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Applications of Artificial Neural Networks in Electric Power Industry: A Review

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Abstract

This paper presents an overview on applications of artificial neural network in electric power industry (EPI) which is currently undergoing an extraordinary development. One of the most thrilling and potentially cost-effective recent developments in this field is increasing usage of artificial intelligence techniques viz. artificial neural networks (ANNs), genetic algorithm, fuzzy logic, and expert systems. ANNs in particular, have involved enormous attention due to the variety of advantages they offer over the conventional methods. Among these advantages the ability to adapt, fast speed, massive parallelism, and robustness are the most profound. According to the growth rate of ANNs applications in different areas of power industry, this paper introduce a brief outline in economic load dispatch, load forecasting, and security assessment. Advantages and disadvantages of using ANNs in above mentioned areas and the main issues in these fields have also been explained.

Keywords: Artificial neural network, economic load dispatch, unit commitment, load forecasting, electric power industry, and security assessment.

Introduction

Mathematical optimization techniques have been used over the years in EPI for many power systems operations, planning, and control problems. Mathematical formulations of real-world problems are derived under certain assumptions and even with these assumptions; the solution of modern power systems is not simple. On the other hand, there are many uncertainties in power system problems because of their large, complex, and geographically widely distributed nature. It is desirable that the solution of such problems should be optimum globally, but solution searched by mathematical optimization techniques, in general, is optimum locally. These facts make it complicated to deal effectively with many problems in this area through strict mathematical formulation alone. Therefore, artificial intelligence techniques which guarantee a global optimum or nearly so, such as expert systems, genetic algorithm, fuzzy logic, and ANNs have emerged in recent years as a complement tool to conventional mathematical techniques. The real beginning of artificial intelligence is often quoted as 1958 McCarthy [17].

Work on ANN or a simply neural network has been motivated right from its inception by the recognition that the human brain computes in an entirely different way from the conventional digital computer [7]. In recent past years there has been a confluence of ideas and methodologies from several disciplinary areas to give rise to an extremely interesting research area known as ANN [4,15]. ANNs are parallel computational models comprised of densely interconnected adaptive processing units, called neurons. It is due to this adaptive nature, where learning by experience replaces programming in solving problem. This feature makes such computational models very appealing in application domains where one has little or incomplete understanding of the problem to be solved but where training data is readily available [6]. The biggest advantage of ANN is that it is a high speed online computational technique, which once trained through an offline algorithm using example patterns, can provide an output corresponding to a new pattern without any iteration in real time [22].

ANN applications in EPI can be categorized under three major areas viz. regression, classification, and combinational optimization. Applications involving regression mainly include forecasting and transient stability, and harmonic evaluation etc. while applications involving classification include harmonic load identification, static and dynamic stability analysis. The third area of combinational optimization includes unit commitment and capacitor control etc. The application of ANNs in these areas has lead to acceptable results [14].

Table I summarizes the number of published papers in IEEE proceedings and conferences about the application of ANNs in EPI in two time periods. The first time period is from 1990 to 1996 [14], while the second one is from 2001 to 2010. Comparison of the two columns can be considered as an evidence of successful or unsuccessful use of ANN in this area. It is to be noted that the following areas has attracted the most attention in the past eight years:

- Economic load dispatch
- Load forecasting
- Security assessment

In this paper we will discuss the applications of ANNs in Economic load dispatch (ELD), load forecasting, and security assessment.

ANN Theory and Model

ANNs are model of human brain developed artificially and they mimic the way brain processes information. The brain is a highly complex, non-linear, and parallel computer (information processing system) [7]. Basic building block of a brain is a nerve cell or a neuron. The brain is bundle of billions of these simple processing units. All units are heavily interconnected and operating in parallel. In brain, each neuron is known to obtain input values from other neurons, modifies the same through the application of a transfer function and sends its output to the next layer of neurons. These neurons in turn send their outputs to other neurons of the next layer in a cascaded manner [6].

ANNs are characterized by its pattern of connection between the neurons – called its architecture (number of layers), the method of determining the weights on the connection – called its training or learning algorithm, topology (connectivity pattern, feed forward or recurrent etc.) and its activation function [12].

Table I: ANN in Electric Power Industry-Survey Of Papers 1990-1996 And 2001 – 2010.

	No of published papers from 1990 to 1996	No of published papers after 2001 to 2010
Power System Engineering	ANN	ANN
A. Planning		
(a) Expansion		
o Generation	-	3
o Transmission	-	2
o Distribution	-	-
(b) Structural		
o Reactive power	1	-
(c) Reliability	-	1
B. Operation		
(a) Plant		
o Generation scheduling	-	8
o Economic load dispatch, opf	1	21
o Unit commitment	-	6
o Reactive power dispatch	1	3
o Voltage control	4	7
o Equipment monitoring	4	5
o Maintenance scheduling	3	2
o Security assessment	13	17
static/dynamic		
(b) System		
o Load forecasting	12	31
o State estimation	4	2
C. Analysis/Modeling		
(a) Power flow	4	9
(b) Harmonics	-	6
(c) Transient stability	5	14
(d) Dynamic stability	13	11
(e) Protection	7	7

Artificial Neuron

The artificial neuron shown in Figure -1[8] is the basic building block/processing unit of an ANN.

