Use of Artificial Intelligence in Electrical Power System

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Abstract- *A continuous and reliable supply of electricity is necessary for the functioning of today's modern and advanced society. Since the early to mid-1980s, most of the effort in power systems analysis has turned away from the methodology of formal mathematical modeling which came from the areas of operations research, control theory and numerical analysis to the less rigorous and less tedious techniques of Artificial Intelligence (AI). AI techniques can deal with difficult tasks faced by applications in modern large power systems with even more interconnections installed to meet increasing load demand. Artificial Intelligence gives designers of Energy Management Systems a way to solve many of the diagnosis and decision problems so as to make the EMS more useful. The application of these techniques has been successful in many areas of power system engineering. In this paper we have discussed various AI techniques being used in Electrical Power Systems.*

Keywords- Artificial Intelligence, Electrical Power System

I. INTRODUCTION

1. Power Systems:

An electrical power system is a network of electrical components used to supply, transmit and use electric power. Power systems engineering is a subdivision of electrical engineering that deals with the generation, transmission, distribution and utilization of electric power and the electrical devices connected to such systems like generators, motors and transformers.

2. Artificial Intelligence:

Commonly, artificial intelligence is known to be the intelligence exhibited by machines and software, for example, robots and computer programs. The term is generally used to the project of developing systems equipped with the intellectual processes features and characteristics of humans, like the ability to think, reason, find the meaning, generalize, distinguish, learn from past experience or rectify their mistakes. Artificial general intelligence (AGI) is the intelligence of a hypothetical machine or computer which can accomplish any intellectual assignment successfully which a human being can accomplish. [1]

3. Need For Artificial Intelligence In Electrical Power Systems:

Power system analysis by conventional techniques becomes more difficult because of:

1) Complex, versatile and large amount of information which is used in calculation, diagnosis and learning.
2) Increase in the computational time period and accuracy due to extensive and vast system data handling.

The modern power system operates close to the limits due to the ever increasing energy consumption and the extension of currently existing electrical transmission networks and lines. This situation requires a less conservative power system operation and control operation which is possible only by continuously checking the system states in a much more detail manner than it was necessary. Sophisticated computer tools are now the primary tools in solving the difficult problems that arise in the areas of power system planning, operation, diagnosis and design. Among these computer tools, Artificial Intelligence has grown predominantly in recent years and has been applied to various areas of power systems. [1]

II. GENERAL CONCEPT

1. Artificial Intelligence (AI):

It is intelligence exhibited by machines. It is an area of computer science that emphasizes the creation of intelligent machines that work and reacts like humans. Some of the activities computers with artificial intelligence are designed for include: speech recognition, learning, planning, problem solving etc. [1]

Research associated with artificial intelligence is highly technical and specialized. The core problems of artificial intelligence include programming computers for certain traits such as: Knowledge, Reasoning, Problem solving, Perception, Learning, Planning, Ability to manipulate and move objects.

Following are the major families of AI techniques are considered to be applied in modern power system protection:

- Artificial Neural Networks (ANNs),
- Expert System Techniques (XPSs),
- Fuzzy logic systems (FL).
- Genetic Algorithms (GA)

III. TYPES OF ARTIFICIAL INTELLIGENCE TECHNIQUES USED IN POWER SYSTEM

1. Artificial Neural Networks Model (ANNs):

Artificial Neural Networks are computing systems inspired by the Biological Neural Networks that constitute of Neurons having Animal like brain structure. Such system learn (progressively improve performance) to do tasks by considering examples, generally without task-specific programming. For example, in image recognition, they might learn to identify images that contain cats by analyzing example images that have been manually labeled as “cat” or “no cat” and using the analytic results to identify cats in other images. An ANN is based on a collection of connected units called artificial neurons. The functioning of neurons is explained bellow. [1]

Neurons:

The human brain contains about one hundred billions cells called Neurons. Neurons are connected to each other through the pathway. A neural pathway is a series of neurons connected together to enable a signal to be sent from one brain region to another in the form of electrical impulses which will be responsible for functioning of our brain.

