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A Survey on Application of Swarm Intelligence Computation to Electric Power System *

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Abstract - **Swarm intelligence computation is becoming an important topic in the field of artificial intelligence, and is successfully applied in a lot of fields, which is indicating fairly great potential for development. Recently, there are abundant reports on its practical applications in power system. In this paper, on the basis of describing three typical swarm intelligence algorithms: ant colony optimization, particle swarm optimization and population-based immune algorithm, the current research situation of the applications in the fields of economic dispatch of power system, unit commitment, reactive power optimization dispatch, generation expansion planning, capacitor placement, short-term load forecasting and optimal design is summarized. Finally, the central research directions of swarm intelligence computation in the future are proposed.**

Index Terms - Power system; Swarm intelligence computation; Ant colony optimization; Particle swarm optimization; Population-based immune algorithm

I. INTRODUCTION

Nowadays, science and technology are becoming intercrossed, pervasive and interactional. This is manifest in the field of computation science, especially for increasing the speed of computation and becoming more intelligent. Two huge challenges to computers are the large amount of computation and the need for real-time responses in practical engineering projects. It is necessary to find out some algorithms for large scale parallel computation. In recent years, swarm intelligence computation is attracting more and more attention of researchers, and it has a special connection with the evolution strategy and the genetic algorithm [1, 2]. With improvements of swarm intelligence and its applications, researchers are now using it to solve some practical optimization problems and it has showed an excellent effort in solving the combined optimization problems [3].

Because of the network connection of power systems and the further innovation of the electricity market, the power system is actually becoming a large scale nonlinear dynamic system, and a lot of complex engineering computations need to be solved. In a long period of time, the researchers of power system were always trying to find out some reliable and efficient methods. Recently, swarm intelligence has lots of successful applications in power system and it shows a great potential of applications [4, 5]. In this paper, we mainly introduce the theories and characters of swarm intelligence and summarize its representative algorithms and the newest applications in the field of power system.

II. SWARM INTELLIGENCE COMPUTATION

A. *The concept of Swarm Intelligence Computation*

Firstly, we introduce the concept of swarm intelligence. Swarm intelligence is an algorithm or a device, which is designed for solving distributed problems. It was illumined by the social behavior of gregarious insects and other animals [6]. Swarm intelligence depends on searching algorithms based on probability. Compared with the grads algorithm and traditional evolutionary computations, swarm intelligence has following characters: (1) The cooperating particle of the swarm is distributed; (2) There is no control and data of the center and the system is more robust; (3) It can realize cooperation with indirect communication instead of direct communication and the system is more easily to extend; (4) The ability of particle in the population is simple, the operating time of every particle is also very short and it is easy to be realized. So the system is simple [7]. Millonas has generalized five basic principles of swarm intelligence [8]: (1) contiguity principle (2) quality principle (3) diverse response principle (4) stability principle (5) adaptability principle. Millonas explained that the five basic principles above just described the common character of swarm intelligence, but not qualitative. Hence, if some kinds of behavior accord with the five basic principles, they should be classified as the swarm intelligence.

Swarm intelligence is the mutual behavior between environment and individuals based on the biology social system. It uses mathematical methods and computer tools to solve the problems, which are hard to establish efficient formalized models and are also very difficult to be solved by traditional optimization methods. Since 1990's, it has appeared two typical swarm intelligence algorithms. One is the ant colony optimization (ACO) [9] and the other is the particle swarm optimization (PSO) [10]. They are all heuristic stochastic search algorithms based on population's search of optimal resolution and they attract much attention in many fields. In recent years, the immune algorithm is active in many research fields. The Population-based immune algorithm [11] has achieved successful applications in engineering fields and it shows good potential of application. Because the characters

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of immune algorithm accord with the five basic principles of swarm intelligence, we classify the Population-based immune algorithm as swarm intelligence in this paper.

B. *Three typical Swarm Intelligence Algorithms*

ACO is proposed by Dorigo in 1991. It is an evolution algorithm which simulates the ants' behavior of searching food. ACO is inspired by research of trying to understand how almost blind ants establish the shortest path from their colony to their feeding sources and back. Essentially, it is found that ants use pheromone as the means of communication. As an ant moves, it lays varying amounts of pheromone, which are detectable by other ants, along its path, thereby marking the path by a trail of such substances. As more ants pass by, more pheromone is deposited on the path. Since ants chase after pheromone, the richer the trail of pheromone in a path, the more likely it would be followed by other ants. Therefore, the ants can establish the shortest way from their colony to the feeding sources and back [12]. Recently, ACO has been applied to solve a set of NP-hard problems with high dimension and some combined optimization problems, meanwhile some novel related systems have been proposed, such as max-mini ant colony system, ant colony system based on sequences [13].

