Artificial Neural Networks and their Applications in Electric Power Industry

Aparna Palit[1] Yukta Ankatwar[2]
[1,2]Department of Electrical Engineering
[1,2]Government College of Engineering Nagpur, Maharashtra, India

Abstract— The goal of the Electric Power Industry is to provide a constant electric supply at minimum cost. To achieve this the power industry has to deal with many complications, viz. variability of load, growing demands of power, requirement of good quality fuels, and fast changing technologies. In recent years, Artificial Intelligence (AI) technologies, namely fuzzy logic, expert systems, genetic algorithm and artificial neural networks (ANN), have gained immense popularity in solving such problems. This paper focuses on Artificial Neural Networks and their applications in the Electric Power Industry. Firstly, it describes the ANN technology and how it can be used in the power industry. Then the intention of this paper is to give a succinct overview of the fields where ANN is being used such as load forecasting, economic load dispatch, security assessment, and fault detection.

Keywords: Artificial Neural Network, ANN, MLP, BP, Forecasting, Electric Load Dispatch

I. INTRODUCTION

Artificial Neural Network (ANN) is a data processing system inspired by the biological nervous system, and containing a large number of interconnected processing elements called nodes which are similar to the biological neurons. ANNs have been studied for many years with the hope of understanding and achieving human-like computational and decision-making abilities. ANNs offer various benefits including fast speed, adaptive capabilities, robustness, high fault tolerance, distributed memory and massive parallelism among others. The parallelism refers to the fact that each node operates independently and concurrently (in parallel) with the others, and the knowledge in the network is distributed over the entire set of weights, rather than focused in a few memory locations as in a conventional computer. Hence, artificial neural networks are intended to do things which humans do well but which conventional computers often do poorly. In recent years ANNs have witnessed rapid growth and hence attracted various researchers and developers to venture into this field of technology. ANNs have an interdisciplinary approach in their development and application including image processing, character recognition, speech recognition, forecasting, etc. This paper includes the power industry applications of ANNs.

The modern power system is operated keeping in mind the ever-increasing energy demands and the extension of currently existing electrical transmission networks and lines. For smooth and accurate functioning, a less conservative power system operation and control operation is required. For achieving this, it is necessary to check continuously the system states in a much more detailed manner. Artificial Intelligence has proved to solve the difficult problems arising in power system planning, design, diagnosis and operation. In power system ANN technology is applied in Load Forecasting, Economic Load Dispatch, Security Assessment and Fault Detection.

II. NEURAL NETWORK

A Neural Network is an interconnected group of simple processing elements, units or nodes whose function is inspired by that of a human brain. To understand the structure of a neural network it is imperative to know some basic aspects of neurobiology. The human brain consists of billions of neurons or nerve cells which communicate with (send electrical signals to) each other via specialized connections called synapses.

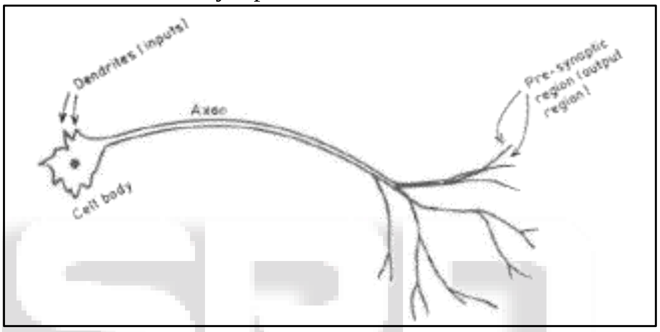

Fig. 1: Biological Neuron

Figure indicates that since a single neuron has hundreds of synapses, a neuron is able to pass its message/signal to hundreds of other neurons. Similarly, since there are many dendrites on each neuron, a single neuron can receive signals from many other neurons. Hence the neural network of our brain is interconnected. It is because of these interconnections this type of system is known as connectionist system [1].

III. ARCHITECTURE OF ANN

Equivalent to the biological neural network, an Artificial Neural Network (ANN) consists of several interconnected computational units or elements called artificial neurons, which are building blocks of an ANN. A neuron is connected to several other neurons through links which are analogous to the biological neural network axon-synapse-dendrite connections. Each link is assigned a weight and this weight is multiplied to the input signal and then sent to the next neuron. The weighted signals undergo arithmetic addition and produce an activation function or transfer function which is the output of the neuron. The transfer functions usually have a sigmoid shape, but they may also take the form of other nonlinear functions, piecewise linear functions, or step functions. They are also often monotonically increasing, continuous, differentiable and bounded. Figure shows the structure of an artificial neuron [2].