ANN converts a set of inputs into a set of outputs by a network of neurons, where each neuron produces one output as a function of inputs. A fundamental neuron can be considered as a processor which makes a simple non linear operation of its inputs producing a single output. The understanding of the working of neurons and the pattern of their interconnection can be used to construct computers for solving real world problems of classification of patterns and pattern recognition. They are classified by their architecture: number of layers and topology: connectivity pattern, feed forward or recurrent. [1]

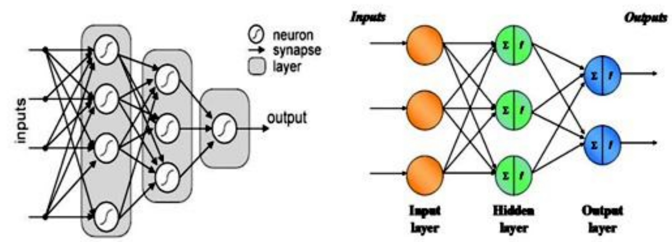

Fig.3.1.1.a Architecture of Feedforward ANN Fig.3.1.1.b Typical Structure of ANN

Figure 1.

Input Layer: The nodes are input units which do not process the data and information but distribute this data and information to other units.

Hidden Layers: The nodes are hidden units that are not directly evident and visible. They provide the networks the ability to map or classify the nonlinear problems.

Output Layer: The nodes are output units, which encode possible values to be allocated to the case under consideration.

Advantages of ANN:

1) Speed of processing.
2) They do not need any appropriate knowledge of the system model.
3) They have the ability to handle situations of incomplete data and information, corrupt data.
4) They are fault tolerant.
5) ANNs are fast and robust. They possess learning ability and adapt to the data.
6) They have the capability to generalize.

Disadvantages of ANN:

1) Large dimensionality.
2) Results are always generated even if the input data are unreasonable.
3) They are not scalable i.e. once an ANN is trained to do certain task, it is difficult to extend for other tasks without retraining the neural network.

Applications of ANN: Power system problems concerning encoding of an unspecified non-linear function are appropriate for ANNs. ANNs can be particularly useful for problems which require quick results, like those in real time operation. This is because of their ability to quickly generate results after obtaining a set of inputs.

How ANNs can be used in power systems: As ANNs operate on biological instincts and perform biological evaluation of real world problems, the problems in generation, transmission and distribution of electricity can be fed to the ANNs so that a suitable solution can be obtained. Given the constraints of a practical transmission and distribution system, the exact values of parameters can be determined. For example, the value of inductance, capacitance and resistance in a transmission line can be numerically calculated by ANNs taking in various factors like environmental factors, unbalancing conditions, and other possible problems. Also the values of resistance, capacitance and inductance of a transmission line can be given as inputs and a combined, normalized value of the parameters can be obtained. In this way skin effect and proximity effect can be reduced to a certain extent. [1]

2. Fuzzy Logic:

Fuzzy logic or Fuzzy systems are logical systems for standardization and formalization of approximate reasoning. It is similar to human decision making with an ability to produce exact and accurate solutions from certain or even approximate information and data. The reasoning in fuzzy logic is similar to human reasoning. Fuzzy logic is the way like which human brain works, and we can use this technology in machines so that they can perform somewhat like humans. Fuzzification provides superior expressive power, higher generality and an improved capability to model complex problems at low or moderate solution cost. Fuzzy logic allows a particular level of ambiguity throughout an analysis. Because this ambiguity can specify available information and minimize problem complexity, fuzzy logic is useful in many applications. For power systems, fuzzy logic is suitable for applications in many areas where the available information involves uncertainty. For example, a problem might involve logical reasoning, but can be applied to numerical, other than symbolic inputs and outputs. Fuzzy logic provide the conversions from numerical to symbolic inputs, and back again for the outputs.[7]

