MultiCraft

International Journal of Engineering, Science and Technology
Vol. 2, No. 3, 2010, pp. 1-7

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY
www.ijest-ng.com

Application of computational intelligence in emerging power systems

D. Saxena*, S.N. Singh+1 and K.S. Verma#

* *Department of Electrical and Electronics Engineering, Invertis Inst. of Engg.& Tech., Bareilly (UP), INDIA.*
+ *Department of Electrical Engineering, CET, Denmark Technical University, Kgs. Lyngby, DENMARK.*
# *Department of Electrical Engineering, K.N.I.T Sultanpur (UP), INDIA.*
E-mails: diptisx@gmail.com (D. Saxena), snsingh@iitk.ac.in (S.N. Singh [1], [1]Corresponding author), ksv02@rediffmail.com (K.S. Verma)

Abstract

Electric power systems, around the world, are changing in terms of structure, operation, management and ownership due to technical, financial and ideological reasons. Power system keeps on expanding in terms of geographical areas, assets additions, and penetration of new technologies in generation, transmission and distribution. This makes the electric power system complex, heavily stressed and thereby vulnerable to cascade outages. The conventional methods in solving the power system design, planning, operation and control problems have been very extensively used for different applications but these methods suffer from several difficulties due to necessities of derivative existence, providing suboptimal solutions, etc. Computation intelligent (CI) methods can give better solution in several conditions and are being widely applied in the electrical engineering applications. This paper highlights the application of computational intelligence methods in power system problems. Various types of CI methods, which are widely used in power system, are also discussed in the brief.

Keywords: Power systems, computational intelligence, artificial intelligence.

1. Introduction

Increased interconnection and loading of the power system along with deregulation and environmental concerns has brought new challenges for electric power system operation, control and automation. In liberalized electricity market, the operation and control of power system become complex due to complexity in modeling and uncertainties. Power system models used for intelligent operation and control are highly dependent on the task purpose. In competitive electricity market along with automation, computational intelligent techniques are very useful. As electric utilities are trying to provide smart solutions with economical, technical (secure, stable and good power quality) and environmental goals, there are several challenging issues in the smart grid solutions such as, but not limited to, forecasting of load, price, ancillary services; penetration of new and renewable energy sources; bidding strategies of participants; power system planning & control; operating decisions under missing information; increased distributed generations and demand response in the electric market; tuning of controller parameters in varying operating conditions, etc. Risk management and financial management in electric sector are concerned with finding an ideal trade-off between maximizing the expected returns and minimizing the risks associated with these investments.

Computational intelligence (CI) is a new and modern tool for solving complex problems which are difficult to be solved by the conventional techniques. Heuristic optimization techniques are general purpose methods that are very flexible and can be applied to many types of objective functions and constraints. Recently, these new heuristic tools have been combined among themselves and new methods have emerged that combine elements of nature-based methods or which have their foundation in stochastic and simulation methods. Developing solutions with these tools offers two major advantages: development time is much shorter than when using more traditional approaches, and the systems are very robust, being relatively insensitive to noisy and/or missing data/information known as uncertainty.

Due to environmental, right-of-way and cost problems, there is an increased interest in better utilization of available power system capacities in both bundled and unbundled power systems. Patterns of generation that results in heavy flows, tend to incur

[1] Corresponding author. Tel: +91-512-2597009

greater losses, and to threaten stability and security, ultimately make certain generation patterns economically undesirable. Hence, new devices and resrources such as flexible ac transmission systems (FACTS), distributed generations, smart grid technologies, etc. are being utilized. In the emerging area of power systems, computation intelligence plays a vital role in providing better solutions of the existing and new problems. This paper lists various potential areas of power systems and provides the roles of computational intelligence in the emerging power systems. A brief review of computational techniques is also presented.

2. Potential Area of Research in Power System Using Computational Intelligence

There are several problems in the power systems which cannot be solved using the conventional approaches as these methods are based on several requirements which may not be true all the time. In those situations, computational intelligence techniques are only choice however these techniques are not limited to these applications. The following areas of power system utilize the application of computational intelligence.

