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Ganesh K. Venayagamoorthy
Missouri University of Science and Technology

Ronald G. Harley

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Swarm Intelligence for Transmission System Control

G. K. Venayagamoorthy, *Senior Member, IEEE* and R. G. Harley, *Fellow, IEEE*

***Abstract*— Many areas related to power system transmission require solving one or more nonlinear optimization problems. While analytical methods might suffer from slow convergence and the curse of dimensionality, heuristics based swarm intelligence can be an efficient alternative. This paper highlights the application of swam intelligence techniques for solving some of the transmission system control problems.**

***Index Terms* — capacitor placement, FACTS placement, reactive power, swarm intelligence, transmission planning, voltage control.**

I. INTRODUCTION

THE North American power grid is the largest man-made machine in the world. It consists of synchronous generators, transformers, transmission lines, switches and relays, active/reactive compensators, loads and controllers. Various control objectives, operation actions and/or design decisions in such a system require solving a multiobjective constrained optimization problem.

The purpose of this panel paper is to present and summarize a few of the swarm intelligent techniques that can be used to provide solutions to the multiobjective constrained power system transmission problems.

II. SWARM INTELLIGENCE

Swarm intelligence is the property of a system whereby the collective behaviors of simple agents interacting locally with each other, directly or indirectly, and their environment, and cause coherent functional global patterns to emerge. A number of swarm intelligence algorithms exist today. These algorithms adhere to a number of principles namely – proximity, quality, diversity, stability and adaptability [26]. Some of these algorithms that have potential and have shown to be promising in providing solutions to power system transmission problems, are briefly described below.

A. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is an evolutionary computation technique, developed by Russell Eberhart and James Kennedy [15]-[[17] in 1995, and was inspired by the social behavior of bird flocking and fish schooling. PSO has its roots in artificial life and social psychology as well as in engineering and computer science. It utilizes a "population" of particles that "fly" through the problem hyperspace with given velocities. At each iteration, the velocities of the individual particles are stochastically adjusted according to the historical best position for the particle itself and the neighborhood best position. Both the particle best and the neighborhood best are derived according to a user defined fitness function [16], [18]. The movement of each particle naturally evolves to an optimal or near-optimal solution. The word "swarm" comes from the irregular movements of the particles in the problem space, now more similar to a swarm of mosquitoes rather than a flock of birds or a school of fish [18].

PSO is a computational intelligence based technique that is not largely affected by the size and nonlinearity of the problem, and can converge to the optimal solution in many problems where most analytical methods fail to converge. It can therefore be effectively applied to different optimization problems in power systems. A number of papers have been published in the past few years that focus on this issue. Moreover, PSO has some advantages over other similar optimization techniques such as Genetic Algorithm (GA), namely:

i. PSO is easier to implement and there are fewer parameters to adjust,
ii. In PSO, every particle remembers its own previous best value as well as the neighborhood best; therefore, it has a more effective memory capability than the GA,
iii. PSO is more efficient in maintaining the diversity of the swarm [24] (more similar to the ideal social interaction in a community), since all the particles use the information related to the most successful particle in order to improve themselves, whereas in GA, the worse solutions are discarded and only the good ones are saved; therefore, in GA the population evolves around a subset of the best individuals.

B. Ant Colony Optimization

The Ant Colony Optimization (ACO) algorithm was introduced by Dorigo in [19]. It is a probabilistic technique for solving computational problems, which can be reduced to finding good paths through graphs. They are inspired by the behavior of ants in finding paths from the colony to the food.

G. K. Venayagamoorthy is with the Real-Time Power and Intelligent Systems Laboratory, Department of Electrical and Computer Engineering, University of Missouri-Rolla, MO 65409, USA (email: gkumar@ieee.org).