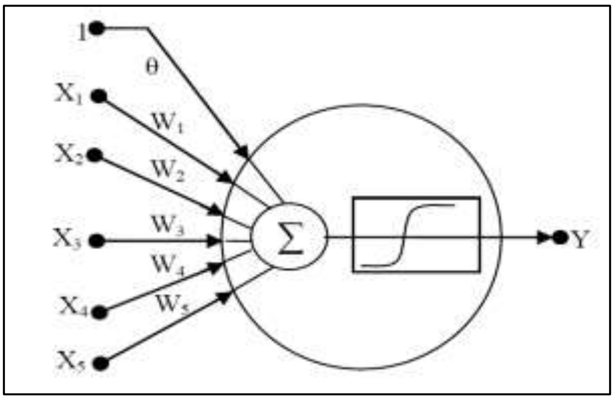

Fig. 2: Artificial Neuron

The neurons can be organised into one or more layers. The layer of neurons receiving external data or signal is called input layer and the layer of neurons which gives out the end result is called output layer. An ANN can have zero or more hidden layers between the input and output layers. These hidden layers perform the required computational operations. These hidden layers contain many neurons which are interconnected. The inputs and outputs of each of these hidden neurons simply go to other neurons. In most networks each neuron in a hidden layer receives the signals from all of the neurons in a layer above it, typically an input layer. After a neuron performs its function it passes its output to all of the neurons in the layer below it, providing a feed-forward path to the output [3].

IV. TYPES OF ANN ARCHITECTURE

A. *Multilayered perceptron (MLP) –*

The basic powering unit of deep learning is Perceptron. A perceptron is a simple binary classification algorithm, proposed by Cornell scientist Frank Rosenblatt. More than three layers of perceptron's with nonlinear Activation functions are stacked together to solve complex problems. It is a feed forward neural network model that maps sets of input data onto a set of appropriate output. It is indeed more powerful than the perceptron as it distinguishes nonlinearly separable data. The Network consists of an input and an output layer with one hidden layer of nonlinearly-activating nodes.

An MLP with a single hidden layer can be represented as follows:

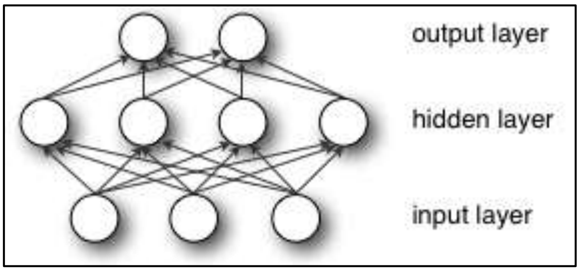

Fig. 3: Structure of MLP

The number of neurons in input layer is same as number of input features. Each node in one layer connects with a certain weight (W) to every other node in the following layer. The network is trained with Back Propagation (BP) algorithm [4].

B. *Hopfield-*

Hopfield neural network is a single-layer, nonlinear, auto associative, discrete or continuous-time network that is easier to implement in hardware. They are constructed from artificial neurons having 'N' inputs. The state of the output is maintained until the neuron is updated. A Hopfield network has distributed representation, asynchronous control, content addressable memory and tolerance towards fault. The applications of HNN include image and speech processing, control, signal processing, database retrieval, fault-tolerant computing, pattern classification and recognition, automatic target recognition, olfactory processing, knowledge processing, while for the analog version we have applications such as image and signal processing, control, olfactory processing, pattern recognition, and in combinatorial optimization problems [5].

V. TRAINING AN ANN

The various inputs to the ANN are represented by the mathematical symbol, x(n). Each of these inputs are multiplied by a connection weight. The weights are represented by w(n). These modified inputs are fed into the summing function, which usually just sums these products. Yet, many different types of operations can be selected. These operations could produce different values such as the average, the largest, the smallest, the ORed values, the ANDed values, etc. which are then propagated forward. Also, software engineers can create their own summing functions via routines coded in a higher-level language (like C language). The summing function is further passed through a transfer function or activation function which controls the output value via thresholds. The result of the activation function determines whether the particular neuron will get activated or not, i.e. it gives a value of either 0 or 1. The activated neuron transmits data to the neuron of the next layer. In this manner the data is propagated through the network and this process is known as forward propagation.

Types of learning algorithms:

The adjusting of weights and thresholds by making small changes to them, is an iterative process done to bring them more in line with the desired values. This process is known as training the network, i.e. the network undergoes a process of learning or adapting to the modified weights and thresholds.

A. *Supervised Learning-*

In Supervised learning, input vectors are presented to the network and a desired output or target output is also fed. The output computed by the ANN is compared with the target output and the difference (error) is measured. This error is then propagated back through the system, according to which the weights are tweaked. This process of tweaking the weights is done many times, so as to reduce the resulting error and achieve values as close to the target value as possible.

