A STUDY OF OPTIMIZATION TECHNIQUES FOR ELECTRIC POWER SYSTEMS

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Abstract: As the power systems are very bulky, compound, geographically widely distributed and are many unexpected events influence them so to solve power systems optimization problems are very difficult. It is therefore necessary to employ most effective optimization technique to take full advantages in simplifying the formulation and implementation of the problem. This article presents study of constraints in optimal solution optimization techniques, neural network. Fuzzy system, artificial intelligence (AI) techniques etc used in optimizing the electric power system problems.

I. INTRODUCTION

ELECTRICITY is a key commodity in modern societies. It not only powers our laptops and televisions, but it also provides us many of the basic items needed for living comfortably, e.g., heating, cooling and lighting, and facilitates economic growth. In fact, it is so ingrained in our way of life that many of us take it for granted. The reality is that the wide-spread availability of this commodity and its accessible cost are the result of the workings of one of man's most complex creations: electric power grids. These systems, which are also known as electric power networks, are collections of power generating sources and power consuming elements, or loads, interconnected through transmission lines, transformers and ancillary equipment. They can cover wide geographical regions and include tens of thousands of components. Significant resources are invested by governments and other organizations in order to improve the hardware and software used by these complex systems as well as the technical skills of its workforce

II. CHALLENGES

In general, optimization problems associated with electric power networks are challenging to solve. The reasons are numerous: First, power networks are characterized by non-convex equality constraints known as the power flow equations”. These constraints make it impossible for practical algorithms that consider these constraints to have global optimality or even feasibility guarantees. Second, many of the control devices used in power networks, such as switched shunt capacitors and tap-changing transformers, have a finite set of possible configurations, and hence accurate models require discrete variables. Third, most electric power networks have no fast energy storage. Energy that is consumed is essentially produced at the same time by some generator. When a contingency occurs, e.g. a generator or transmission line outage, a power imbalance can cause cascading failures and even a system-wide blackout in a matter of seconds. This is even more challenging when the economic forces are pushing systems to operate closer to their security limits. Therefore, optimization algorithms used during operations need to be timely in detecting problems and suggesting corrective actions. Lastly, uncertainty is becoming an important factor to consider due to the planned increase of variable and distributed generation, in particular solar and wind. Unfortunately, 146odelling this uncertainty within optimization problems significantly increases their size and complexity.

III. THE OPTIMIZATION PROBLEM

In case of optimization some parameters are set between predefined limits. Typically we look for the minimum or the maximum of the objective (or cost) function. In a simple case we have only one cost function, we call it Single Objective Optimization – SOO, in other cases we look for the optimum of more values. This is the Multi Objective Optimization – MOO. In the complicated energy sector we face mainly the MOO, e.g. the energy strategy.

Nowadays dozens of tools stay at disposal to solve the large optimization tasks by computer. In our case we concentrate on the problem definition and problem mapping. In the Single Objective Optimization (SOO) we look for min or max of a cost function (1) taking into account constraints:

Min/Max F(x) (1)

where F(X) is the cost or objective function. In MOO case the general formalization is [**Error! Reference source not found.**]:

$$Minimize\ F(x) = [F_1(x), F_2(x), F_3(x), \dots, F_k(x)]^T \quad (2)$$

IV. TASKS AND TECHNIQUES

An optimization problem is a mathematical model where main objective is to minimize undesirable things (e.g. cost, energy loss, errors, etc.) or maximize desirable things (e.g. profit, quality, efficiency, etc.), subject to some constraints. The main advantages of algorithmic methods include[**Error! Reference source not found.**]:

- Optimality is mathematically rigorous in some algorithms.
- Problems can be formulated to take advantage of the existing sparsity techniques applicable to large-scale power systems.
- There are a wide range of mature mathematical programming technologies, such as linear programming (LP)/interior point (IP) method and quadratic programming (QP), nonlinear programming (NLP), decomposition technique, integer and mixed integer programming, dynamic

programming (DP), etc.

- Solving the problem by different techniques we should arrive at the same conclusion. The difference of the approaches can be characterized by the time spent for the prototyping, the robustness in industrial environment. The numerous activities related to the operation of multilevel continent wide power system(s) require some optimum searching techniques [**Error! Reference source not found.**] [**Error! Reference source not found.**]:

1. Conventional optimization methods including
   - Unconstrained optimization approaches
   - Nonlinear programming (NLP)
   - Linear programming (LP)
   - Quadratic programming (QP)
   - Generalized reduced gradient method
   - Newton method
   - Network flow programming (NFP)
   - Mixed - integer programming (MIP)
   - Interior point (IP) methods
2. Intelligence search methods such as
   - Neural network (NN)
   - Evolutionary algorithms (EAs)
   - Tabu search (TS)
   - *Particle swarm optimization (PSO)*
3. Nonquantity approaches to address uncertainties in objectives and constraints
   - Probabilistic optimization
   - Fuzzy set applications
   - Analytic hierarchical process (AHP)

4.1 CONVENTIONAL METHODS

4.1.1 Unconstrained Optimization Approaches

Unconstrained optimization approaches are the basis of the constrained optimization algorithms. In particular, most of the constrained optimization problems in power system operation can be converted into unconstrained optimization problems. The major unconstrained optimization approaches that are used in power system operation are gradient method, line search, Lagrange multiplier method, Newton – Raphson optimization, trust – region optimization, quasi – Newton method, double dogleg optimization, and conjugate gradient optimization, etc.

