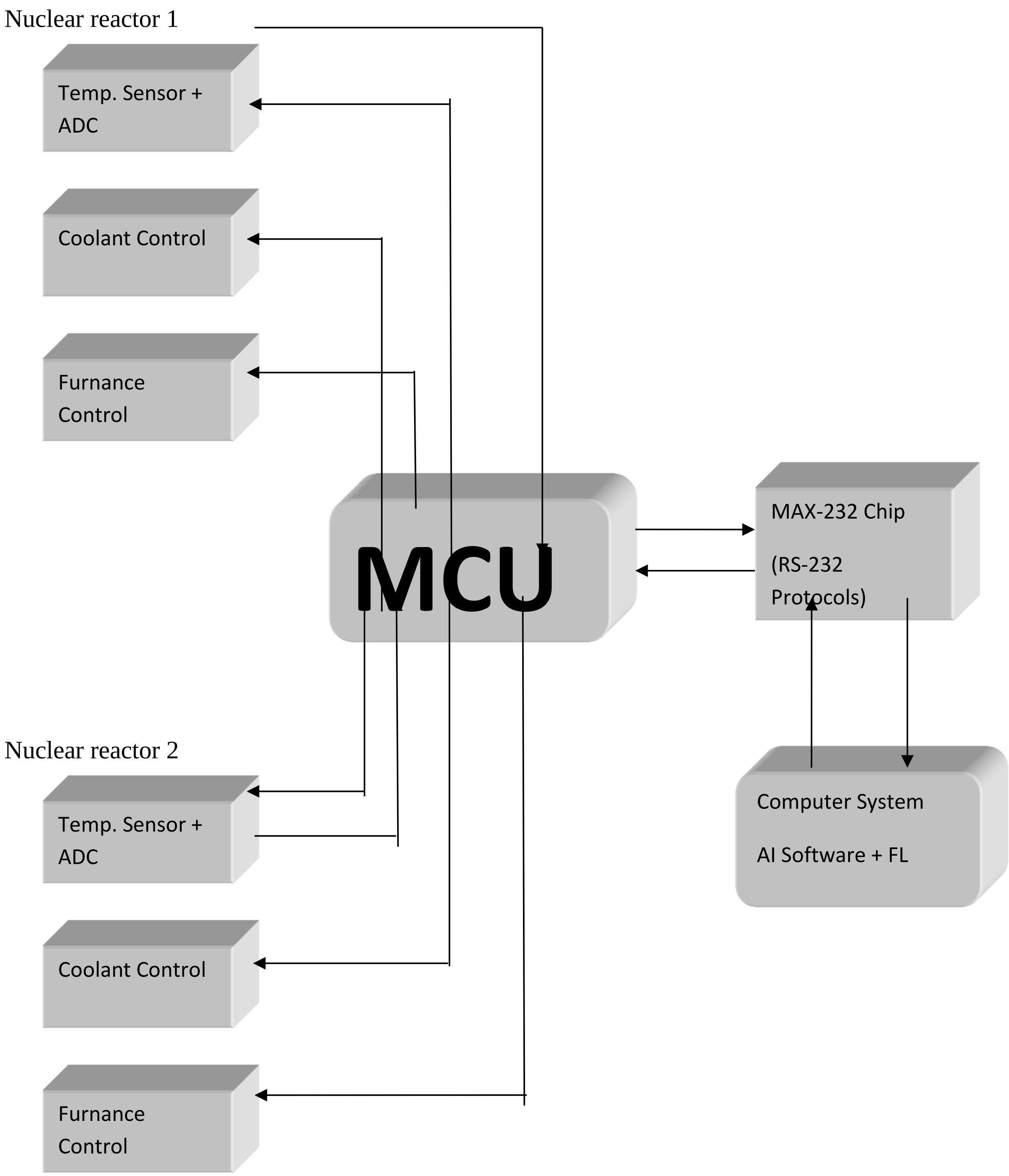


Fig 4.2 Hardware control of nuclear power plant

4.2 COMPONENTS USED IN HARDWARE

S.No	Component	No
1	Mcu 89s52	1
2	ADC0804	2
3	LM35	2
4	RELAY 12V	2
5	BC548	4
6	CRYSTAL OSCILLATOR	1
7	LED	7
8	LM7805	1
9	CAP. 150PF	2
10	CAP. 33PF	2
11	DIODE 1N14007	6
12	CAP 2200µf	1
13	CAP 1µf	4
14	CAP 10µf	1
15	RESET SWITCH	1
16	RESISTOR 1KΩ	9
17	RESISTOR 10KΩ	3
18	MOTORS	2
19	HEATING ELEMENT	2
20	TRANSFORMER 0-12	1
21	VARIABLE RESISTOR 10KΩ	2
22	DB9 CONNECTOR FEMALE	1
23	RIBBON WIRE	1METER
24	IC BASE 40 PIN	1
25	IC BASE 18 PIN	2
26	PCB	

Table 4.1 List of components used in hardware

4.2.1 ADC0804

These A/Ds appear like memory locations or I/O ports to the microprocessor and no interfacing logic is needed. Differential analog voltage inputs allow increasing the common-mode rejection and offsetting the analog zero input voltage value. In addition, the voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full 8 bits of resolution.

i. compatible with 8080 µP derivatives—no interfacing logic needed - access time - 135 ns
ii. Easy interface to all microprocessors, or operates stand alone
iii. Differential analog voltage inputs
iv. Logic inputs and outputs meet both MOS and TTL voltage level specifications
v. Works with 2.5V (LM336) voltage reference
vi. On-chip clock generator
vii. 0V to 5V analog input voltage range with single 5V supply
viii. No zero adjust required
ix. 0.3" standard width 20-pin DIP package
x. 10. 20-pin molded chip carrier or small outline package
xi. 11. Operates ratiometrically or with 5 VDC, 2.5 VDC or analog span adjusted voltage reference

TEMP RANGE		**0°C TO 70°C**	**0°C TO 70°C**	**−40°C TO +85°C**
ERROR	±1⁄4 Bit Adjusted	ADC0802LCWM		ADC0801LCN
	±1⁄2 bit Unadjusted	ADC0804LCWM		ADC0802LCN
	±1⁄2 Bit Adjusted			ADC0803LCN
	±1Bit Unadjusted		ADC0804LCN	ADC0805LCN /ADC0804LCJ
PACKAGE OUTLINE		M20B—Small Outline	N20A—Molded DIP	

Table 4.2 ADC maximum temperature range

4.2.2 LM35

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigra descaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1⁄4°C at room temperature and ±3⁄4°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply it has very low self-heating less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range while the LM35C is rated for a −40° to +110°C range −10° with improved accuracy. The LM35 series is available packaged in hermetic TO-46 transistor packages.

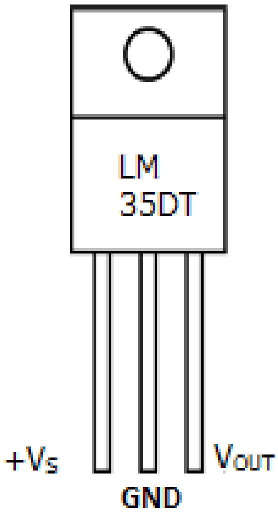


Fig 4.3 Temperature sensor

i. calibrated directly in ° Celsius (Centigrade)
ii. Linear + 10.0 mV/°C scale factor
iii. 0.5°C accuracy guarantee able (at +25°C)
iv. Rated for full −55° to +150°C range
v. Suitable for remote applications
vi. Low cost due to wafer-level trimming
vii. Operates from 4 to 30 volts
viii. Less than 60 μA current drain
ix. Low self-heating, 0.08°C in still air
x. Nonlinearity only ±1⁄4°C typical
xi. Low impedance output, 0.1 W for 1 mA load

LM35 , LM35A	−55°C to +150°C
LM35C, LM35CA	−40°C to +110°C
LM35D	0°C to +100°C
ESD Susceptibility	2500V
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
TO-46 Package (Soldering, 10 seconds)	300°C
TO-92 and TO-220 Package (Soldering, 10 seconds)	260°C
TO-46 Package,	−60°C to +180°C
TO-92 Package	−60°C to +150°C
SO-8 Package	−65°C to +150°C
TO-220 Package	−65°C to +150°C

Table 4.3 LM35 maximum rating

4.2.4 BC548

NPN General Purpose Amplifier This device is designed for use as general purpose amplifiers and switches requiring collector currents to 300 mA.