It is a mathematical function conceived as a crude model, or abstraction of biological neurons. These are the main constitutive units in an ANN. These neurons are similar to their biological counterpart in the sense that they generate an internal activation based on weighted summation of input signals [12]. It receives one or more inputs (representing the one or more dendrites) from the actual environment or from the other neurons and sums them to produce an output (synapse) which is given to other neurons or the environment [15]. Usually the sums of each node are weighted, and the sum is passed through a non-linear function known as an activation function or transfer function. This non-linearity makes the system powerful [15]. The transfer functions usually have a sigmoid shape, but they may also take the form of other non-linear functions, piecewise linear functions, or step functions. They are also often monotonically increasing, continuous, differentiable and bounded.

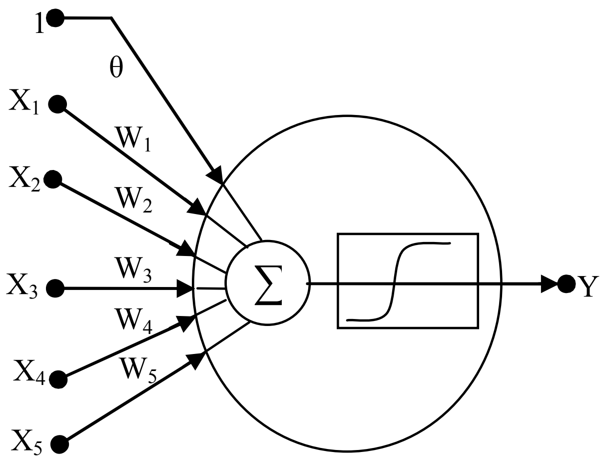

Figure 1: An Artificial Neuron.

An ANN may have of one or more layer of neurons.

Training

One of the most significant attributes of an ANN is its ability to learn or train by interacting with its environment or with an information source. Learning in an ANN is normally accomplished through an adaptive procedure, known as learning rule or algorithm, whereby the weights of the network are incrementally adjusted so as to improve a predefined performance measure over a time. Training can be of two types: supervised and unsupervised. In supervised a global error signal governs the adaptation of weights of the network, typically using an error correction or gradient descent method [6,7]. In unsupervised training the network create internal representations of the impinging vector stream using information that is locally available to a connection [6,7].

Back Propagation Algorithm

The gradient descent algorithm for multilayered feed forward neural networks where neurons have sigmoid signal functions is called the backpropagation learning algorithm [12]. It trains a neural network using a gradient descent algorithm in which the mean square error between the network's output and the desired output is minimized. This creates a global cost function which is minimized iteratively by back propagating the error from the output nodes to the input nodes. Once the network's error has decreased to less than or equal to the specified value, the network has converged and is considered to be trained.

ANNs Classification

Figure - 2 shows a general classification of ANNs. Literature survey conducted in the field of EPI suggests that Hopfield networks and feed forward networks using backpropagation algorithm are more common.