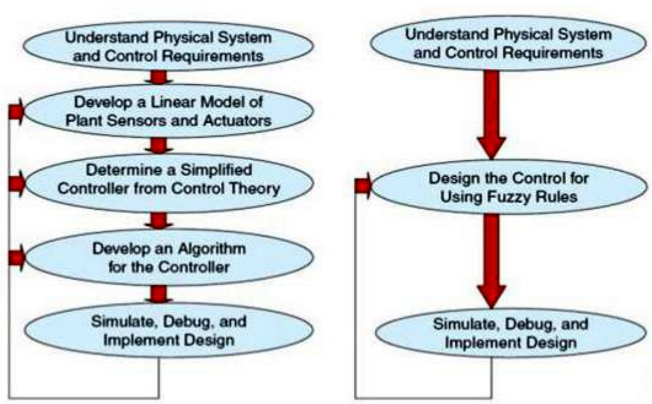

Figure 2. Benefits of using fuzzy logic

Fuzzy Logic Controller: Simply put, it is a fuzzy code designed to control something, generally mechanical input. They can be in software or hardware mode and can be used in anything from small circuits to large mainframes. Adaptive fuzzy controllers learn to control complex process much similar to as we do. [7]

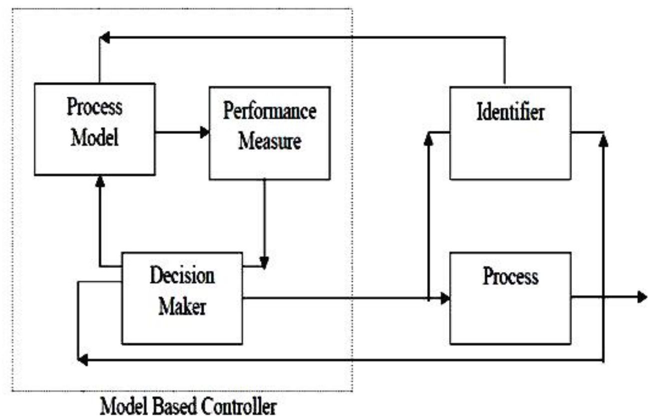

Figure 3. Fuzzy Logic Controller

Applications of Fuzzy Logics in Power System:

1. Stability analysis and enhancement.
2. Power system control.
3. Fault diagnosis.
4. Security assessment.
5. Load forecasting.
6. Reactive power planning and its control.
7. State estimation.

Reactive Power and Voltage Control Main types of voltage problems are:

1) Planning of system reactive power demands and control faciities.
2) Installation of reactive power control resources.
3) The operation of existing voltage resources and control device.

For reactive power control with the objective of enhancing the voltage profile of power system, fuzzy logic has been applied. The voltage deviation and controlling variables are converted into fuzzy set or fuzzy system notations to construct the relations between voltage deviation and controlling ability of the controlling device. The main control variables are generator excitation, transformer taps and VAR compensators. A fuzzy system is formed to select these control variables and their movement.

The control variables are selected on the basis of:

1) Local controllability towards a bus having unacceptable voltage.

2) Overall controllability towards the buses having poor voltage profile.

How fuzzy logic can be used in power systems: Fuzzy logic can be used for designing the physical components of power systems. They can be used in anything from small circuits to large mainframes. They can be used to increase the efficiency of the components used in power systems. As most of the data used in power system analysis are approximate values and assumptions, fuzzy logic can be of great use to derive a stable, exact and ambiguity-free output. [7]

3. Expert Systems:

An expert system obtains the knowledge of a human expert in a narrow specified domain into a machine implementable form. Expert systems are computer programs which have proficiency and competence in a particular field. This knowledge is generally stored separately from the program's procedural part and may be stored in one of the many forms, like rules, decision trees, models, and frames. They are also called as knowledge based systems or rule based systems. Expert systems use the interface mechanism and knowledge to solve problems which cannot be or difficult to be solved by human skill and intellect. [10]

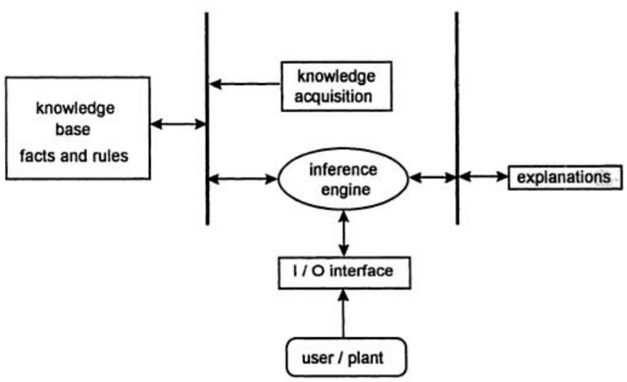

Figure 4. Structure of an Expert System

Advantages of Expert System:

1) It is permanent and consistent.
2) It can be easily documented.
3) It can be easily transferred or reproduced.