SYMBOL	PARAMETER	VALUE	UNITS
v_{CEO}	Collector-Emitter Voltage	30	V
V_{CES}	Collector-Bare Voltage	30	V
V_{EBO}	Emitter-Base Voltage	5.0	V
I_C	Collector Current-Continuous	500	mA
T_J , T_{STG}	Operating and Storage Junction Temperature Range	-55 to +150	C

Table 4.3 LMBC548 maximum rating

4.2.5 LM7805

The LM140/LM340A/LM340/LM78XXC monolithic 3-terminal positive voltage regulators employ internal current limiting thermal shutdown and safe area compensation making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.0A output current. They are intended as fixed voltage regulators in a wide range of applications including local regulation for elimination of noise and distribution problems associated with single point regulation. In addition to use as fixed voltage regulators these devices can be used with external components to obtain adjustable output voltages and currents. Considerable effort was expended to make the entire series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output although this does improve transient response.

Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply. The 5V, 12V, and 15Vregulator options are available in the steel TO-3 power package. TheLM340A/LM340/LM78XXC series is available in the TO-220 plastic power package and the LM340-5.0 is available in the SOT-223 package as well as the LM340-5.0 and LM340-12 in the surface-mount TO- 263 package.

i. Complete specifications at 1A load
ii. Output voltage tolerances of ±2% at Tj = 25°C and ±4%
iii. over the temperature range (LM340A)
iv. Line regulation of 0.01% of VOUT/V of ∆VIN at 1A load(LM340A)
v. Load regulation of 0.3% of VOUT/A (LM340A)
vi. Internal thermal overload protection
vii. Internal short-circuit current limit
viii. Output transistor safe area protection
ix. P+ Product Enhancement tested

DC Input Voltage	
LM7824/LM7824C	35V
LM7824/LM7824C	40V
Internal Power Dissipation	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	-65°C to +150°
TO-3 Package (K	300°C
TO-220 Package (T), TO-263	230°C
ESD Susceptibility	2 Kv
LM140A, LM140	−55°C to +125°C
LM340A, LM340, LM7800	0°C to +125°C

Table 4.5 LM7805 maximum rating

4.2.6 CAPACITOR

In a conventional capacitor electrical energy stored statically by charge separation typically electrons in an electric field between two electrode plates. The amount of charge stored per unit voltage is essentially a function of the size the distance and the plates material properties and the material the dielectric placed between the electrodes while the potential between the plates is limited by the strength. Nearly all conventional industrial capacitors except some special styles such as feed through capacitors are constructed as plate capacitors even if their electrodes and the dielectric between are wound or rolled to a winding. The capacitance formula for plate capacitors is

$$C=\frac{\varepsilon A}{d}$$

The capacitance ***C*** for conventional capacitors increases with area ***A*** of the electrodes and with permittivity ***ε*** of the dielectric material and decreases with the distance ***d***. The capacitance is therefore greatest in devices made from materials with a high permittivity large plate area and small distance between plates.

4.2.7 MCU8085

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of NOR flash is also often included on chip as well as small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor memory and input/output devices. Thus microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common integrating analog components needed to control non-digital electronic systems. Some microcontrollers may use four-bit words and operate at clock rate frequencies as low as 4 kHz, for low power consumption single-digit milliwatts or microwatts. They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping may be just nanowatts making many of them well suited for long lasting battery applications. Other microcontrollers may serve performance-critical roles, where they may need to act more like a digital signal processor (DSP) with higher clock speeds and power consumption.

- 8051 Central Processing Unit

  4k × 8 ROM (80C51)

  8k × 8 ROM (80C52)

  128 × 8 RAM (80C51)

  256 × 8 RAM (80C52)

  Three 16-bit counter/timers

  Boolean processor

  Full static operation

  Low voltage (2.7 V to 5.5 V@ 16 MHz) operation

- Memory addressing capability

  64k ROM and 64k RAM

- Power control modes

  Clock can be stopped and resumed

  Idle mode

  Power-down mode

- CMOS and TTL compatible
- TWO speed ranges at VCC = 5 V

  0 to 16 MHz

  0 to 33 MHz
- Three package styles
- Extended temperature ranges
- Dual Data Pointers
- Security bits

  ROM (2 bits)

  OTP/EPROM (3 bits)
- Encryption array – 64 bytes
- 4 level priority interrupt
- 6 interrupt sources
- Four 8-bit I/O ports
- Full–duplex enhanced UART

  Framing error detection

  Automatic address recognition
- Programmable clock out
- Asynchronous port reset
- Low EMI (inhibit ALE and slew rate controlled outputs)
- Wake-up from Power Down by an external interrupt

4.2.8 RESISTOR

A resistor is a passive two terminal electrical component that implements electrical resistance as a circuit element.

The current through a resistor is in direct proportion to the voltage across the resistor's terminals. This relationship is represented by ohm's law

$$I = \frac{V}{R}$$

Where I is the current through the conductor in units of amperes, V is the potential difference measured across the conductor in units of volts and R is the resistance of the conductor in units of ohms.

The ratio of the voltage applied across a resistor's terminal to the intensity of current in the circuit is called its resistance and this can be assumed to be a constant for ordinary resistors working within their ratings.

4.2.9 CRYSTAL OSCILLTOR

A crystal oscillator is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a very precise frequency. This frequency is commonly used to keep track of time as in quartz wristwatches to provide a stable clock signal for digital integrated circuit and to stabilize frequencies for radio transmitters and receivers. The most common type of piezoelectric resonator used is the quartz crystal so oscillator circuits incorporating them became known as crystal oscillators but other piezoelectric materials including polycrystalline ceramics are used in similar circuits.

Two types of quartz crystals exist left handed and right handed differing in the optical rotation but identical in other physical properties. Both left and right-handed crystals can be used for oscillators if the cut angle is correct. In manufacture right-handed quartz is generally used. The SiO_4tetrahedrons form parallel helixes the direction of twist of the helix determines the left or right hand orientation. The helixes are aligned along the z-axis and merged sharing atoms. The mass of the helixes forms a mesh of small and large channels parallel to the z-axis the large ones are large enough to allow some mobility of smaller ions and molecules through the crystal.

Quartz exists in several phases. At 573 °C at 1 atmosphere and at higher temperatures and higher pressures the α-quartz undergoes quartz inversion transforms reversibly to β-quartz. The reverse process however is not entirely homogeneous and crystal twinning occurs. Care has to be taken during manufacture and processing to avoid the phase transformation. Other phases e.g. the higher-temperature phases tridymite and cristobalite are not significant for oscillators. All quartz oscillator crystals are the α-quartz type.

4.2.10 RELAY

A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low power signal or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits repeating the signal coming in from one circuit and re transmitting it to another. Relays were used extensively in telephone exchanges and early computers to perform logical operations.

A type of relay that can handle the high power required to directly control an electric motor or other loads is called a contactor. Solid state relays control power circuits with no moving parts instead using a semiconductor device to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults in modern electric power systems these functions are performed by digital instruments still called protective relays.