- Power system operation (including unit commitment, economic dispatch, hydro-thermal coordination, maintenance scheduling, congestion management, load/power flow, state estimation, etc.)
- Power system planning (including generation expansion planning, transmission expansion planning, reactive power planning, power system reliability, etc.)
- Power system control (such as voltage control, load frequency control, stability control, power flow control, dynamic security assessment, etc.)
- Power plant control (including thermal power plant control, fuel cell power plant control, etc.)
- Network control (location and sizing of facts devices, control of facts devices, etc.)
- Electricity markets (including bidding strategies, market analysis and clearing, etc.)
- Power system automation (such as restoration and management, fault diagnosis and reliability, network security, etc.)
- Distribution system application (such as operation and planning of distribution system, demand side management & demand response, network reconfiguration, operation and control of smart grid, etc.)
- Distributed generation application (such as distributed generation planning, operation with distributed generation, wind turbine plant control, solar photovoltaic power plant control, renewable energy sources, etc.)
- Forecasting application (such as short term load forecasting, electricity market forecasting, long term load forecasting, wind power forecasting, solar power forecasting, etc.)

Several research papers are published in various journals and conferences. Some conferences in the power system areas are completely dedicated to intelligent system applications and organized regularly such as intelligent system application to power systems (ISAP) held alternate years in different locations of the world. Power system computing conference is another very important conference held once in three years. Similarly, several reputed journals are dedicated to CI applications in the field of engineering and science. There are several books which address of CI application in power systems (Fogel *et al*, 1966; Sobajic, 1993; Song, 1996; Warvick, 1997; El-Hawary, 1998; Lai, 1998; Wehnekel, 1998; Momoh, 2000).

3. Various Computational Intelligence Techniques

Computational intelligence (CI) methods, which promise a global optimum or nearly so, such as expert system (ES), artificial neural network (ANN), genetic algorithm (GA), evolutionary computation (EC), fuzzy logic, etc. have been emerged in recent years in power systems applications as effective tools. These methods are also known as artificial intelligence (AI) in several works. In a practical power system, it is very important to have the human knowledge and experiences over a period of time due to various uncertainties, load variations, topology changes, etc. This section presents the overview of CI/AI methods (ANN, GA, fuzzy systems, EC, ES, ant colony search, Tabu search, etc.) used in power system applications.

3.1 Artificial Neural Networks

An artificial neural network (ANN) is an information-processing paradigm that is inspired by the biological nervous systems, such as the brain, process information (Bishop, 1995). The key element of this paradigm is the novel structure of the information processing system composed of a large number of highly interconnected processing elements (neurons) working in unison to solve the specific problems. ANNs, like people, learn by example. The starting point of ANN application was the training algorithm proposed and demonstrated, by Hebb in 1949, how a network of neurons could exhibit learning behaviour. During the training phase, the neurons are subjected to a set of finite examples called training sets, and the neurons then adjust their weights according to certain learning rule. ANNs are not programmed in the conventional sense, rather they learn to solve the problem through interconnections with environment. Very little computation is carried out at the site of individual node (neuron). There is no explicit memory or processing locations in neural network but are implicit in the connections between nodes. Not all sources of input feeding a node are of equal importance. It all depends on weight which can be negative or positive. Inputs arriving at a node are transformed according to the activation function of node.

The main advantages of ANNs are as follows:

- ANNs with suitable representation can model any degree of non-linearity and thus, are very useful in solving the non-linear problems.
- These do not require any apriori knowledge of system model.
- ANNs are capable of handling situations of incomplete information, corrupt data and they are fault tolerant.
- Massive parallelism provided by the large number of neurons and the connections amongst them provide good search and distributed representations.
- ANN is fast and robust. It possesses learning ability and adapts to the data.

Though the neural network (NN) training is generally computationally expensive, it takes negligible time to evaluate correct outcome once the network has been trained. Despite the advantages, some disadvantages of the ANN are: (i) large dimensionality, (ii) selection of the optimum configuration, (iii) choice of training methodology, (iv) the 'black-box' representation of ANN – they lack explanation capabilities and (v) the fact that results are always generated even if the input data are unreasonable. Another drawback of neural network systems is that 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 NN. Artificial neural networks are most promising method for many power system problems and have been used for several applications.