PSO was originally designed by Kennedy and Eberhart. The technique involves simulating social behavior among individuals (particles) "flying" through a multidimensional search space, each particle representing a single intersection of all search dimensions. The particles evaluate their positions relative to a goal (fitness) at every iteration, and particles in a local neighborhood share memories of their "best" positions, then use those memories to adjust their own velocities, and thus subsequent positions [14]. PSO has the advantages of parallel computation, robustness and so on, and it can find out the global optimization solution with a higher probability and efficiency than traditional methods. The biggest advantage of PSO is easy to realize, fast converging and intelligent. It can be applied in both scientific research and engineering fields.

PBIA is a parallel and distributed adaptive system. It uses learning, memory, and associative retrieval to solve recognition and classification tasks [11]. Compared with other evolution algorithms, PBIA has following characters: (1) construct memory unit to ensure fast convergence; (2) compute affinity so that reflecting the diversity of real immune system; (3) Through restraining and advancing generations of antibody, realize the adaptive adjusting of immune responses. Because of these characters, PBIA can keep the diversity of colony, avoid getting into the local minimum and converge very quickly.

III. Applications of Swarm Intelligence in Power System

In recent years, applications of swarm intelligence in power system have gained lots of achievements. They are mainly in the fields of power system optimal operation and control, power system plan and power system optimal design.

A. *Economic Dispatch*

The economic dispatch model of power system is usually an optimization problem with no protruding and nonlinear constraints and it is hard to solve. Hou [15] proposes the generalized ant colony optimization (GACO) to solve the economic dispatch problem. It uses the forward feedback, distributed calculation and greedy illumination principle to search the optimal solution. It also applies the immovable point theory, and points out the sufficient conditions for convergence. But it can only solve simple economic dispatch problems. Then, Hou [16] integrates GACO with PSO. It applies PSO in the local search of GACO and uses GACO to carry out the global search and find out the spectrum of optimal solutions, meanwhile it uses PSO to carry out the local search to improve the precision and speed of the algorithm. Further, Hou [17] proposes an improved PSO. It brings the mutation, the disturbance and the partial search and so on into the basic PSO as special operators. The convergence speed and the precision of PSO are increased a lot. Based on the random analysis theory, it also proves that PSO can converge to the global optimal solution based on probability with any original colony whose distribution is random. Park [18] considers the cost function of generators as unsmooth subsection conic, and applies an improved PSO. This method makes the search space of every particle fit to the equation and inequation constraints by using one process mechanism of constraints. Meanwhile, it designs a dynamic space search reduction principle to increase the convergence speed of PSO. Tsay [19] considers the economic dispatch of unit generation companies under competitive market environment. The object function takes consideration of the cost of generation fuel, evacuating filth and spare cost of circumrotating. It also proposes an improved PBIA and uses an operator in which the competition mechanism and the adaptive adjust mechanism are crossed and evolved, so it effectively avoids premature convergence of the algorithm and can gain satisfying adjust. Zhao [20] applies PSO to calculate the dynamic economic dispatch model which considers the competition mechanism under power market. This model synthetically considers the constraints of climbing rate, line's capacity and release of polluted gas, so makes it more practical and meaningful. However, the power system in this paper is too simple.