4.1.2 Linear Programming

The linear programming (LP) - based technique is used to linearize the nonlinear power system optimization problem, so that objective function and constraints of power system optimization have linear forms. The simplex method is known to be quite effective for solving LP problems. The LP approach has several advantages. First, it is reliable, especially regarding convergence properties. Second, it can quickly identify infeasibility. Third, it accommodates a large variety of power system operating limits, including the very important contingency constraints. The disadvantages of LP - based techniques are inaccurate evaluation of system losses and insufficient ability to find an exact solution compared with an accurate nonlinear power system model. However, a great deal of practical applications show that LP - based solutions generally meet the requirements of engineering precision. Thus LP is widely used to solve power system operation problems such as security – constrained economic dispatch, optimal power flow, steady - state security regions, reactive power optimization, etc.

4.1.3 Nonlinear Programming

Power system operation problems are nonlinear. Thus nonlinear programming (NLP) based techniques can easily handle power system operation problems such as the OPF problems with nonlinear objective and constraint functions. To solve a nonlinear programming problem, the fi rst step in this method is to choose a search direction in the iterative procedure, which is determined by the first partial derivatives of the equations (the reduced gradient). Therefore, these methods are referred to as first - order methods, such as the generalized reduced gradient (GRG) method. NLP - based methods have higher accuracy than LP - based approaches, and also have global convergence, which means that the convergence can be guaranteed independent of the starting point, but a slow convergent rate may occur because of zigzagging in the search direction.

4.1.4 Quadratic Programming

Quadratic programming (QP) is a special form of nonlinear programming. The objective function of QP optimization model is quadratic, and the constraints are in linear form. Quadratic programming has higher accuracy than LP – based optimization is the generator cost function, which generally is a quadratic. Thus there is no simplification for such objective function for a power system optimization problem solved by QP.

4.1.5 Newton’s Method

Newton ’ s method requires the computation of the second - order partial derivatives of the power flow equations and other constraints (the Hessian) and is therefore called a second - order method. The necessary conditions of optimality commonly are the Kuhn – Tucker conditions. Newton ’ s method is favored for its quadratic convergence properties.

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4.1.6 Interior Point Methods

The interior point (IP) method is originally used to solve linear programming. It is faster and perhaps better than the conventional simplex algorithm in linear programming. IP methods were fi rst applied to solve OPF problems in the 1990s, and recently, the IP method has been extended and improved to solve OPF with QP and NLP forms.

4.1.7 Mixed-Integer Programming

The power system problem can also be formulated as a mixed - integer programming (MIP) optimization problem with integer variables such as transformer tap ratio, phase shifter angle, and unit on or off status. MIP is extremely demanding of computer resources, and the number of discrete variables is an important indicator of how diffi cult an MIP will be to solve. MIP methods that are used to solve OPF problems are the recursive mixed - integer programming technique using an approximation method and the branch and bound (B & B) method, which is a typical method for integer programming. A decomposition technique is generally adopted to decompose the MIP problem into a continuous problem and an integer problem. Decomposition methods such as Benders' decomposition method (BDM) can greatly improve efficiency in solving a large - scale network by reducing the dimensions of the individual subproblems. The results show a significant reduction of the number of iterations, required computation time, and memory space. Also, decomposition allows the application of a separate method for the solution of each subproblem, which makes the approach very attractive. Mixed - integer programming can be used to solve the unit commitment, OPF, as well as the optimal reconfiguration of electric distribution network.

4.1.8 Network Flow Programming

Network flow programming (NFP) is special linear programming. NFP was fi rst applied to solve optimization problems in power systems in 1980s. The early applications of NFP were mainly on a linear model. Recently, nonlinear convex network flow programming has been used in power system' optimization problems. NFP - based algorithms have the features of fast speed and simple calculation. These methods are efficient for solving simplified OPF problems such as security - constrained economic dispatch, multiarea systems economic dispatch, and optimal reconfiguration of an electric distribution network.