ANNs are mainly categorized by their architecture (number of layers), topology (connectivity pattern, feed forward or recurrent, etc.) and learning regime. Based on the architecture ANN model may be single-layer ANN which includes perceptron model (suggested by Rosenblot, in 1959) and ADALINE (suggested by Widrow & Hoff in 1960). ANN model can be further categorized as Feed forward NN and Feed Backward NN based on neuron interactions. Learning of ANN may be Supervised Learning, Unsupervised Learning, and Reinforcement Learning. Based on neuron structure ANN model may be classified as multilayer perceptron model, Boltzman machine, cauchy machine, Kohonen self-organizing maps, bidirectional associative memories, adaptive resonance theory-I (ART-1), adaptive resonance theory-2 (ART-2), counter propagation ANN. Some other special ANN models are parallel self-hierarchical NN, recurrent NN, radial basis function NN, knowledge based NN, hybrid NN, wavelet NN, cellular NN, quantum NN, dynamic NN, etc.

3.2 Genetic Algorithms

Genetic algorithm (GA) is an optimization method based on the mechanics of natural selection and natural genetics. Its fundamental principle is the *fittest member of population has the highest probability for survival.* The most familiar conventional optimization techniques fall under two categories viz. calculus based method and enumerative schemes. Though well developed, these techniques possess significant drawbacks. Calculus based optimization generally relies on continuity assumptions and existence of derivatives. Enumerative techniques rely on special convergence properties and auxiliary function evaluation. The genetic algorithm, on the other hand, works only with objective function information in a search for an optimal parameter set. The GA can be distinguished from other optimization methods by following four characteristics.

(i) The GA works on coding of the parameters set rather than the actual parameters.
(ii) The GA searches for optimal points using a population of possible solution points, not a single point. This is an important characteristic which makes GA more powerful and also results into implicit parallelism.
(iii) The GA uses only objective function information. No other auxiliary information (e.g. derivatives, etc.) is required.
(iv) The GA uses probability transition rules, and not the deterministic rules.

Genetic algorithm is essentially derived from a simple model of population genetics. It has five following components:

- Chromosomal *representation* of the variable characterizing an individual.
- An *initial population* of individuals.
- An *evaluation function* that plays the role of the environment, rating the individuals in terms of their *fitness* that is their aptitude to survive.
- *Genetic operators* that determine the composition of a new population generated from the previous one by a mechanism similar to sexual reproduction.
- Values for the *parameters* that the GA uses.

The advantages of GA over traditional techniques are as follows:

- It needs only rough information of the objective function and puts no restriction such as differentiability and convexity on the objective function.
- The method works with a set of solutions from one generation to the next, and not a single solution, thus making it less likely to converge on local minima.

- The solutions developed are randomly based on the probability rate of the genetic operators such as mutation and crossover as the initial solutions would not dictate the search direction of GA.

Major disadvantage of GA method is that it requires tremendously high computational time in case of the large variables and constraints. The treatment of equality constraints is also not well established in G.A. Alander (1996) has presented a bibliography of genetic algorithm in the power systems. GA has been widely used in the power system. There are several versions of GA available for different applications.

3.3 Fuzzy Logic

Fuzzy logic (FL) was developed by Zadeh (Zadeh, 1965) in 1964 to address uncertainty and imprecision, which widely exist in the engineering problems. FL was first introduced in 1979 for solving power system problems. Fuzzy set theory can be considered as a generalization of the classical set theory. In classical set theory, an element of the universe either belongs to or does not belong to the set. Thus, the degree of association of an element is crisp. In a fuzzy set theory, the association of an element can be continuously varying. Mathematically, a fuzzy set is a mapping (known as membership function) from the universe of discourse to the closed interval [0, 1]. Membership function is the measure of degree of similarity of any element in the universe of discourse to a fuzzy subset. Triangular, trapezoidal, piecewise-linear and Gaussian functions are most commonly used membership functions. The membership function is usually designed by taking into consideration the requirement and constraints of the problem. Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules.