4.2.11 DIODE

In electronics a diode is a two terminal electronic component with asymmetric conductance it has low resistance to current flow in one direction and high resistance in the other it is a crystalline piece of semiconductor material with a p-n junction connected to two electrical terminals. A vacuum tube diode is a vacuum tube with two electrodes a plate anode and a heated cathode. The most common function diode is to allow an electric current to pass in one direction called diodes forward direction while blocking current in opposite direction in reverse direction. Thus the diode can be viewed as an electronic version of a check value. This unidirectional behaviour is called rectification and is used to convert alternating current to direct current including extraction of modulation from radio signal in radio receivers these diodes are form of rectifiers

4.2.12 INTEGRATED CIRCUIT

An integrated circuit or monolithic integrated circuit it is also referred to as an IC. It is a set of electronic circuits on one small plate chip of semiconductor material normally silicon. This can be made much smaller than a discrete circuit made from independent components. The integration of large numbers of tiny transistors into a small chip was an enormous improvement over the manual assembly of circuits using discrete electronic components. The integrated circuits mass production capability, reliability, and building block approach to circuit design ensured the rapid adoption of standardized integrated circuits in place of designs using discrete transistors.

Modern electronic component distributors often further sub-categorize the huge variety of integrated circuits now available

- Digital ICs are further sub-categorized as logic ICs, memory chips, interface ICs power management ICs, and programmable devices.
- Analog ICs are further sub-categorized as linear ICs and RF ICs.
- Mixed-signal integrated circuits are further sub-categorized as data acquisition ICs and clock/timing ICs.

4.3 VISUAL BASIC

VISUAL BASIC is a visual and event-driven programming language. These are the main divergence from the old BASIC. In BASIC programming is done in a text only environment and the program is executed sequentially. In VB6 programming is done in a graphical environment. In the old BASIC you have to write program code for each graphical object you wish to display it on screen, including its position and its color. However in VB6 you just need to drag and drop any graphical object anywhere on the form, and you can change its properties using the properties window. The events usually comprises but not limited to the user's inputs. Some of the events are load, click, double click, drag and drop, pressing the keys and more. We will learn more about events in later lessons. Therefore a VB6 Program is made up of many subprograms, each has its own program code, and each can be executed independently and at the same time each can be linked together in one way or another.

When you start a new Visual Basic 6 Standard EXE project, you will be presented with the Visual Basic 6 Integrated Development Environment (IDE). The Visual Basic 6 Integrated Programming Environment is show in Figure 4.4. It consists of the toolbox, the form, the project explorer and the properties window.

It consists of four parts [8]

- Toolbox
- Form
- Properties Window
- Project Explorer Window

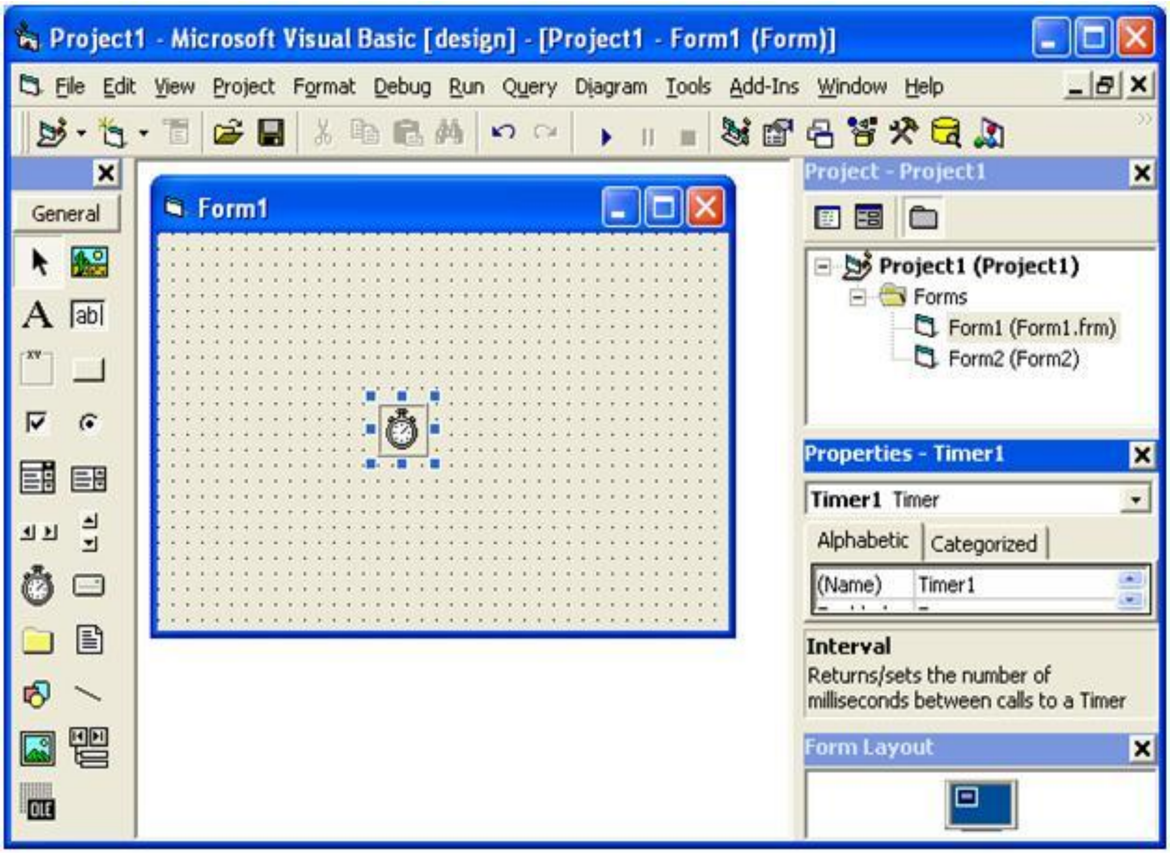


Fig 4.4 VB6 programming environment

4.4 VISUAL MODEL OF NUCLEAR REACTOR

There are three visual models of NUCLEAR REACTOR are shown in figure 4.5, 4.6 and 4.6 respectively

- Visual model with manual mode
- Visual model with semi-auto mode
- Visual model with intelligent mode

4.4.1 CIRCUIT DESCRIPTION OF VISUAL MODEL OF NUCLEAR REACTOR

The visual model includes three modes, mode selection window and authentication window

i. Authenticaation window which provides the hallmark to user

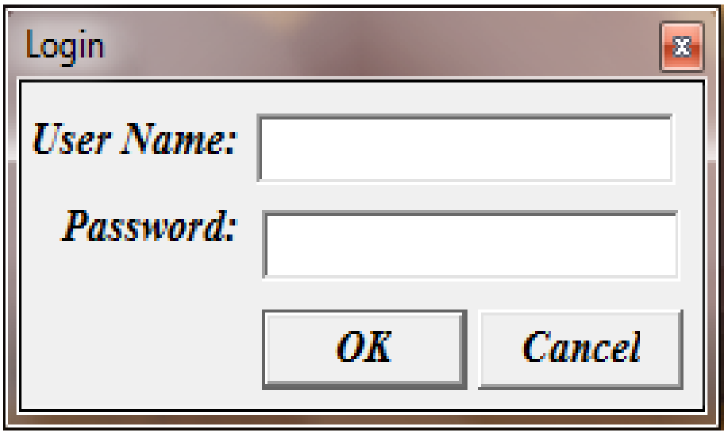


Fig 4.5 Authentic window

ii. Mode selection window: This window work with three different modes to operate as according to user requirment

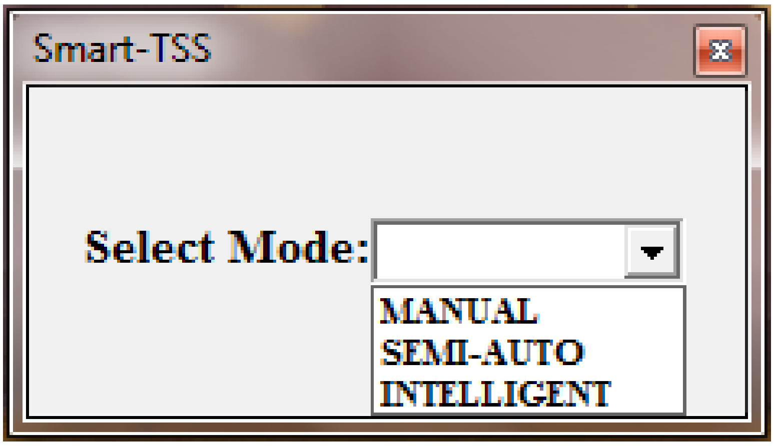


Fig.4.6 Mode selection window

iii. Manual mode is to monitor the temperature and have to turn ON/OFF the controls of reactor from visual application software manually