4.2 INTELLIGENT SEARCH METHODS

4.2.1 Optimization Neural Network

Optimization neural network (ONN) was fi rst used to solve linear programming problems in 1986. Recently, ONN was extended to solve nonlinear programming problems. ONN is completely different from traditional optimization methods. It changes the solution of an optimization problem into an equilibrium point (or equilibrium state) of nonlinear dynamic system, and changes the optimal criterion into energy functions for dynamic systems. Because of its parallel computational structure and the evolution of dynamics, the ONN approach appears superior to traditional optimization methods.

4.2.2 Evolutionary Algorithms

Natural evolution is a population - based optimization process. The evolutionary algorithms (EAs) are different from the conventional optimization methods, and they do not need to differentiate cost function and constraints. Theoretically, like simulated annealing, EAs converge to the global optimum solution. EAs, including evolutionary programming (EP), evolutionary strategy (ES), and GA are artificial intelligence methods for optimization based on the mechanics of natural selection, such as mutation, recombination, reproduction, crossover, selection, etc. Since EAs require all information to be included in the fi tness function, it is very diffi cult to consider all OPF constraints. Thus EAs are generally used to solve a simplified OPF problem such as the classic economic dispatch, security - constrained economic power dispatch, and reactive optimization problem, as well as optimal reconfiguration of an electric distribution network.

4.2.3 Tabu Search

The tabu search (TS) algorithm is mainly used for solving combinatorial optimization problems. It is an iterative search algorithm, characterized by the use of a flexible memory. It is able to eliminate local minima and to search areas beyond a local minimum. The TS method is also mainly used to solve simplified OPF problems such as unit commitment and reactive optimization problems.

4.2.4 Particle Swarm Optimization

Particle swarm optimization (PSO) is a swarm intelligence algorithm, inspired by social dynamics and an emergent behavior that arises in socially organized colonies. The PSO algorithm exploits a population of individuals to probe promising regions of search space. In this context, the population is called a swarm and the individuals are called particles or agents. In recent years, various PSO algorithms have been successfully applied in many power engineering problems including OPF.

4.3 APPLICATION OF FUZZY SET THEORY

The data and parameters used in power system operation are usually derived from many sources, with a wide variance in their accuracy. For example, although the average load is typically applied in power system operation problems, the actual load should follow some uncertain variations. In addition, generator fuel cost, VAR compensators, and peak power savings may be subject to uncertainty to some degree. Therefore, uncertainties due to insufficient information may generate an uncertain region of decisions. Consequently, the validity of the results from average values cannot represent the uncertainty level. To account for the uncertainties in information and goals related to multiple and usually conflicting objectives in power system optimization, the use of probability theory, fuzzy set theory, and analytic hierarchical process may play a significant role in decision - making.

The fuzzy sets may be assigned not only to objective functions, but also to constraints, especially the nonprobabilistic uncertainty associated with the reactive power demand in constraints. Generally speaking, the satisfaction parameters (fuzzy sets) for objectives and constraints represent the degree of closeness to the optimum and the degree of enforcement of constraints, respectively. With the maximization of these satisfaction parameters, the goal of optimization is achieved and simultaneously the uncertainties are considered. The application of fuzzy set theory to the OPF problem is also presented in Chapter 13 .

The analytic hierarchical process (AHP) is a simple and convenient method to analyze a complicated problem (or complex problem). It is especially suitable for problems that are very diffi cult to analyze wholly quantitatively, such as OPF with competitive objectives, or uncertain factors. The details of the AHP algorithm are given in Chapter 7 . AHP is employed to solve unit commitment, multiarea economic dispatch, OPF, VAR optimization, optimal load shedding, and uncertainty analysis in the power system.

V. CONCLUSION

This article has shed some light on the important mathematical optimization and AI techniques used in power system applications. Despite remarkable advances in mathematical optimization techniques,conventional mathematical methods have yet to achieve fast and reliable real timeapplications in power system applications. AI relies heavily on good problem description and extensive domain knowledge. ES, which is a knowledge-based system, suffers from a knowledgebottleneck by having an inability to learn or to adapt to new situations. Knowledge-based system can enhance the capabilities of a power system, whereas ANN can acquire knowledge through adaptive training andgeneralization. ANN, fuzzy, and ES suffer from the same requirement of expertuser in their design and implementation. They also suffer from a lack of theformal model theory and mathematical rigors and so are vulnerable to the experts'depth of knowledge in problem definition. Fuzzy theory with its of realisticdescription of power system problems and ANN with its promise of adaptivetraining and generalization deserves scope for further study. GA, by contrast,access deep knowledge of systems problem by well-established models. GA hasmuch more potential in power systems analysis and are also latest entry into the AI fields and are getting most of the current attention. GA needs to be understoodin relation to the computation requirements and convergence properties. Theapplication of hybrid systems in power system problems is a novel development,which represents a definite future trend in power systems research..

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