Due to the use of fuzzy variables, the system can be made understandable to a non-expert operator. In this way, fuzzy logic can be used as a general methodology to incorporate knowledge, heuristics or theory into controllers and decision makers. The advantages of fuzzy theory are as follows:

(i) It more accurately represents the operational constraints of power systems and

(ii) Fuzzified constraints are softer than traditional constraints.

Momoh *et al.* (2000) have presented the overview and literature survey of fuzzy set theory application in power systems. A recent survey shows that fuzzy set theory has been applied mainly in voltage and reactive power control, load and price forecasting, fault diagnosis, power system protection/relaying, stability and power system control, etc.

3.4 Evolutionary Computation: Evolutionary Strategies and Evolutionary Programming

Natural evolution is a hypothetical population-based optimization process. Simulating this process on a computer results in stochastic optimization techniques that can often perform better than classical methods of optimization for real-world problems. Evolutionary computation (EC) is based on the Darwin's principle of 'survival of the fittest strategy'. An evolutionary algorithm begins by initializing a population of solutions to a problem. New solutions are then created by randomly varying those of the initial population. All solutions are measured with respect to how well they address the task. Finally, a selection criterion is applied to weed out those solutions, which are below standard. The process is iterated using the selected set of solutions until a specific criterion is met. The advantages of EC are adaptability to change and ability to generate good enough solutions but it needs to be understood in relation to computing requirements and convergence properties. EC can be subdivided into GA, evolution strategies, evolutionary programming (EP), genetic programming, classified systems, simulated annealing (SA), etc. The first work in the field of evolutionary computation was reported by Fraser in 1957 (Fraser, 1957) to study the aspects of genetic system using a computer. After some time, a number of evolutionary inspired optimization techniques were developed.

Evolution strategies (ES) employ real-coded variables and, in its original form, it relied on mutation as the search operator and a population size of one. Since then, it has evolved to share many features with GA. The major similarity between these two types of algorithms is that they both maintain populations of potential solutions and use a selection mechanism for choosing the best individuals from the population. The main differences are:

- ESs operates directly on floating point vectors while classical GAs operate on binary strings,
- GAs rely mainly on recombination to explore the search space while ES uses mutation as the dominant operator and
- ES is an abstraction of evolution at individual behavior level, stressing the behavioral link between an individual and its offspring, while GA maintains the genetic link.

Evolutionary programming (EP), which is a stochastic optimization strategy similar to GA, places emphasis on the behavioral linkage between parents and their offspring, rather than seeking to emulate specific genetic operators as observed in nature. EP is similar to evolutionary strategies, although the two approaches were developed independently. Like ES and GA, EP is a useful method of optimization when other techniques such as gradient descent or direct analytical discovery are not possible. Combinatorial and real-valued function optimizations, in which the optimization surface or fitness landscape is "rugged" and possessing many locally optimal solutions, are well suited for evolutionary programming.

3.5 Simulated Annealing

This method was independently described by Scott Kirkpatrick, C. Daniel Gelatt and Mario P. Vecchi in 1983 (Kirkpatrick *et al.*, 1983), and by Vlado CČerny in 1985 (Cerny, 1985). Based on the annealing process in the statistical mechanics, the simulated annealing (SA) was introduced for solving complicated combinatorial optimization problems. In a large combinatorial optimization problem, an appropriate perturbation mechanism, cost function, solution space, and cooling schedule are required in order to find an optimal solution with simulated annealing. SA is effective in network reconfiguration problems for large-scale distribution systems and its search capability becomes more significant as the system size increases. Moreover, the cost function with a smoothing strategy enables the SA to escape more easily from local minima and to reach rapidly to the vicinity of an optimal solution.

The advantages of SA are its general applicability to deal with arbitrary systems and cost functions; its ability to refine optimal solution; and its simplicity of implementation even for complex problems. The major drawback of SA is repeated annealing. This method cannot tell whether it has found optimal solution or not. Some other methods (e.g. branch and bound) are required to do this. SA has been used in various power system applications like transmission expansion planning, unit commitment, maintenance scheduling, etc.