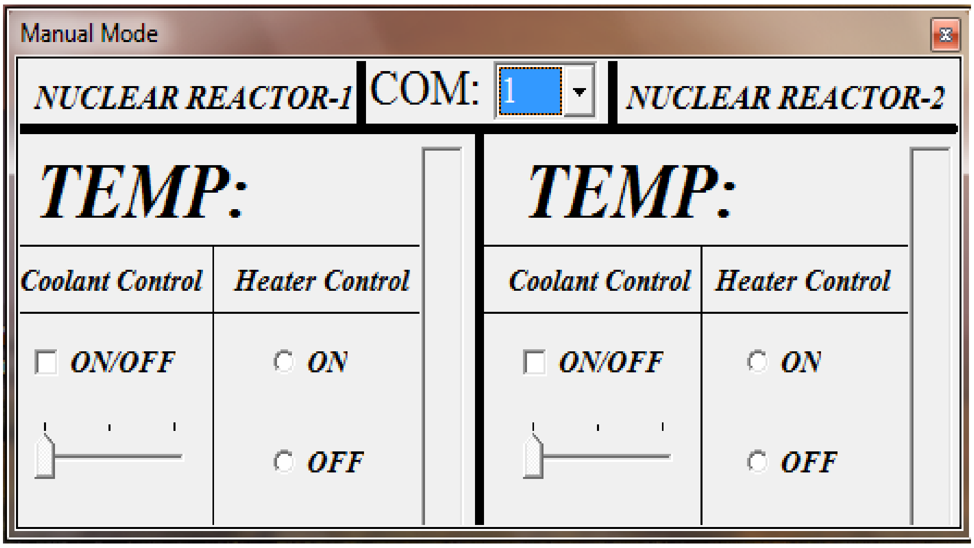


Fig 4.7 Manual mode form

iv. Semi-auto mode: user has to provide values and weights to ANN's modes in software which then intelligently controls reactor according to provided weights.

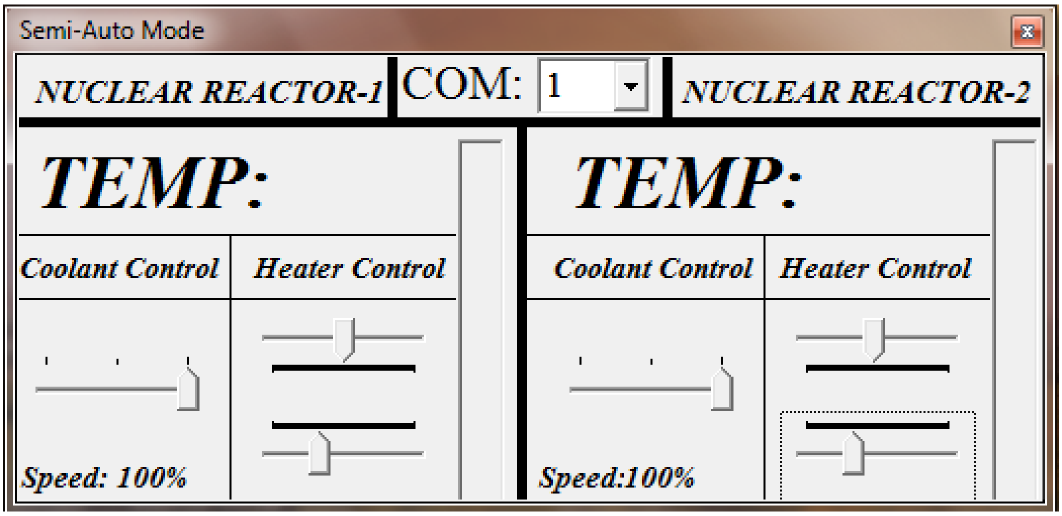


Fig 4.8 Semi-auto mode form

v. Intelligent mode: nodes are already provided with weights,and user does not have to give them manually. It controls the reactor in fully smart way and remove user's interference.

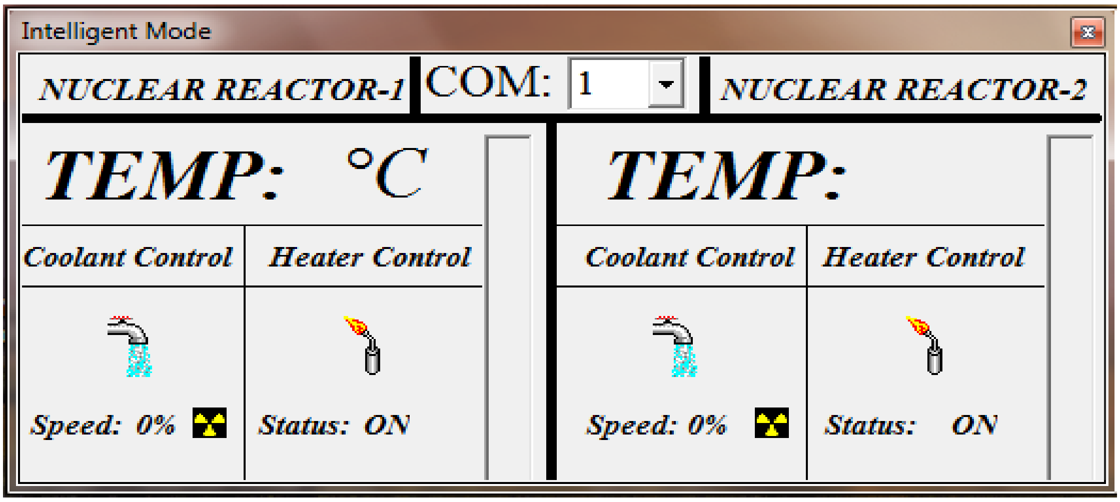
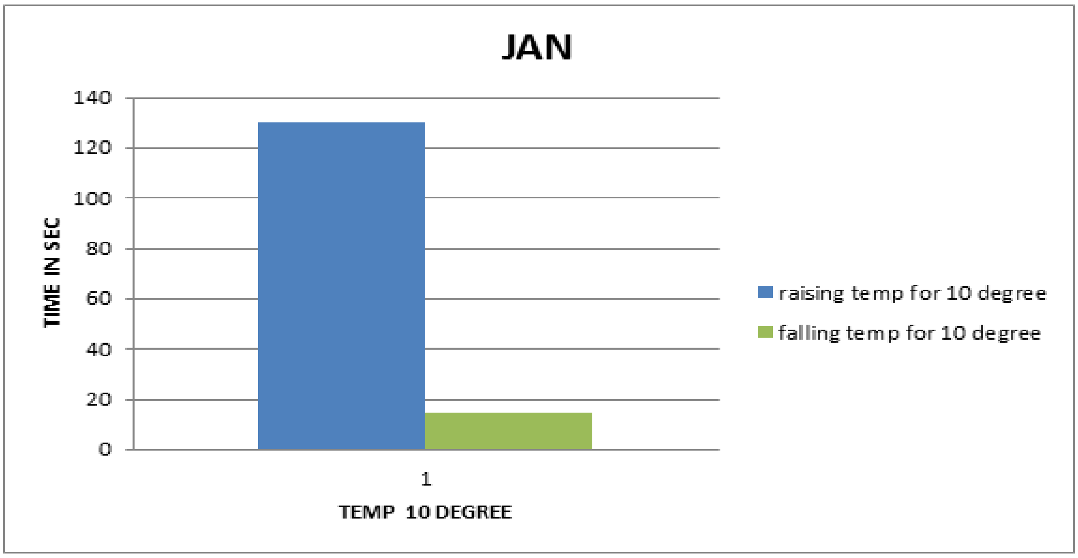