Disadvantage: Expert Systems are unable to learn or adapt to new problems or situations.

Applications: Many areas of applications in power systems match the abilities of expert systems like decision making, archiving knowledge, and solving problems by reasoning, heuristics and judgment. Expert systems are especially useful for these problems when a large amount of data and information must be processed in a short period of time.

How expert systems can be used in power systems: Since expert systems are basically computer programs, the process of writing codes for these programs is simpler than actually calculating and estimating the value of parameters used in generation, transmission and distribution. Any modifications even after design can be easily done because they are computer programs. Virtually, estimation of these values can be done and further research for increasing the efficiency of the process can be also performed.

4. Genetic Algorithms (GA):

Genetic algorithm is an optimization technique based on the study of natural selection and natural genetics. Its basic principle is that the fittest individual of a population has the highest probability and possibility for survival. Genetic algorithm gives a global technique based on biological metaphors. The Genetic algorithm can be differentiated from other optimization methods by:

1) Genetic algorithm works on the coding of the variables set instead of the actual variables.
2) Genetic algorithm looks for optimal points through a population of possible solution points, and not a single point.
3) Genetic algorithm uses only objective function information.
4) Genetic algorithm uses probability transition laws, not the deterministic laws.

Genetic algorithm is derived from an elementary model of population genetics. It has following components:

1) Chromosomal representation of the variable describing an individual.
2) An initial population of individuals.
3) An evaluation function which plays the environment's part, ranking the individuals in terms of their fitness which is their ability to survive.
4) Genetic operators which determine the configuration of a new population generated from the previous one by a procedure.
5) Values for the parameters that the GA uses. [4]

Applications: Areas of applications in power systems include:

1) Planning: Wind turbine positioning, reactive power optimization, network feeder routing, and capacitor placement.

2) Operation: Hydro-thermal plant coordination, maintenance scheduling, loss minimization, load management, control of FACTS.
3) Analysis: Harmonic distortion reduction, filter design, load frequency control, load flow. [4]

How genetic algorithms can be used in power systems: As genetic algorithms are based on the principle of survival of fittest, several methods for increasing the efficiency of power system processes and increasing power output can be proposed. Out of these methods, using genetic algorithms, the best method which withstands all constraints can be selected as it is the best method among the proposed methods (survival of fittest). [9]

5. Comparison of AI Techniques in Power System Protection:

Table 1.

I. Feature	II. XPS	III. ANNs	IV. FL
V. Knowledge used	**VI.** Expert knowledge in the form of rules, objects, frames etc.	**VII.** Information extracted from the training set of cases.	**VIII.** Expert knowledge in the form of protection criteria.
IX. Troubleshooting and improving a relay	**X.** Change of rules required.	**XI.** Difficult- the internal signals are almost impossible to interpret.	**XII.** Convenient- the internal signals are understandable and analyzable
XIII. Self-learning	**XIV.** Possible	**XV.** Natural	**XVI.** Possible
XVII. Handling unclear cases	**XVIII.** Possible	**XIX.** Natural	**XX.** Natural
XXI. Robustness	**XXII.** Not-critical and easy to ensure.	**XXIII.** Difficult to ensure	**XXIV.** Not critical and easy to ensure
XXV. Setting a relay	**XXVI.** Convenient	**XXVII.** Large number of simulation required.	**XXVIII.** Convenient. Both knowledge and simulation are used
XXIX. Computations	**XXX.** Extensive	**XXXI.** Dedicated hardware	**XXXII.** Moderate

IV. ADVANTAGES

1. Advantages of Using Artificial Intelligence in Electrical Power System:

1) Integrate easily with existing energy management systems.