Supervised neural networks are applied in power system analysis in the following areas:

– Planning (long-term load forecasting)

- Operation (optimal power flow, static and dynamic security assessment, fault detection, fault location, system voltage stability assessment, short-term load forecasting, substation maintenance etc.)
- analysis (dynamic stability assessment, generator voltage and speed control system design both analogue and digital, identification of coherent dynamic equivalents, signal processing in harmonic analysis, bad data detection, monitoring and protection) [6].

B. Unsupervised Learning-

In Unsupervised learning, input vectors are presented to the network but desired output or target output is not given. As a result, the network does not use any external influences to adjust the weights. Instead, the system itself decides what changes are to be made, based on the regularities or trends it monitors in the input signals, and hence makes appropriate adaptations according to the function for which the ANN is designed. Unsupervised learning is therefore sometimes called as self-supervised or self-organizing learning.

C. Competitive Learning-

Some networks want a neuron to inhibit the other neurons in the same layer. This is called lateral inhibition. For example, in text recognition if the probability of a character being a "P" is 0.85 and the probability of the character being an "F" is 0.65, the network will choose the highest probability and inhibit all the others due to lateral inhibition. This is also known as Competition. In other words, the nodes compete with each other for the “right” to respond to the input vector. Only one node gets activated and gives output by simultaneously inhibiting all other competitors [7]. Competitive Learning is a form of Unsupervised Learning.

There is a notable difference between supervised and unsupervised learning. Unsupervised learning helps to organise complex features into classes whereas supervised learning will then calculate follow-up features for specific classes. Unsupervised networks can therefore be viewed as a data pre-processing step which reduces the size of the data set before learning the data's characteristics with supervised learning. For Security Assessment, the combination of an unsupervised step for operating space reduction and a supervised step for operating state classification has been applied by several researchers.

VI. APPLICATIONS OF ANN IN POWER INDUSTRY

A. Load forecasting-

Load forecasting is an important technique used in the Electrical power industry to predict the electrical load demand. Load forecasting is a difficult task as the load series is complex and also indicates several levels of casualties. Detailed models for electric power load forecasting are crucial in the operation, planning and management of load generation. It helps in making decisions regarding purchasing and generating electric power, load switching, and infrastructure development. Load forecasting can be classified into three categories: short-term forecasts which are usually from one hour to one week, medium forecasts which are usually from a week to a year, and long-term forecasts which are longer than a year. The forecasts for different time horizons are important for different operations within a utility company [8].

During Load forecasting many factors such as weekends, holidays, condition of weather, and unusual sports match days, festivals are to be lucratively considered. All such factors can be assessed with ANN’s ability to analyse with many input factors. ANN is suitable for load forecasting because of the availability of historical load data on the utility databases. Use of ANN has increased in forecasting as it can adjust the parameters for ANN inputs that have no functional relationship between them such as weather conditions and load profile. It also conducts off-line without time constraints, and has Direct coupling to the power system for data acquisition.

Short-term load forecasting over an interval ranging from a few minutes to a week is important for various applications such as economic load dispatch, unit commitment, real-time control, and energy transfer scheduling. It makes use of a combination of supervised and unsupervised learning patterns. Self-organizing feature map (SOFM) neural network has also shown impressive accuracy in short term forecasting. Mid-term load forecasting is estimated from one month to five years, and is chiefly used to buy adequate fuel for power plants after electricity tariffs calculations. Long-term load forecasting covers the range from 5 to 20 years or more, used by planning engineers and economists to determine the type and the size of generating plants that depreciate the fixed and variable costs [9].

B. Economic load dispatch -

Economic operation and a higher degree of reliability in the power system are required to gain profit on capital invested. Economic load dispatch (ELD) is a major issue of the present energy management system. The objective of Economic load dispatch is to determine the optimal output of available generating stations, at minimum fuel cost while serving the load demand and several operational limitations. For the optimal operation of power system, generating units must be adjusted in such a way that total cost of delivering power is minimum. The motive of power engineer is to minimize the total generator fuel cost or total generator cost and emission of thermal units while still fulfilling load and transmission losses.

ELD problem is the solution of mainly two problems, viz. the unit commitment and the online economic dispatch. Researchers and scientists have proposed various methods to overcome these problems. Newton-Raphson’s economic method, Beale’s quadratic programming, Linear programming techniques particularly dynamic programming, Lagrangian augmented function, Lagrangian relaxation method, Genetic Algorithms and ANNs are used. Lagrangian multiplier method can’t be applied directly as ELD is a non-convex optimization problem.