R. G. Harley is with School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA (email: ron.harley@ece.gatech.edu)

In the real world, ants initially wander randomly, and upon finding food, they return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep traveling at random, but rather follow the trail, returning and reinforcing it if they eventually find food [20]. However, the pheromone trail starts to evaporate over time, therefore reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the quicker it takes for the pheromones to evaporate. A short path, by comparison, gets marched over faster and thus the pheromone density remains high as it is laid on the path as fast as it can evaporate. Pheromone evaporation also has the advantage of avoiding the convergence to a locally optimal solution. If there were no evaporation at all, the paths chosen by the first ants would tend to be excessively attractive to the ants following ones. In that case, the exploration of the solution space is constrained. Thus, when one ant finds a short path from the colony to a food source (i.e., a good solution), other ants are more likely to follow that path, and positive feedback eventually leaves all the ants following a single path.

The idea of the ant colony algorithm is to mimic this behavior with "simulated ants" walking around the graph representing the problem to solve. ACO algorithms have an advantage over simulated annealing and GA approaches when the graph may change dynamically, since the ant colony algorithm can be run continuously and adapt to changes in real time [20], [21].

C. *Bacteria Foraging Algorithm (BFA)*

Animals with poor foraging strategies (methods for locating, handling and ingesting food) are eliminated by the process of natural selection. This process in turn favors the propagation of genes of those animals that have been successful in their foraging strategies. Species who have better food searching ability are capable of enjoying reproductive success and the ones with poor search ability are either eliminated or reshaped. The BFA mimics the foraging behavior of the *E. coli* bacterium present in our intestines. This algorithm has been successful demonstrated as an optimization tool in a number of applications including power system harmonic estimation [23]. The foraging process consists of four stages: Chemotaxis, Swarming, Reproduction and Elimination [22].

D. *Population Based Immune Algorithms*

The biologically motivated information processing systems of human beings can he classified into brain-nervous systems, genetic systems and immune systems. A natural immune system is a very complex system with several mechanisms for defense against pathogenic organisms and maintenance against a hostile dynamically changing environment. According to immunology, an immune system is composed of a population of immune organs, immune cells and immune molecules. The Immune algorithm (IA) operates on a population of points in a search space simultaneously, not on only on one point. It works with a coded string representing the parameter, and not the parameter itself like an evolutionary strategy, and its rules for transition are probabilistic. IA has more merits and better characteristics which show the superior optimization performance than many other algorithms. The IA has been applied in power systems for voltage control [8].

III. Transmission System Applications

A. *Capacitor Placement*

Capacitor allocation plays an important role in transmission and distribution system planning and operation. Optimal placement of capacitors in a network can help reduce the losses, improve the power factor, improve the voltage profile, provide on the spot reactive power generation and therefore release the capacity of lines and feeders [196]. The nature of the problem is a nonlinear optimization approach which can be efficiently solved using PSO and ACO [13].

B. *FACTS Placement*

Power electronic devices have had a revolutionary impact on the electric power systems around the world. The availability and application of thyristors has resulted in a new breed of thyristors-based fast operating devices called Flexible AC Transmission System (FACTS) devices used for control and switching operations. FACTS devices, such as a STATCOM, a SVC, a SSSC and a UPFC can be connected in series or shunt (or a combination of the two) to achieve numerous control functions, including voltage regulation, system damping and power flow control. Heuristic approaches are traditionally applied to determining the location of FACTS devices, for instance, shunt FACTS devices are usually connected to the bus with the lowest voltage. These heuristics are sufficiently accurate in a small power system; however, more scientific methods are required in larger power networks. Traditional optimization methods such as mixed integer linear and non linear programming have been investigated to address this issue; however difficulties arise due to multiple local minima and overwhelming computational effort. Hernandez *et al.* have used PSO in finding the optimal STATCOM location and size in a medium size power system (45 bus power network) [11], [12]. In this case, the fitness function used in the PSO algorithm is defined based on the voltage profile throughout the power system, in a way that the voltage deviations of the buses, with respect to their corresponding nominal values, are minimized by installing a minimum STATCOM size. (The fitness function also contains the STATCOM size).