2) Generate and modify power network configurations and display them graphically.
3) Accommodate various methods of knowledge representation.
4) Create knowledge bases for different power.
5) System analysis and control applications.
6) Link efficiently with numerical analysis programs.
7) Incorporate and control different inference mechanisms including those which have the ability to reason about time dependent events and deal with uncertainty.
8) Provide adequate explanation facilities.

V. LIMITATIONS:

1. Limitations for AI in Power system:

1) Large dimensionality.
2) Results are always generated even if the input data are unreasonable.
3) They are not scalable i.e. once an ANN is trained to do certain task; it is difficult to extend for other tasks without retraining the neural network.

VI. APPLICATIONS:

1. Current Applications of AI in Power Systems:

Several problems in power systems cannot be solved by conventional techniques are based on several requirements which may not feasible all the time. In these situations, artificial intelligence techniques are the obvious and the only option. Areas of application of AI in power systems are:

1) Operation of power system like unit commitment, hydro-thermal coordination, economic dispatch, congestion management, maintenance scheduling, state estimation, load and power flow.
2) Planning of power system like generation expansion planning, power system reliability, transmission expansion planning, reactive power planning.
3) Control of power system like voltage control, stability control, power flow control, load frequency control.
4) Control of power plants like fuel cell power plant control, thermal power plant control.
5) Control of network like location, sizing and control of FACTS devices.
6) Electricity markets like strategies for bidding, analysis of electricity markets.
7) Automation of power system like restoration, management, fault diagnosis, network security.
8) Applications of distribution system like planning and operation of distribution system, demand side response and demand side management, operation and control of smart grids, network reconfiguration.
9) Applications of distributed generation like distributed generation planning, solar photovoltaic power plant control, wind turbine plant control and renewable energy resources.
10) Forecasting application like short term and long term load forecasting, electricity market forecasting, solar power forecasting, wind power forecasting. [8]

2. Practical Application of AI Systems in Transmission Line.

Consider a practical transmission line. If any fault occurs in the transmission line, the fault detector detects the fault and feeds it to the fuzzy system. Only three line currents are sufficient to implement this technique and the angular difference between fault and pre-fault current phasors are used as inputs to the fuzzy system. The fuzzy system is used to obtain the crisp output of the fault type. Fuzzy systems can be generally used for fault diagnosis.

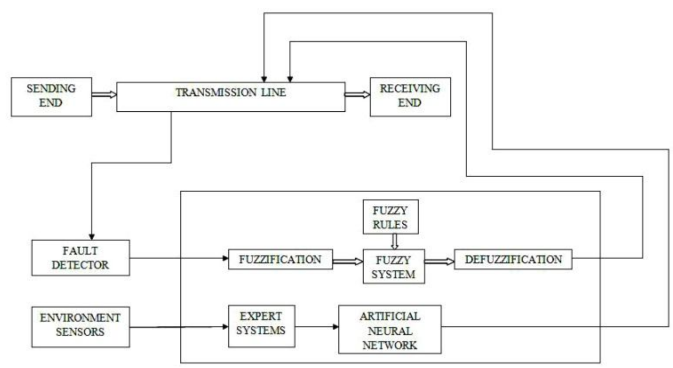

Figure 5. Practical Application of AI Systems in Transmission Line.

Artificial Neural Networks and Expert systems can be used to improve the performance of the line. The environmental sensors sense the environmental and atmospheric conditions and give them as input to the expert systems. The expert systems are computer programs written by knowledge engineers which provide the value of line parameters to be deployed as the output. The ANNs are trained to change the values of line parameters over the given ranges based on the environmental conditions. Training algorithm has to be given to ANN. After training is over, neural network is tested and the performance of updated trained neural network is evaluated. If performance is not up to the desired level, some variations can be done like varying number of hidden layers, varying number of neurons in each layer. The processing speed is directly proportional to the number of neurons. These networks take different neurons for different layers and different activation functions between input and hidden layer and hidden and output layer to obtain the desired output. In this way the performance of the transmission line can be improved. [2]

3. Examples of AI Systems Already in Service:

While many of the expert systems developed are prototypes, there are also systems which are now used in real-life power systems. Some examples are given below.