3.6 Expert Systems

AI programs that achieve expert-level competence in solving the problems by bringing knowledge about specific tasks are called knowledge-based or expert systems (ES) which was first proposed by Feigenbaum *et al.* in the early 1970s (Feigenbaum *et al*, 1971). ES is a knowledge-based or rule based system, which uses the knowledge and interface procedure to solve problems that are difficult enough to be solved by human expertise. Main advantages of ES are:

(a) It is permanent and consistent
(b) It can be easily transferred or reproduced
(c) It can be easily documented.

Main disadvantage of ES is that it suffers from a knowledge bottleneck by having inability to learn or adapt to new situations. The knowledge engineering techniques started with simple rule based technique and extended to more advanced techniques such as object-oriented design, qualitative reasoning, verification and validation methods, natural languages, and multi-agent systems. For the past several years, a great deal of ES applications has been developed to prepare plan, analyze, manage, control and operate various aspects of power generation, transmission and distributions systems. Expert system has also been applied in recent years for load, bid and price forecasting.

3.7 Ant Colony and Tabu Search

Dorigo introduced the ant colony search (ACS) system, first time, in 1992 (Dorigo, 1992). ACS techniques take inspiration from the behavior of real ant colonies and are used to solve functional or combinational problems. ACS algorithms to some extent mimic the behavior of real ants. The main characteristics of ACS are positive feedback for recovery of good solutions, distributed computation, which avoids premature convergence, and the use of a constructive heuristic to find acceptable solutions in the early stages of the search process. The main drawback of the ACS technique is poor computational features. ACS technique has been mainly used in finding the shortest route for transmission network.

Tabu search (TS) is basically a gradient-descent search with memory. The memory preserves a number of previously visited states along with a number of states that might be considered unwanted. This information is stored in a Tabu list. The definition of a state, the area around it and the length of the Tabu list are critical design parameters. In addition to these Tabu parameters, two extra parameters are often used such as aspiration and diversification. Aspiration is used when all the neighboring states of the current state are also included in the Tabu list. In that case, the Tabu obstacle is overridden by selecting a new state. Diversification adds randomness to this otherwise deterministic search. If the Tabu search is not converging, the search is reset randomly.

TS is an iterative improvement procedure that starts from some initial solution and attempts to determine a better solution in the manner of a ‘greatest descent neighborhood’ search algorithm. Basic components of TS are the moves, Tabu list and aspiration level. TS is a metahuristic search to solve global optimization problem, based on multi-level memory management and response exploration. TS has been used in various power system application like transmission planning, optimal capacitor placement, unit commitment, hydrothermal scheduling , fault diagnosis/alarm processing, reactive power planning, etc.

3.8 Particle Swarm Optimization

The particle swarm optimization (PSO) method introduced by Kennedy and Eberhart (Kennedy *et al*., 1995) is a self-educating optimisation algorithm that can be applied to any nonlinear optimisation problem. In PSO, the potential solutions, called particles, fly through the problem space by following the best fitness of the particles. It is easily implemented in most programming languages and has proven to be both very fast and effective when applied to a diverse set of optimization problems. In PSO, the particles are "flown" through the problem space by following the current optimum particles. Each particle keeps the track of its coordinate in the problem space, which is associated with the best solution (fitness) that it has achieved so far. This implies that each particle has memory, which allows it to remember the best position on the feasible search space that has ever visited. This value is commonly called as *pbest* . Another best value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the neighborhood of the particle. This location is commonly called as *gbest*.