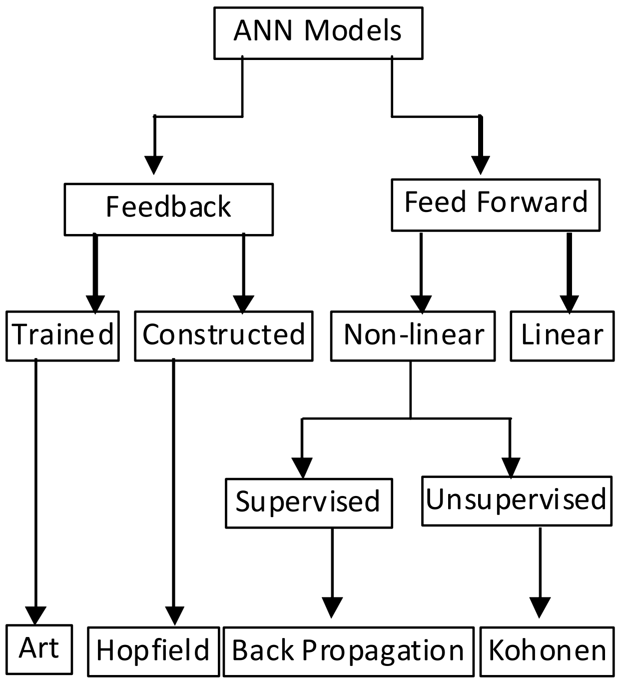

Figure 2

Economic Load Dispatch

The operation of a power system is characterized by maintaining a high degree of economy and reliability [20]. Among the options that are available to the power engineer in choosing how to operate the system, economic load dispatch (ELD) is the most significant. The ELD is one of the most important optimization problems in load flow analysis in an electric power industry and forms the basis of many application programs [16]. ELD problem basically, involves the solution of two different types of problems, namely the unit commitment and the online economic dispatch. The unit commitment is the selection of unit that will supply the anticipated load of the system over a required period of time at minimum cost as well as provide a specified margin of the operating reserve, known as the spinning reserve. The function of the online economic dispatch is to distribute the load among the generating units actually paralleled with the system in such a manner as to minimize the total cost of supplying the minute to minute requirements of the system [5,21]. Thus, ELD problem is the solution of a large number of load flow problems and choosing the one which is optimal in the sense that it needs minimum cost of electric power generation [19].

In practice, due to operational, environmental and economical limitations load always can not be allocated to the whole operating range of a unit. Many researchers and scientists have proposed various methods in the past for solving ELD problems such as Newton-Raphson's economic method, Beale's quadratic programming, linear programming techniques especially dynamic programming, Lagrangian augmented function, Lagrangian relaxation method, and most recently Genetic Algorithms and ANNs. The Lagrangian multiplier method, which is the most commonly used method in solving ELD problems, can not to be applied directly any longer as the ELD problem becomes a non convex optimization problem. Dynamic programming approach is one of the commonly used methods but for a practical-sized system having large number of units and the fine step size, frequently causes the 'curse of dimensionality'. Main issues of Tabu search and genetic algorithm used for solving ELD are longer search time, difficulty to define the fitness function, and finding the several sub-optimum solutions without the guarantee of locally optimum solution. On the other hand, ANNs in general and the Hopfield model in particular have a well-established potential of solving combinational optimization problem. This model can be used to solve the conventional ELD problems for units with continuous quadratic, piecewise quadratic, or cubic fuel cost functions.

Various types of physical constraints like transmission capability limitations, losses in the transmission lines, constraints on unit's pollution, penalty factor when we have special units etc. can be easily incorporated to this model of the network. It is due to this peculiar capability, solving ELD problem using this network becomes the main area of research and lots of papers have been published recently in this field. The chief problem of Hopfield neural network is its slow converging speed. This dilemma can be avoided by decreasing the limitations, but in nonlinear cases this is not suggested. Current attractive tools for solving ELD are neural networks based on fuzzy systems and genetic algorithm.

Load Forecasting

The forecasting of electricity demand has become one of the most important research fields in EPI as it plays a significant role in economic and financial development, expansion and planning of electric power systems. Load forecasting is however a difficult job [9]. First, because the load series is complex and exhibits several levels of seasonality: the load at a given hour is dependent not only on the load at the previous hour, but also on the load at the same hour on the previous day, and on the load at the same hour on the day with the same capacity in the previous week [9]. Secondly, because there are many vital exogenous variables that must be considered, especially whether-related variables [9]. Generally most of the papers and projects in this area are categorized into three groups:

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. A lot of research has been done with different methods for using of short-term load forecasting [8,9,23,27]. Some of these methods may be classified as follow: Kalman filtering [10], Box & Jenkins model, Regression model, Fuzzy inference, Neurofuzzy models, Expert systems, and Chaos time series analysis. Some of these methods have main restrictions such as difficulty to find functional relationship between all attribute variables and instantaneous load demand, difficulty to upgrade the set of rules that govern at expert system neglecting of some forecasting attribute condition, and disability to adjust themselves with rapid nonlinear system-load changes.

Mid-term load forecasting generally is considered from one month to five years, and is mostly used to buy adequate fuel for power plants after electricity tariffs are calculated [18].

Long-term load forecasting covers the range from 5 to 20 years or more, used by planning engineers and economists to find out the type and the size of generating plants that minimize both fixed and variable costs [8].

ANN is most suited for load forecasting because of the availability of historical load data on the utility databases. The majority of the projects using ANNs have considered lots of factors such as weekends, holidays, condition of weather, and unusual sport matches days in forecasting model, lucratively. This is because of learning ability of ANNs with many input factors. Main plus points of ANNs responsible for their increased interest in the field of forecasting are as: 1- Capability to adjust the parameters for ANN inputs that has not functional relationship between them such as weather conditions and load profile, 2-Being conducted off-line without time constrains, and 3- Direct coupling to power system for data acquisition [8,25,26].