B. *Unit Commitment*

Unit commitment is a large scale nonlinear hybrid integer programming problem, and it is an important method for improving the operation economy of traditional power system. Zhang [21] proposes an optimization algorithm for unit commitment based on the immune algorithm. It first uses the PRI method to create original colonies which can effectively reflect the problems' transcendent knowledge. Meanwhile it uses a kind of from back to front, from front to back and bidirectional circuity advancing condense program to improve the partial optimality of the individuals' available solution. The simulation results show that it has high convergence speed and nearly linear computation complexity when the size of system is enlarged. For solving the phenomenon of easy stagnancy in ACO algorithm, Hao [22] designs a novel ACO with random disturbance. It applies the disturbance operator with converse index curve and proposes the corresponding random selection strategy and disturbance strategy. Moreover, the cursory adjusting and the meticulous adjusting are used repeatedly to ascertain the parameter and its spectrum. This method can effectively avoid the ACO's weakness of having long computation time and easily to be stagnancy, and it has better ability of global optimization. Zhao [23] relaxes the zero-one variables in unit commitment and transforms this problem into a non-linear programming problem with continuous variable by penalty function. The improved PSO considers the information of not only its own individuals and global extremenesses but also other particles for the renewal of each particle's speed and position. Yuan [24] integrates an improved discrete binary particle swarm optimization (BPSO) with the standard PSO method for solving unit commitment (UC) problem with complicated constraints mixed-integer programming. The UC problem is decomposed into two embedded optimization sub problems: a unit on off status schedule problem with integer variables that can be solved by the BPSO and an economic dispatch problem with continuous that can be solved by the standard PSO method.

Recently, some researchers integrate swarm intelligence computation with other methods to solve unit commitment problems. Song [25] integrates PSO with Lagrange relaxation technology (LR) to update the Lagrange operator and improve the optimization efficiency. Liao [26] integrates IA, GA with FS to propose IGAFS. It first integrates GA with FS into IGA, which effectively improves the search ability of GA; meanwhile, applying chaos search technology and FS method to change the mutation rate and the cross rate for making IGAFS able to find out the globe optimization quickly and accurately.

C. *Reactive Power Optimization*

The balance of the reactive power in power system is important to ensure the voltage quality of power system. The reactive power optimization can sufficiently use the reactive power generator to improve the voltage quality, reduce the network's waste and increase the stability of voltage.

Zhang [27] applies PSO to solve the reactive power optimization problems in a practical large-scale power system. PSO can conveniently deal with the discrete and continuous variables and solve the problem whose constraints are out of the limits. However, it does not tell how to select variables when applying PSO. Esmin [28] uses HPSOM to ascertain the expiation of capacitor to reduce the waste of system networks. It is believed that the voltage collapsing point is the point which can effectively reduce system loss. Firstly apply the tangent vector technology to ascertain the critical area of voltage collapse and then use one kind of HPSOM which is added into mutation operator to ascertain the scheme of capacitor expiation in this area and the waste of nets can be effectively reduced. An immune algorithm (IA) [29] is proposed for power system reactive power optimization. Through calculation of affinity, the antibody is evaluated and the boost or restrain of its generation is determined, thus, the possibility of the evolutionary process falls into local optima is decreased. Through the memory mechanism, the ability of local search is improved; therefore, the calculation is speeded up. However, this thesis does not tell how to deal with the discrete and continuous variables in reactive power optimization. Chen [30] adds the cross operator and the mutation operator into the basic ACO and adaptively adjusts the volatilization modulus, so it effectively improves the globe search ability and the search speed of ACO. However, this thesis only tests the simple power system. Zhao [31] integrates multi-agent system (MAS) and particle swarm optimization algorithm (PSO) to solve the reactive power dispatch problem. An agent in MAPSO represents a particle to PSO and a candidate solution to the optimization problem. Making use of these agent-agent interactions and evolution mechanism of PSO, MAPSO realizes the purpose of optimizing the value of objective function. It gains good optimization results and supplies a new way. Guo [32] proposes an improved BPIA algorithm based on the clone selection to solve the reactive power dispatch problem. Based on the previous optimal antibody, this algorithm not only strengthens the partial search but also gives attention to the global search through parallel searching in both a small domain and a big domain, so it improves the search speed and precision. Meanwhile, it proposes a simple "cut" technology to deal with the discrete variable. Liu [33] proposes a chaotic PSO algorithm (CPSO) for the reactive power optimal flow problem. It avoids the premature convergence of PSO and it endows chaotic state search to particles, so improves the search ability of PSO.

D. *Transmission network expansion planning and generation planning*

Recently, applying swarm intelligence to plan transmission network and generation has many improvements. However, excellent solutions for these large scale complex nonlinear combined optimization problems have not been found yet.