The position and velocity vectors of the i[th] particle of a d-dimensional search space can be represented as $X_i = (x_{i1}, x_{i2}, ...x_{id})$ and $V_i = (v_{i1}, v_{i2}, ...v_{id})$ respectively. On the basis of the value of the evaluation function, the best previous position of a particle is recorded and represented as $pbest_i = (P_{i1}, P_{i2}, ...P_{id})$. If the g^{th} particle is the best among all particles in the group so far, it is represented as $gbest = pbest_g (P_{g1}, P_{g2}, ..P_{gd})$. The particle tries to modify its position using the current velocity and the distance from $pbest$ and $gbest$. The modified velocity and position of each particle for fitness evaluation in the next iteration are calculated using the following equations

$$v_{id}^{k+1`} = w \times v_{id}^{k`} + c_1 \times rand_1 \times (pbest_{id} - x_{id}^k) + c_2 \times rand_2 \times (gbest_{gd} - x_{id}^k) \quad (1)$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1`} \quad (2)$$

where, w is the inertia weight parameter, which controls the global and local exploration capabilities of the particle. c_1, c_2 are cognitive and social coefficients and $rand_1$ and $rand_2$ are random numbers between 0 and 1. A large inertia weight factor is used during initial exploration and its value is gradually reduced as the search proceeds. The concept of time-varying inertial weight (TVIM) is given by

$$w = (w_{\max} - w_{\min}) \times \frac{iter_{\max} - iter}{iter_{\max}} + w_{\min} \quad (3)$$

where $iter_{\max}$ is the maximum number of iterations.

The velocity update expression (1) can be explained as follows. Without the second and third terms, the first term (representing inertia) will keep a particle flying in the same direction until it hits the boundary. Therefore, the first term tries to explore new areas and corresponds to the diversification in the search procedure. In contrast, without the first term, the velocity of the flying particle is only determined by using its current position and its best positions in history. Therefore, the second representing memory) and third terms (representing cooperation) try to converge the particles to their P_{best} and/or G_{best} and correspond to the intensification in the search procedure.

3.9 Support Vector Machines

Support vector machine (SVM) is one of the relatively new and promising methods for learning, separating functions in pattern recognition (classification) tasks as well as performing function estimation in regression problems. It is originated from supervised learning systems derived from the statistical learning theory introduced by Vapnik for "distribution free learning from data" (Vapnik, 1998). In this method, the data are mapped into a high dimensional space via a nonlinear map, and using this high dimensional space, an optimal separating hyper-plane or linear regression function is constructed. This process involves a quadratic programming problem and produces a global optimal solution. The great advantage of SVM approach is that it greatly reduces the number of operations in the learning mode and minimizes the generalization error on the test set under the structural risk minimization (SRM) principle. Main objective of the SRM principle is to choose the model complexity optimally for a given training sample. The input space in a SVM is nonlinearly mapped onto a high dimensional feature space. The idea is to map the feature space into a much bigger space so that the boundary is linear in the new space. SVMs are able to find non-linear boundaries if classes are linearly non-separable. Another important feature of the SVM is the use of kernels. Kernel representations offer an alternative solution by nonlinearly projecting the input space onto a high dimensional feature space. The advantage of using SVMs for classification is the generalization performance. SVM performs better than neural networks in term of generalization. There is problem of over fitting or under fitting if so many training data or too few training data are used. The computational complexity is other factor for the choice of SVMs as classifier. The other advantage of SVM based system is that it is straight forward to extend the system when new types of cases are added to the classifier.

4. Conclusion

The current interest in using the computation intelligence (CI) for power system applications is increasing amongst the researchers and academicians. It is noticed that huge amount of research papers and articles are available in all the area of engineering and science. There is no specific guideline for the application of CI techniques in the power systems. In this paper, various computational techniques widely used in power system applications are briefly described. The potential areas of CI application are also highlighted. New intelligent system technologies using digital signal processing techniques, expert systems, artificial intelligent and machine learning provide several unique advantages in solving the power system problems.

Acknowledgement

Authors acknowledge the suggestions and corrections made by Dr Guang Ya Yang, Centre of Electric Technology, Electrical Engineering Department, Denmark Technical University, Denmark. Dipti Saxena is grateful to the CM and Director, Invertis Institute of Engineering and Technology, Bareilly for permitting her to carry our PhD work from UP Technical University, Lucknow, India.