Fig 4.9 Intelligent mode form

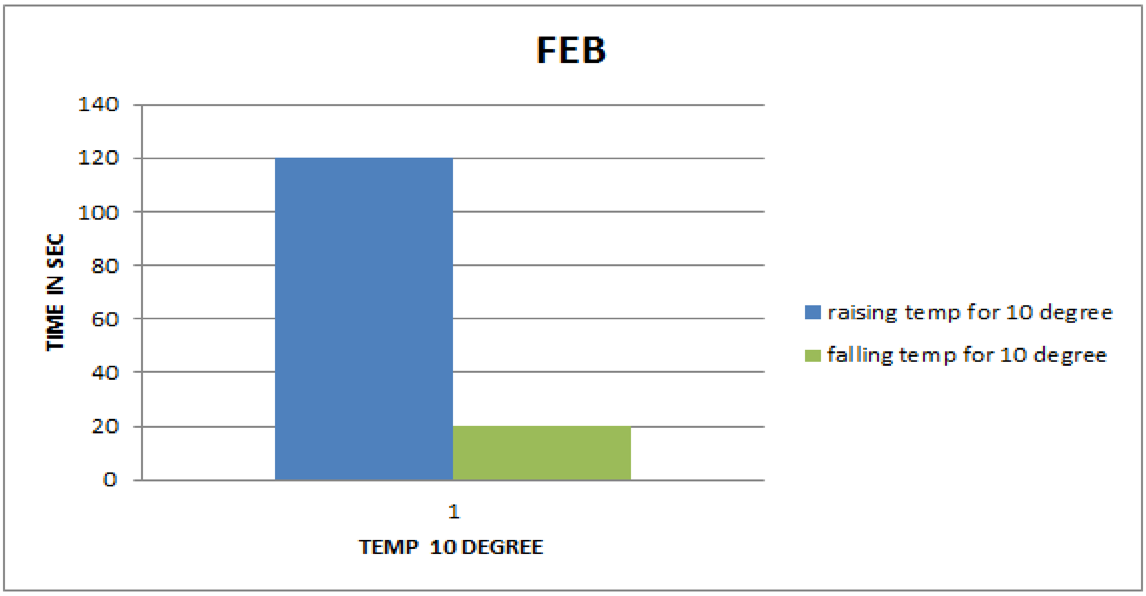
4.5 CIRCUIT DESCRIPTION ABOUT TEMPERATURE CONTROL MODEL

This model gives as various readings about temperature in different months. These readings tell us about the time requirement to control per 10 degree temperature



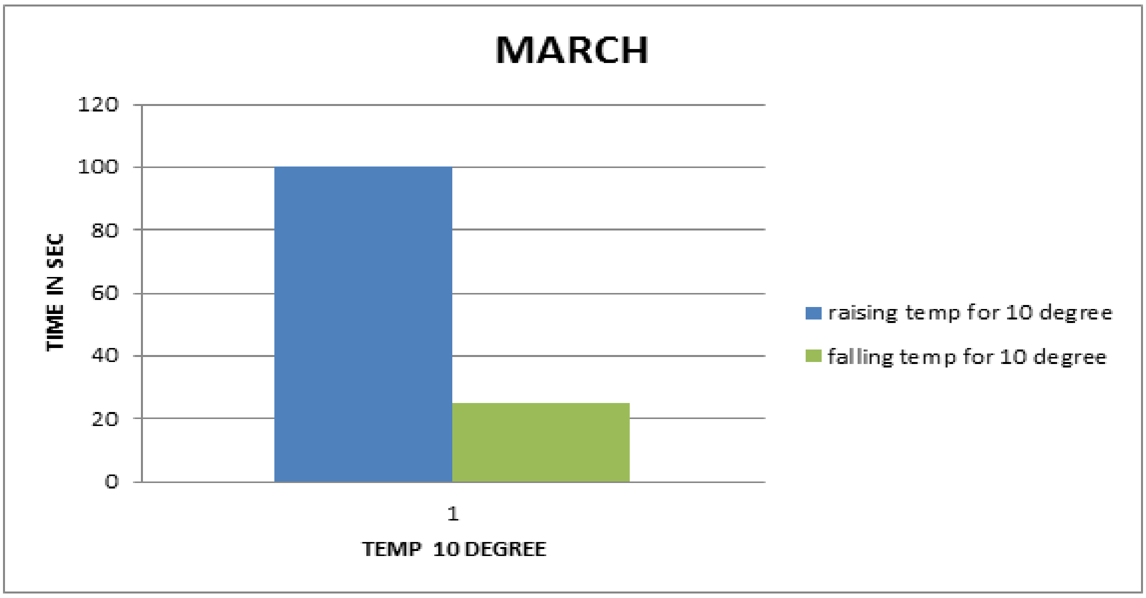
Graph 1 Temperature versus time for the month of january

For the month of january it requires 130 sec for rise in temperature and 15 sec. for temperature fall. It works in intelligent mode thus it requires less cost



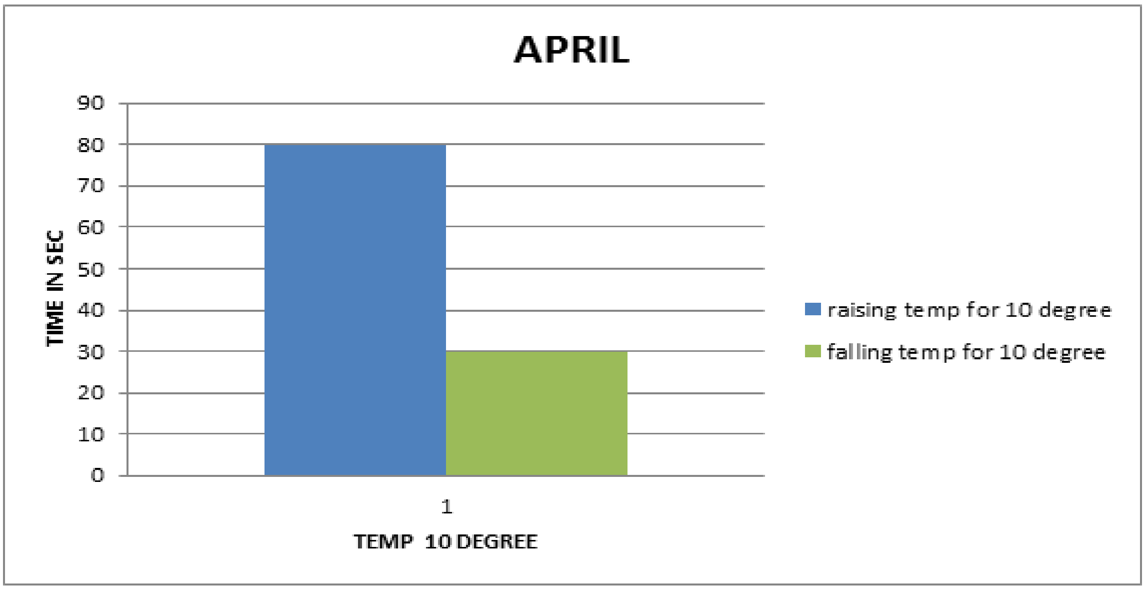
Graph 2 Temperature versus time for the month of february

For the month of february it requires 120 sec for rise in temperature and 20 sec. for temperature fall. It works in intelligent mode thus it requires less cost