Kannan [34] applies the void mapping program (VMP) and the penalized factor algorithm (PFA) into many kinds of heuristic search methods, and proposes one intelligent initialized party generator (IIPG). It effectively improves the calculation precision and reduces the calculation time. Through comparing with other traditional methods, it also analyses advantages and disadvantages of PSO and ACO. Jin [35] proposes a particle initialization method according to nonlinear simplex method. It can improve the quality of initialization particles, and accelerate the convergence speed of PSO. Furthermore, the oscillation phenomenon caused by the use of penalty function is also analyzed, and then it proposes an intercross iteration method for PSO calculation based on Dual Lagrange method. An electric transmission planning algorithm of multi-population central solution searching is proposed according to a new conception of computation resource's efficient allocation [36]. It uses the setting of memory cells of immune algorithm as reference, improves the memorizing efficiency by region memorizing in contrast to the usual point memorizing, and it can recognize and memorize local optimum effectively. What's more, it escapes from the local optimum by the information entropy describing of solution distances. To compensate limitations of single algorithm, Chen [37] proposes TS-ACO hybrid algorithm to solve the distribution network planning. It takes advantage of the forward feedback mechanism of ACO to overcome the decentralization of partial search in TS algorithm and it improves the partial search ability of TS when it is used for centralized partial search. Testing example shows that it has both the search advantages of ACO and TS, and it can effectively solve the planning problems.

E. *Capacitor optimization configuration*

Collocating capacitors reasonably and making it more optimal is actually a nonlinear mixed integer optimization problem, and its object function usually can not be gained. With increase of the transmission network size, the complexity of computation is increased quickly.

Huang [38] applies immune algorithm to solve the capacitor optimization configuration problem in distribution system network. It considers all kinds of constraints synthetically, using the investment cost and the least waste of system network as the object function and considering the object function and the constraints as the antibody. Using the computing mechanism based on the appetency to restrain or advance the antibody. Through iterative mutation, the thesis treats the best antibody as one optimal solution of the problem. However, this thesis has not considered the impacts of the harmonious wave. Yu [39] considers the aberrance of the harmonious wave, applying PSO to optimize the expiation capacitor. It disperses the PSO method for the dispersed variables in the model and simulates two systems. The results show that PSO can effectively gain the globe optimization of capacitor optimization configuration. Chiou [40] integrates ACO, hybrid difference evolution (HDE) with integer planning to solve capacitor configuration problems in large scale distribution system network. In order to gain the appropriate mutation operator of HDE, it applies the ACO search technology and the HDE's ability of global convergence during optimization is improved.

F. *Short-term load forecasting*

Short-term load forecasting is the basis of attempering generators' running, and its forecasting precision may affect the economic benefits of power system. Swarm intelligence computation has been applied to short-term load forecasting and has already shown good potential of application.

Based on analyzing the parameter performance of support vector machine (SVM), an immune support vector machines method for short-term load forecasting is presented in which the parameters are optimized by immune algorithm [41]. Through simulations of interactions between antigens and antibodies, the immune algorithm can effectively overcome the premature convergence and promote the diversity of colony. The results show that the presented immune SVM method can offer more accurate forecasting results than SVM method. Huang [42] applies the automatic regress move average model (ARMAX) to forecast the short-term load. It applies PSO to identify the ARMAX model and PSO can effectively avoid partial extremenesses of forecasting error function and converge to satisfying results quickly and accurately. This thesis only considers the impacts of temperature, but humidity, speed of wind, etc, have not been included.

G. *Optimization design*

Now, the PID controller is broadly applied to the control of power system, and swarm intelligence computation supplies the design of PID's parameters with a new way.

Gaing [43] applies PSO to optimize the PID's parameters in the automatic voltage regulating system (AVR). It proposes a novel PSO-PID controller and compares it with the GA-PID controller. Applying PSO can avoid the premature convergence of GA and be more robust and efficient. However, it has not discussed the selection of PSO's parameters. Zhan [44] applies ACO to the parameter’s optimization design of PID controller. Compared with GA, simulation results show that ACO is more practical and meaningful.

IV. CONCLUSION AND FUTURE WORK

In this paper, we introduce the swarm intelligence computation and its applications in power system. Because swarm intelligence does not need any precondition of centralized control and global model, it is very suitable to solve large scale power system nonlinear optimization problems which are hard to establish effective formalized models and difficult to be solved by traditional methods. In order to apply swarm intelligence better in power system, we propose two central research directions in the future: (1) The mathematical basis of swarm intelligence is unsubstantial and it lacks profound and pervasive theoretical analysis, so we must analysis its convergence and selection of parameters, especially the parameter selection of large scale power system optimization problems. (2) Because swarm intelligence is internally parallel, we should realize it based on the parallel computation theory. This work will also be helpful for the real-time need of power system.

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