References

Alander J. T., 1996, *An indexed bibliography of genetic algorithm in power engineering*, Power Report Series 94-1.
Bishop C.M., 1995, *Neural networks for pattern recognition*, Oxford University Press, Oxford.
Cerny V., 1985, A thermodynamical approach to the travelling salesman problem: an efficient simulation algorithm. *Journal of Optimization Theory and Applications*, vol.45, pp.41-51.
Dorigo M., 1992, *Optimization, learning and natural algorithms*, PhD thesis, Politecnico di Milano, Italy.
El-Hawary, Mohamed E., 1998, *Electric power applications of fuzzy systems*, John Wiley USA.
Feigenbaum, E.A., Buchanan, B.G., Lederberg J., 1971, On generality and problem solving: A case study using the DENDRAL program, in *Machine Intelligence 6*, Edinburgh University Press.
Fogel L.J., Owens A.J., Walsh M.J., 1966, "*Artificial intelligence through simulated evolu*tion", Wiley, New York
Fraser A. S. 1957, Simulation of genetic systems by automatic digital computers, *I. Introduction.Australian. J. Biol. Sci.,* vol.10, pp.484–491.
Kennedy J., and Eberhart R., 1995, Particle swarm optimization, *Proc. of the IEEE Int. Conf. on Neural Networks*, Piscataway, NJ, pp. 1942–1948.
Kirkpatrick S., Gelatt C. D., Vecchi M. P., 1983, "Optimization by simulated annealing". Science. New Series 220, pp.671–680.
Lai, Loi Lei, 1998, *Intelligent system applications in power engineering: evolutionary programming and neural networks*, John Willey & Sons, UK.
Momoh James A., EL-Hawary Mohamed E., 2000, *Electric systems, dynamics, and stability with artificial intelligence*, Marcel Dekker, Inc. USA.
Sobajic Dejan J., 1993, *Neural network computing for the electric power industry*, Routledge Publisher, USA.
Song Yong-Hua Song, Johns Allan, Aggrawal Raj,1996. *Computation intelligence applications to power systems*, Kluwer Academic Publishers, USA.
Vapnik N., 1998, *Statistical learning theory*, John Wiley and Sons, New York.
Warwick K., Ekwue Arthur, Aggarwal Raj, 1997, *Artificial intelligence techniques in power systems*, IEE UK.
Wehenkel Louis A., 1998, *Automatic learning techniques in power systems*, Kluwer academic publisher, USA.
Zadeh L.A.,1965, *Information and Control*, vol. 8, no. 3, pp. 338-353.

Biographical notes:

D. Saxena obtained B. Tech. (Hons) in Electrical Engineering from KNIT Sultanpur (UP), India and M. Tech. in Process Control from Netaji Subhas Institute of Technology, New Delhi, India in 1999 and 2003, respectively. Presently, she is working as reader in Electrical and Electronics Engineering Department at Invertis Institute of Engineering And Technology, Bareilly. She is registered as PhD candidate in UP Technical University Lucknow, India. Her research interests are power quality, power electronics, control systems and DSP application in power.

S. N. Singh received M. Tech. and Ph.D. from Indian Institute of Technology Kanpur, India in 1989 and 1995, respectively. He is a Professor in the Department of Electrical Engineering, Indian Institute of Technology Kanpur, India. Presently he is on leave from IIT Kanpur and working with the Centre for Electric Technology (CET), Technical University of Denmark, Denmark. His research interests include power system restructuring, power system optimization & control, voltage security and stability analysis, power system planning, and ANN application to power system problems. He is a Fellow of IE (India), Fellow of IETE (India) and senior member of IEEE.

K.S. Verma received his B. Tech. (Hons) in Electrical Engineering and M. Tech. in Electrical Engineering (Power Systems) both from KNIT Sultanpur (India) in 1987 and 1998, respectively. He obtained his Ph.D. degree in Electrical Engineering (Power Systems) from Indian Institute of Technology, Roorkee, Roorkee (India) in 2003. Presently, Prof Verma is Director, KNIT Sultanpur (India). His research interests include FACTS Technology, distributed generation, power system optimization & control, power quality and AI application in power system.

Received February 2010
Accepted March 2010