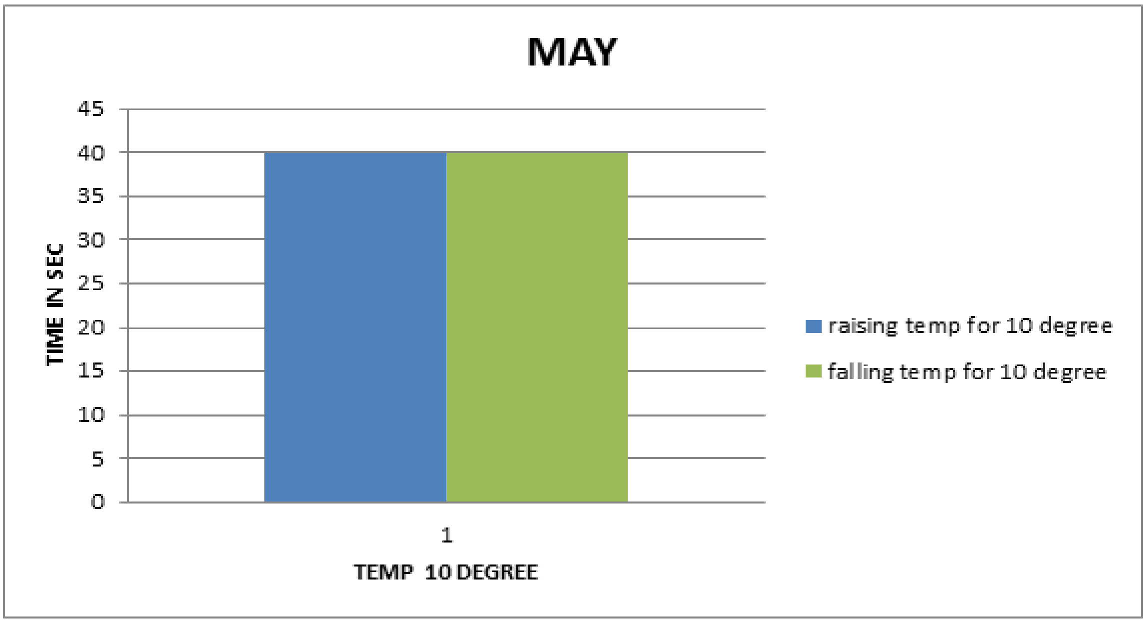
Graph 3 Temperature versus time for the month of march

For the month of march it requires 100 sec for rise in temperature and 20 sec. for temperature fall.It works in semi-auto mode thus it requires less cost than manual mode



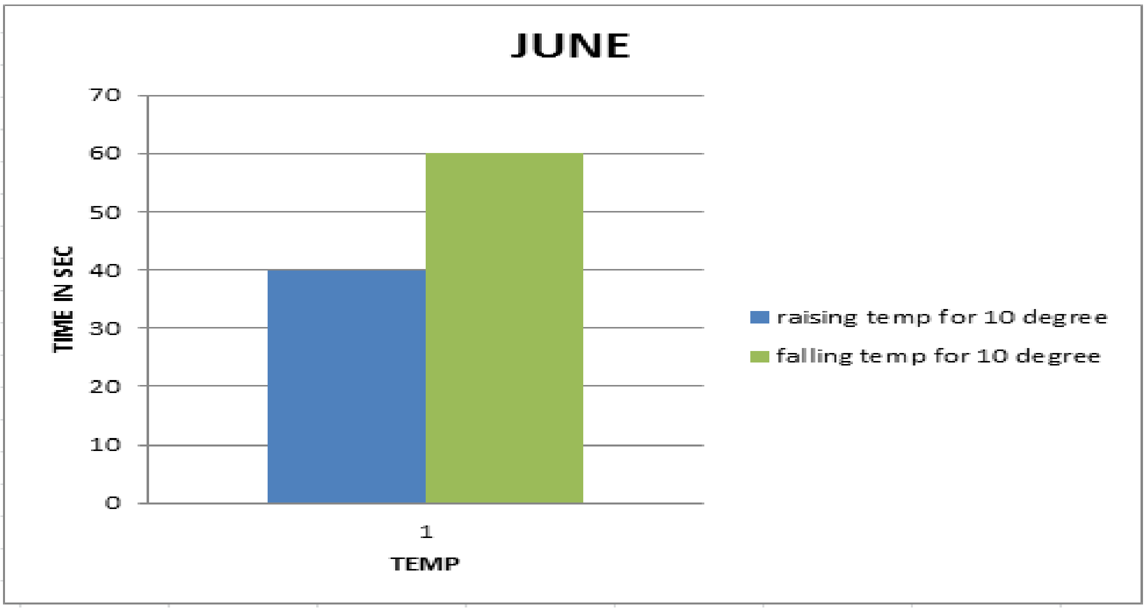
Graph 4 Temperature versus time for the month of april

For the month of april it requires 80 sec for rise in temperature and 30 sec. for temperature fall. It works in semi-auto mode thus it requires less cost than manual mode



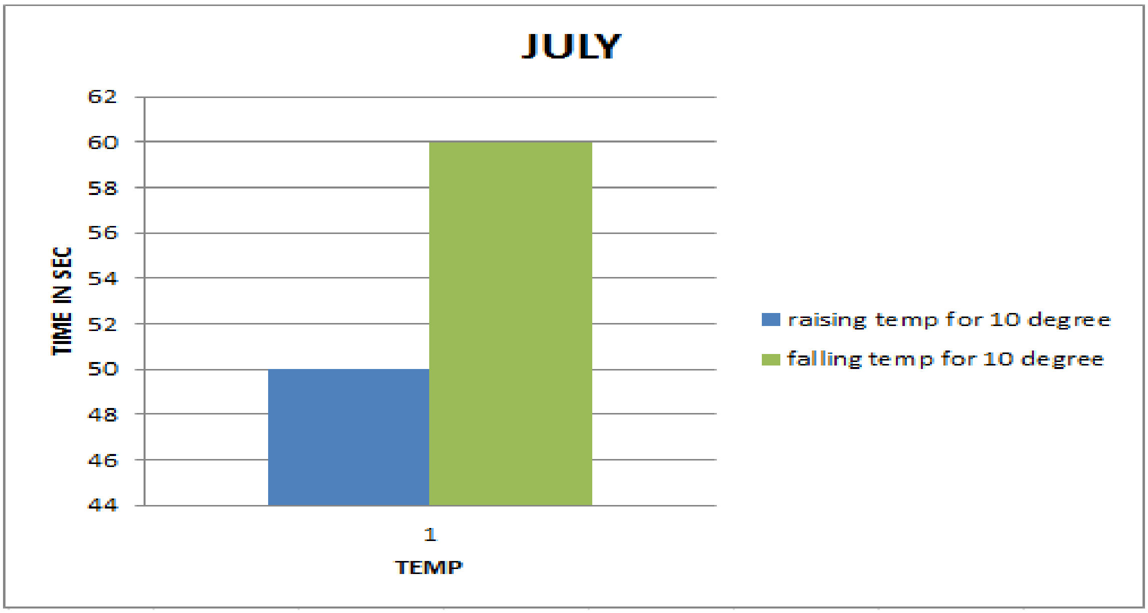
Graph 5 Temperature versus time for the month of may

For the month of may it requires 40 sec for rise in temperature and40 sec. for temperature fall.It works in manual mode thus it requires more cost.