Dynamic programming approach is implied for practical-sized system having large number of units and the fine step size, resulting in the ‘curse of dimensionality’. It also uses Mathematical programming methods that include gradient method, linear programming or quadratic programming (QP). ANN and particularly Hopfield model is capable of solving combinational optimization problem. This model resolves the conventional ELD problems in units with continuous quadratic, piecewise quadratic, or cubic fuel cost functions. Many physical limitations like transmission capability limitations, losses in the transmission lines, constraints on unit's pollution, penalty factor are resolved using this model. The major problem in Hopfield neural network model is its slow converging speed. It is not suggested in non-linear cases.

Another method called as Augmented Lagrange Hopfield network (ALHN) is also used for solving the ED power loss problem. ALHN is a continuous Hopfield network with its energy function based on an augmented Lagrange function. In ALHN, the energy function is amplified from a Hopfield Neural network and penalty factors from Lagrangian function to damp out oscillation of the Hopfield network during the convergence process. This concludes that ALHN can overcome the drawbacks of the conventional Hopfield network by its optimal solution and faster convergence [10].

C. Security Assessment –

The main goal of security assessment is to evaluate the robustness of the system, to predict the vulnerability of possible events and to check the security level during and after any accidental situation. Security assessment can be seen as an algorithm that forecasts the future evolution of the system, assesses the probability of a security violation into a determined period of time, and determines if a preventive control action should be taken to prevent hazardous operating conditions [11].

Non-linear mapping of Multilayer perceptron (MLP) is utilized for on-line computation. Contingency ranking and sensitivity factor methods have reduced the number of critical contingencies to be computed. ANNs have played a challenging role in the security area. To overcome the problem of high dimensionality, the following approaches are used

1) Supervised ANNs similar to MLP are used to limit the number of contingencies and characterization of the security boundaries.
2) Unsupervised ANNs similar to Oja-Sanger networks reduce the dimension of the operating vector.
3) Clustered algorithm is used to quantify the operating point into a reduced number of classes.

Usually the ANNs that satisfy these conditions are MLP with Back Propagation (BP) learning algorithm. But there are two issues with MLP, viz. selection of proper input data and overtraining. These are resolved using the security indicators as input to ANN and BP with selective learning algorithm [12].

D. Fault detection/ diagnosis-

A quick response and well co-ordination is required to detect, isolate and then to rectify the fault. Fault diagnosis involves the detection of fault and accordingly getting it cleared. ANN are useful in classifying the failures in electrical apparatus and has been proven successful for years. Real time data is used in setting up the ANN. Not only it records the failure but also has the capability to reproduce them. The main advantage is that the diagnosis is carried out without interrupting the service or dismantling the switch.

Various fault detection methods such as quantitative model based methods, qualitative model based methods and data driven methods are used. Among these, data driven method is extensively used as it effectively captures the system's dynamic behaviour.

Multilayer perceptron (MLP) identifies the type and location of faults for the relevant conditions. Kohonen net (KN) handles the classification of fault patterns. MLP is preferred over KN as it is more accurate due to unsupervised learning. Radial basics function network (RBF) and Back propagation (BP) models are also used in fault diagnosis.

During transformer testing, all possible signals of faults are studied using ANN. After analysing, the ANN then acts as an experienced evaluator. During study of underground oil switches, ANN classifies the corrosive or non-corrosive state of switch. This helps in diagnosis without interrupting the service. Fault detection using ANN is also applied in electrical power transmission system. The three phase currents and voltages of one end are usually taken as inputs. The feed forward neural network along with Back Propagation (BP) algorithm has been employed for detection and classification of the fault. This results in analysis of each of the three phases involved in the process.

VII. CONCLUSION

An overview of ANN and its applications in Power System has been presented in this paper. The practical difficulties in electrical power industry and their proposed solutions using neural networks are reviewed. Neural Networks give improved performance and faster results over conventional techniques. Use of ANN is highly preferred in the Power System due to the following reasons:

– Can directly couple to Power System for data acquisition.
– High fault tolerance.
– Capable of solving combinational optimization problems.
– Quick in classifying the failures in the electrical apparatus.
– Adaptive capability.

ANN doesn't require additional memory for storing the history of load patterns. This increases accuracy and results in cost saving. ANN should be used in addition to the classical methods in power industry to ease the working of power system. ANN also has several drawbacks such as lack of end-user interaction, excessive computation time to process data, etc. To overcome these drawbacks, integration of ANN with other technologies such as Fuzzy sets, genetic algorithm, chaotic dynamics, etc could be considered for future research work.

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