a. Intelligent Alarm Processor (IAP) of Public Utilities Board, Singapore:

This system is for real-time alarm processing and for the identification of malfunctioning of circuit-breakers. It has been in service since the end of 1990.

b. Expert system for on-line diagnosis of turbine-generators:

This system was developed jointly by Camegie-Mellon University Robotics Institute and Westinghouse Electric Corporation and it has been in service since 1985.

c. Advanced Operation Guidance Expert System for 500 kV substations:

This system has been in service since February, 1991 in a 500 kV switching station of Kansai Electric Power CO, Japan.

d. Expert system for procedure generation of power system restoration:

This system has been applied to a regional control centre of Electric Power Development Co., Japan, since April, 1991.

4. Other possible applications of AI to Power System Operation:

A. Real-Time Control Problems:

1) Alarm Processing:

The alarm processing problem is really an extension of the diagnosis problem. When a serious disruption occurs on the power system, operators can be overloaded with alarm messages. Because many of the alarm messages are redundant or present information related to the same event the operators may have difficulty in understanding precisely what has happened. The use of AI to intercept alarm messages and present a concise diagnosis is now under active development in several organizations.

2) Switching Operations:

Statistics show that about 40 percent of the tasks at a power system control center are related to operations on circuit breakers and line switches. Therefore, the automation of these tasks should benefit system operators. One potential application is the automatic generation of switching sequences. Some work has been done on verification of the switching sequences.

3) Voltage Control:

Incorporation of static optimization techniques such as an Optimal Power Flow (OPF) is common for new control centers which desire to control the system voltage profile. However, the control actions recommended by the OPF do not take account of the future load prediction or past history of control actions and may prove very difficult to implement since many of the controls require manual entry by the operator.

4) Restoration Control:

A large-scale blackout may happen on a power system, although quite infrequently. The fact that blackouts happen infrequently makes the operator's job that much harder because of the limited exposure to solving the problem of restoring the system. As a result, most control centers have restoration plans and attempt to train operators in restoration using training simulators. However, the number of possible ways to restore a power system is very large and can change depending on the state of critical components at the time the blackout occurs. To this end, a system which supports operators by giving them with a tool for short term operations planning is quite desirable. [6]

B. Operations planning:

1. Load Flow Planning:

Load flows are run by system operators to determine effects of planned changes to the system and to help the operator study appropriate alternatives should equipment loading fall outside appropriate operating limits. An intelligent and friendly interface to the load flow program will help the operator in setting up cases to be run, interpreting the results of solved cases, and especially in how to interpret results if the load flow fails to converge.

2. Unit Commitment:

One of the problems encountered in the use of unit commitment programs is the difficulty of expressing all the constraints that operators must meet in scheduling units. Present practice in many control centers with unit commitment programs is to run the program and then alter the resulting schedule to meet constraints not included in the program.

C. Operator Training

1) Personal Tutoring:

Large-scale training simulators are installed in power system control centers to enhance operator’s skills. One point of view states that the operator acquires these skills through the efforts of classroom instruction and over-the-shoulder advice of a training instructor while solving difficult operating problems on the simulator. Another point of view adds the capability of having the training simulator provide custom-tailored advice for a specific operator and a specific training situation.

2) Scenario Building:

Another aspect of operator training is the need to provide adequately difficult training scenario cases for the training sessions. These scenarios need to be made difficult enough and specific enough so that targeted levels of skill can be reached in each aspect of power system operation. Building such scenarios can be quite difficult for training instructors and AI Systems have an expert system which can allow the instructor to build a scenario given a specific level of difficulty for the training exercise and the type of problem that is to be presented to the operator. [6]

VII. CONCLUSION

The main feature of power system design and planning is reliability, which was conventionally evaluated using deterministic methods. Moreover, conventional techniques don’t fulfill the probabilistic essence of power systems. This leads to increase in operating and maintenance costs. Plenty of research is performed to utilize the current interest AI for power system applications. A lot of research is yet to be performed to perceive full advantages of this upcoming technology for improving the efficiency of electricity market investment, distributed control and monitoring, efficient system analysis, particularly power systems which use renewable energy resources for operation.

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