C. *FACTS Controllers*

Despite the various modern controller design techniques for power systems reported in literature, the power utilities still prefer conventional PI controllers. This is probably because of the simplicity and ease of tuning the controllers and the lack of confidence in the stability related to some adaptive control, variable structure control, and intelligent control. The conventional control of FACTS devices consists of Proportional plus Integral type (PI) action. The best performance of these FACTS devices is obtained by tuning the parameters of the PI control. Since power systems are highly nonlinear systems, with configurations and parameters that change with time, the classical controller design based on a linearized model of the power system cannot guarantee its performance in a practical operating environment. Thus, it is important to determine the parameters of the controllers for the FACTS devices using power system simulation models and tools where the nonlinear behavior of the power system is realizable but this becomes a challenge as the size of the system. Swarm intelligence has been reported in the design of controllers for SVC [25], STATCOM [8], UPFC [9], [10].

D. Reactive Power/Voltage Control

One of the important tasks of a power utility operator is to maintain the voltage profile within specified limits for high quality of services at each consumer load point. The variations in load and generation profiles during normal and abnormal operating states of a power system may worsen the voltage profile at different nodes. This is so because sustained or intermittent overvoltages ultimately lead to equipment insulation failure. On the other hand, under-voltages impact adversely on the system voltage stability margin and bulk power carrying capacity of transmission lines which, if left unchecked, can lead to steady state or dynamic voltage collapse phenomenon. Consequently, the operator in the control center re-dispatches the reactive power control devices such as generators, tap positions of on-load tap changers of transformers, static shunt capacitors and shunt reactors. As a result not only the voltage profiles are kept within the desired limits but also the power losses are reduced.

Over the years, many useful studies based on classical techniques for solving the reactive power dispatch problem have been carried out. This includes nonlinear programming (NLP), successive linear programming, mixed integer programming, Newton and quadratic techniques. Most of these approaches can be broadly categorized as constrained optimization techniques. Even though these techniques have been successfully utilized in some sample power systems, there are still several issues to be addressed with regard to real power systems. Undoubtedly, the reactive power control problem is essentially a global optimization with several local minima. The first obvious problem is where a local minimum is returned instead of a unique global minimum. The second difficulty is the inherent integer nature of the problem. Most control devices (transformer tap positions, shunt capacitor and reactor banks) have pre-specified discrete values. Thus no matter the accuracy of the continuous solution, it is impossible, without making some reasonable approximations, in order to assign these values directly to the physical control devices. Mixed integer programming could be helpful in dealing with these variables, but it seems to be more complicated than conventional continuous methods. Recently, swarm intelligence based techniques have been developed to solve reactive power and voltage control problems [3], [6], [14].

E. Power System Islanding

Even though power systems are designed to be tolerant to disturbances, they may become unstable during severe faults, especially when they are operated close to their stability limits. Studies show that many blackouts can be avoided and significant losses reduced if proper defensive islanding actions are taken in time prior to or following a catastrophe. Defensive islanding intentionally deployed to avoid larger losses, the power system will be running in a less versatile, but more robust abnormal state. Power system splitting especially for large scale power systems is a combinatorial explosion problem. Thus, it is very difficult to find an optimal solution (if one exists) for large scale power system in real time. Swarm based algorithms such as PSO have been applied to solve this problem [4], [5].

F. Transmission Planning

Multiple objectives are often considered simultaneously in practical transmission network planning. These objectives may be conflicting ones. It is difficult to find a single solution, which is optimal for all objectives. In this context, an appropriate compromised solution is determined. This complex problem is often simplified by the planners who use mathematical models to solve the transmission network planning problem, which consists of minimizing the investment costs of new transmission facilities, subject to operational constraints, to meet the power system requirements for a single future demand and generation configuration expected in a future year, which may be, for instance, 5, 10 or 20 years from now. The swarm approaches are ideal optimization methods for this kind of problem [7], [14].