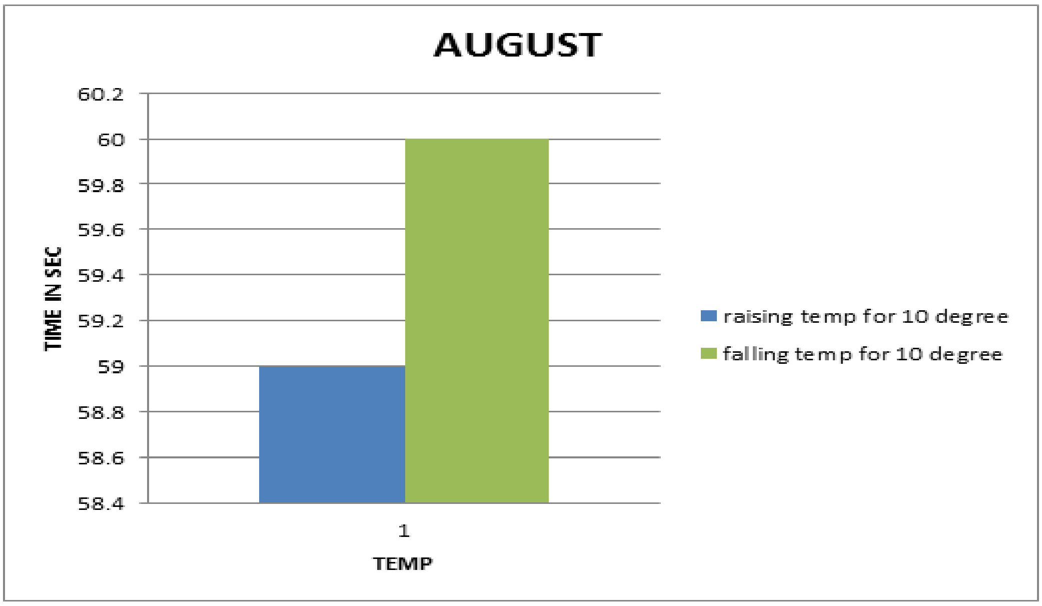
Graph 6 Temperature versus time for the month of june

For the month of dune it requires 40 sec for rise in temperature and 60 sec. for temperature fall.It works in manual mode thus it requires more cost.



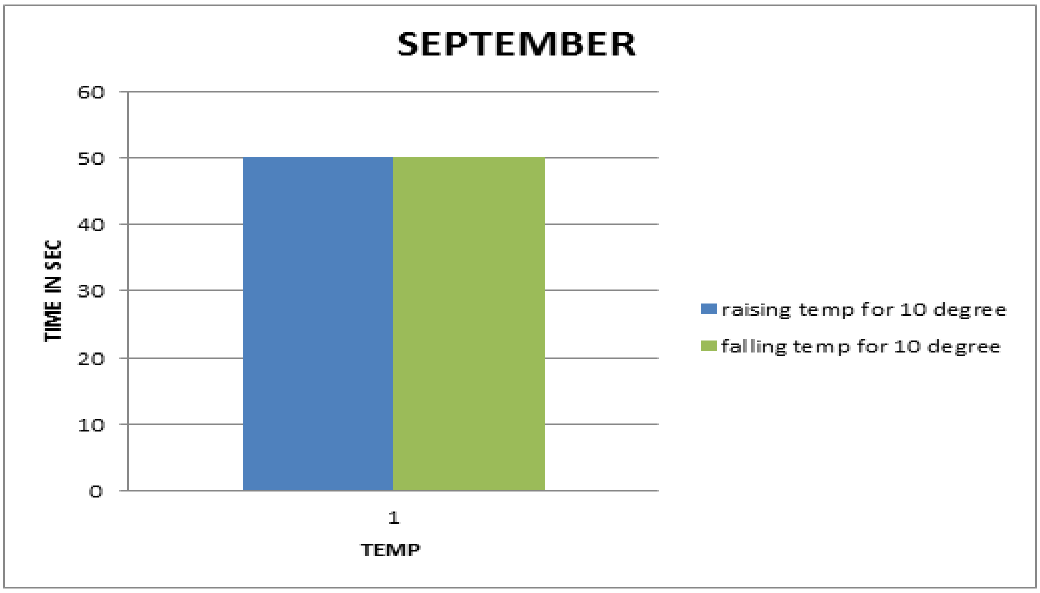
Graph 7 Temperature versus time for the month of july

For the month of july it requires 50 sec for rise in temperature and 60 sec. for temperature fall.It works in manual mode thus it requires more cost.



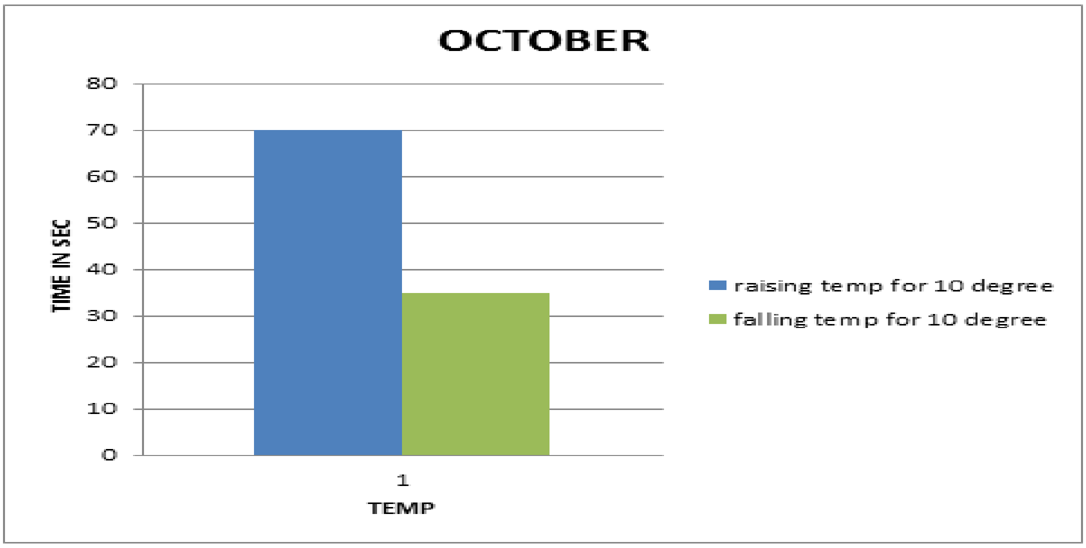
Graph 8 Temperature versus time for the month of august

For the month of august it requires 59 sec for rise in temperature and 60 sec. for temperature fall.It works in manual mode thus it requires more cost.



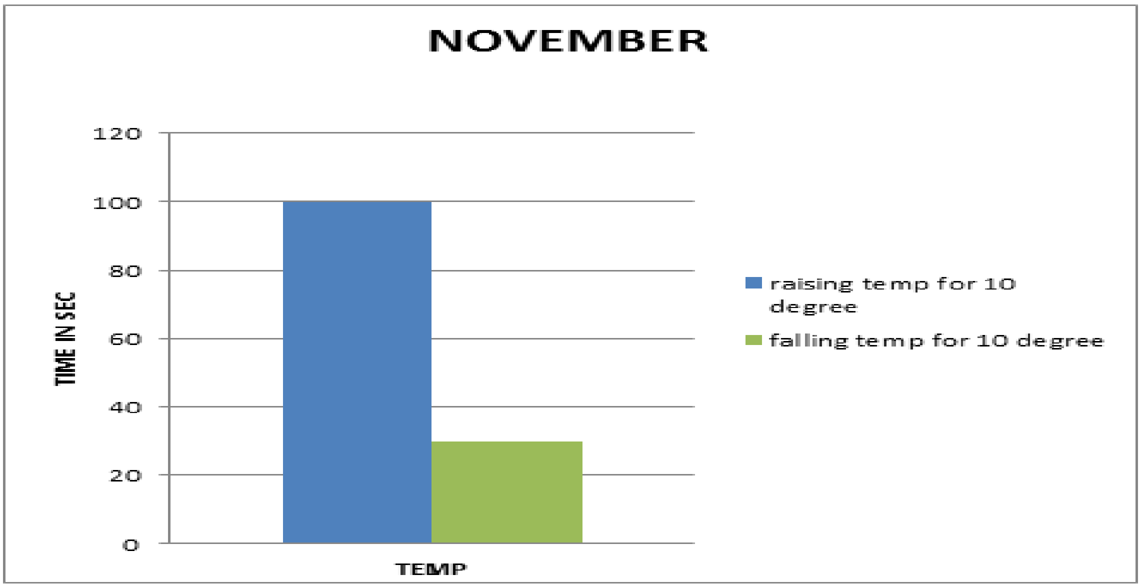
Graph 9 Temperature versus time for the month of september

For the month of september it requires 50 sec for rise in temperature and50 sec. for temperature fall.It works in manual mode thus it requires more cost.