Security Analysis

The foremost task of an EPI is to deliver the power requested by the customers, without exceeding acceptable voltage and frequency limits. This task has to be solved in real time with consistency and in economical and safe manner. Figure – 3 shows a simplified diagram of the main data flow in a power system where real-time measurements are stored in a database. The state estimation then adjusts awful and missing data. Based on the estimated values the existing mathematical model of the power system is established. Based on simulation of potential equipment outage, the security level of the system is determined. If the system is considered unsafe with respect to one or more potential outages, control actions accordingly have to be taken.

In general, there are two types of security assessments: static security assessment and dynamic security assessment [13]. In both types different operational states are defined as follows:

- Normal or secure state: In this state, all customer demands are met and operating limit is within existing limits.
- Alert or critical state: In this state the system variables are still within limits and constraints are satisfied, but little disturbance can lead to variable toward instability.
- Emergency or unsecured state: In this case, the power system enters the emergency mode of operation upon violation of security related inequality constraints.

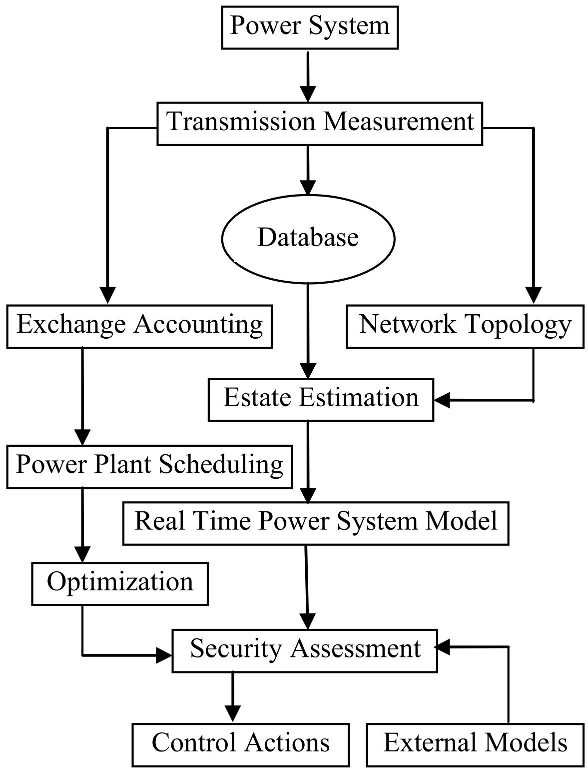

Figure 3

In realistic modern power systems the dimension of the operating system is very large. To overcome this curse of high dimensionality, following three main approaches are followed:

- Limit the number of contingences and characterization of the security boundaries. This is done with supervised ANNs similar to multi layer perceptron (MLP).
- Reduce the dimension of the operating vector; this is done with unsupervised ANNs similar to Oja-Sanger networks.
- Quantify of the operating point into a reduced number of classes, this is done with clustering algorithms for example the nearest neighbor or the k-means clustering algorithms.

Usually the ANNs that satisfy these conditions are MLP with backpropagation learning algorithm. The main motivation for this is on-line learning ability. There are two issues with using MLP, selecting of proper the input data and overtraining. An excellent technique for first issue is using some of the security indicators currently calculated by the energy management system as inputs to the ANN. To overcome the second issue, back propagation with selective learning algorithm is employed.

With the growth of EPI and energy demand and to have more reliable and secure energy, in most cases we see high dimensional problems with many limitations and constraints. To have the state of system fast, in addition to MLP network, nowadays Hopfield network has also been adopted.

Conclusion

In this paper the application of ANNs in electric power industry have been reviewed. ANN's advantages and disadvantages compared to other methods have also been discussed. Main advantages of using ANNs are:

- Very fast irrespective of the complexity of the problems
- On-line processing and classification
- Capability of handing with stochastic variations of the scheduled operating point with increasing data
- Implicit nonlinear modeling and filtering of system data automatically
- Massively parallel distributed structure and ability to learn

In spite of the plus points there are some negative points which are as under:

- Determination of various parameters like the number of hidden layers
- Number of neurons in the hidden layer
- Finding the optimal configuration of ANNs is a very time consuming process
- In contrast to conventional techniques or expert systems, which attempts to formalize knowledge and develop partial quality system models, ANN do not provide a formal representation of the relation between input and output data, it is therefore essential to test the ANN performance by statistical tools
- ANN suffers from the requirement of expert user in their design and implementation. They also suffer from a lack of the formal model theory and mathematical rigors and so are exposed to the experts' depth of knowledge in problem definition.

However, ANNs for power system should be viewed as an additional tool instead of a replacement for conventional or other AI based power system techniques. Currently ANNs rely on conventional simulations in order to produce training vectors and analysis the training vectors, especially with noisy data. There are some major issues to be tackled using ANNs for power system: training time, selection of training vector, upgrading of trained neural nets and integration of technologies. ANN with its promise of adaptive training and generalization deserves scope for further study.

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