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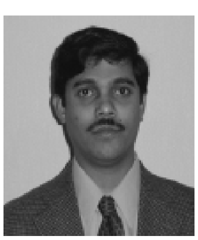

Ganesh Kumar Venayagamoorthy (S'91, M'97, SM'02) received the B.Eng. (Honors) degree with a first class honors in Electrical and Electronics Engineering from the Abubakar Tafawa Balewa University, Bauchi, Nigeria, and the MScEng and PhD degrees in Electrical Engineering from the University of Natal, Durban, South Africa, in March 1994, April 1999 and February 2002, respectively. He was a Senior Lecturer at the Durban Institute of Technology, South Africa prior to joining the University of Missouri-Rolla (UMR), USA in May 2002. He is currently an Associate Professor of Electrical and Computer and the Director of the Real-Time Power and Intelligent Systems Laboratory at UMR.

His research interests are in power systems stability and control, computational intelligence, alternatives sources of energy and evolvable hardware. He has published over 200 papers in refereed journals and international conference proceedings. Dr. Venayagamoorthy is a recipient of the following awards: a 2004 NSF CAREER Award, the 2006 IEEE Power Engineering Society (PES) Walter Fee Outstanding Young Engineer Award, the 2006 IEEE St. Louis Section Outstanding Section Member Award, the 2005 IEEE Industry Applications Society (IAS) Outstanding Young Member Award, the 2005 South African Institute of Electrical Engineers (SAIEE) Young Achievers Award, the 2004 IEEE St. Louis Section Outstanding Young Engineer Award, the 2003 International Neural Network Society (INNS) Young Investigator Award, a 2001 IEEE Computational Intelligence Society (CIS) Walter Karplus Summer Research Award and five prize papers with the IEEE Industry IAS and IEEE CIS. He is also a recipient of the 2006 UMR School of Engineering Teaching Excellence Award and the 2005 UMR Faculty Excellence Award. He is an Associate Editor of the IEEE Transactions on Neural Networks. He is a Senior Member of the SAIEE, a Member of INNS, the Institute of Engineering & Technology, UK, and the American Society for Engineering Education (ASEE). He is currently the IEEE St. Louis CIS and IAS Chapter Chairs, the Chair of the Task Force on Intelligent Control Systems and the Secretary of the Intelligent Systems subcommittee of IEEE PES and the Chair of the IEEE CIS Task Force on Power System Applications. Dr. Venayagamoorthy is listed in the 2007 edition of Who's Who in America.

Ronald G Harley (M'77-SM'86-F'92) received the MScEng degree (cum laude) in electrical engineering from the University of Pretoria, South Africa in 1965, and the Ph.D. degree from London University in 1969. In 1971 he was appointed to the Chair of Electrical Machines and Power Systems at the University of Natal in Durban, South Africa. At the University of Natal in South Africa he was a professor of Electrical Engineering for many years, including the Department Head and Deputy Dean of Engineering.

He is currently the Duke Power Company Distinguished Professor at the Georgia Institute of Technology, Atlanta, USA. His research interests include the dynamic behavior and condition monitoring of electric machines, motor drives, power systems and their components, and controlling them by the use of power electronics and intelligent control algorithms. Dr. Harley has co-authored some 380 papers in refereed journals and international conferences and three patents. Altogether 10 of the papers attracted prizes from journals and conferences. He is a Fellow of the British IEE, and a Fellow of the IEEE. He is also a Fellow of the Royal Society in South Africa, and a Founder Member of the Academy of Science in South Africa formed in 1994. During 2000 and 2001 he was one of the IEEE Industry Applications Society's six Distinguished Lecturers. He was the Vice-President of Operations of the IEEE Power Electronics Society (2003-2004) and Chair of the Atlanta Chapter of the IEEE Power Engineering Society. He is currently Chair of the Distinguished Lecturers and Regional Speakers program of the IEEE Industry Applications Society. He received the Cyrill Veinott Award in 2005 from the Power Engineering Society for "Outstanding contributions to the field of electromechanical energy conversion".