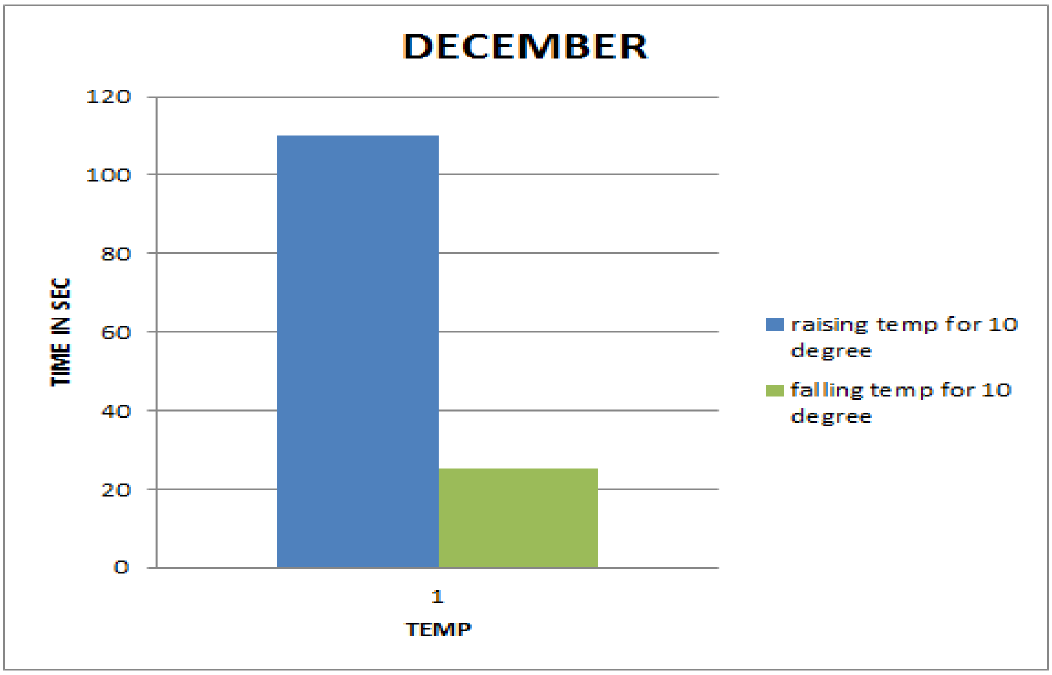
Graph 10 Temperature versus time for the month of october

For the month of october it requires 70 sec for rise in temperature and45 sec. for temperature fall.It works in semi-auto mode thus it requires less cost than manual mode.



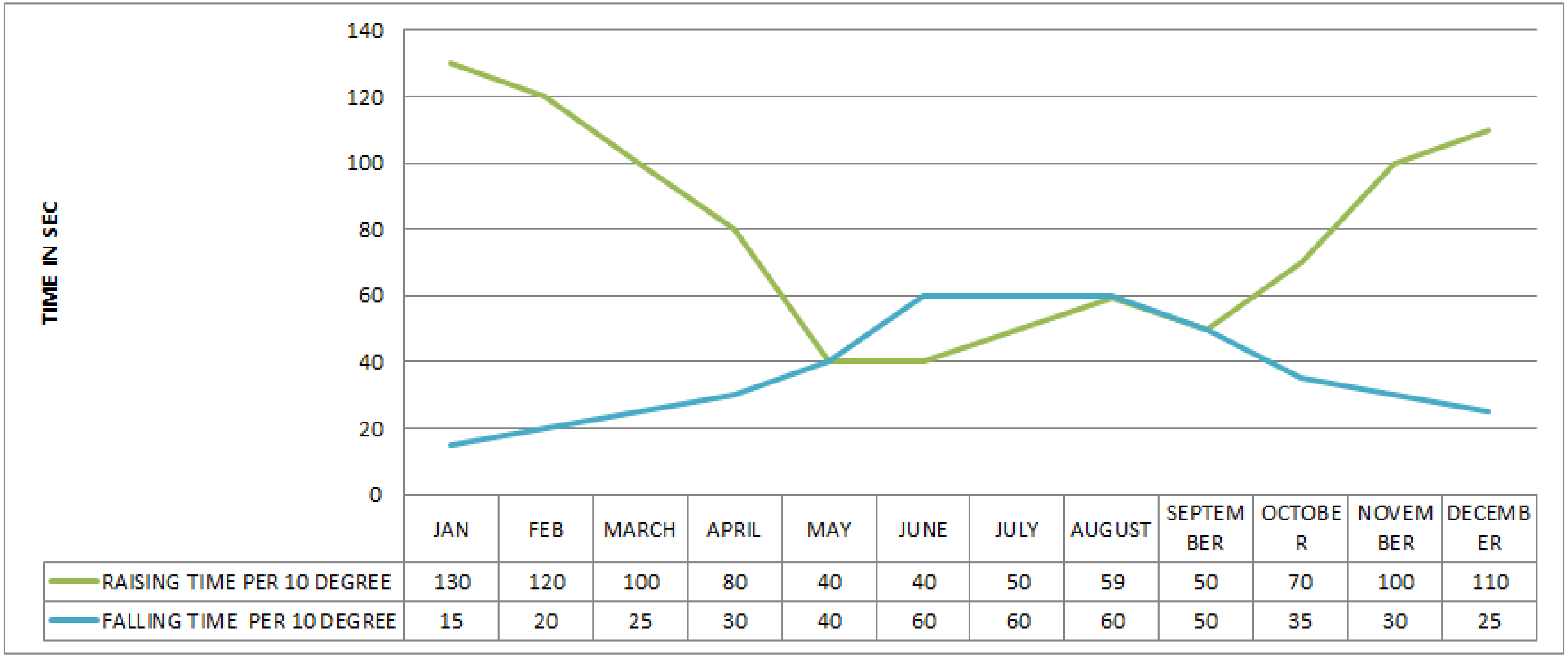
Graph 11 Temperature versus time for the month of november

For the month of november it requires 100 sec for rise in temperature and25 sec. for temperature fall.It works in intelligent mode thus it requires less cost



Graph 12 Temperature versus time for the month of december

For the month of december it requires 105 sec for rise in temperature and25 sec. for temperature fall. It works in intelligent mode thus it requires less cost



	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
RAISING TIME PER 10 DEGREE	130	120	100	80	40	40	50	59	50	70	100	110
FALLING TIME PER 10 DEGREE	15	20	25	30	40	60	60	60	50	35	30	25

Graph 13 Temperature versus time for yearly temperature variation

CHAPTER 5
CONCLUSION& FUTURE SCOPE

5.1 CONCLUSION

In this thesis necessity of real time action in such a critical areas can be achieved using artificial intelligent algorithms. Effort is done to propose a network which will be used in nuclear reactor for safe power generation without effecting human society. Here the whole process is executed by monitoring temperature artificial intelligence is used as a combination of neuro and fuzzy logic, human effort is completely eliminated by adding intelligence to software, switching of nuclear reactor to control is very fast, flexibility to change temperature are given in semiconductor mode, flexible constant speed is added for amount of temperature, high speed and accurate sensing device and high resolution A/D are required to capture minimum changes in temperature, high speed MCU is employed in each reactor for processing the updated temperature and to send it by RS232 communication interface, authentication is provided to software for avoiding an authorized excess within system. Thus by achieving the concept of real time we can reduce lots of risk factors that may be dangerous in the field of power generation areas. The research in the field of nuclear reactor will provide a safety and optimization.

5.2 FUTURE SCOPE

i. Temperature prediction can be used in a system to sense temperature in both directions.
ii. High grade authentication can be done in systems like IRIS , finger printing, voice matching to provide security

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