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A Comparative Survey for Optimal Power Flow Enhancement with Classical and Intelligent Techniques

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***Abstract*: Ideal Power Flow considered the back-bone tool in the complex power system. The growing in demands lead to expanding in generation that requires increment the transmission limit, consequently the issue of optimal power flow OPF still under numerous investigations so as to limit the cost, losses, emission of harm gases, and so forth. FACTS is the fundamental articles of this paper incorporate the last nontraditional OPF techniques, hybrid methods, multi-objective OPF, and OPF with FACTS gadgets. Likewise, there are three Tables contain the ongoing stander and hybrid methods used, mostly, in solving OPF problems with their merits, demerits, and their applications that may help the analysts in this field, in the long run some important points have been discussed.**

***Keywords*: Optimal power flow, FACTS.**

1. Introduction

Optimal power flow has an important for solving the complex problems in large power systems at many reality constraints. The problems are nonlinear, non-convex, non-differentiable, and non-smooth, so many researches adopted the modification of theories used for solving OPF based on minimizing the consuming time beside achieving the best fitness. For these reasons it might be of interest to represent the historical survey of the researches dealing with this field. In our work, generally, OPF researches are classified in two categories OPF and OPF with FACTS devices. The objectives of OPF without FACTS devices is made to minimize: 1) Total generation cost of thermal units. 2) Total real power loss of transmission system. 3) Gas emission from thermal units. 4) Voltage deviation of system buses.The first and second objectives could be taken as the main objectives for all optimization problems and could be considered as the own required objective to be solved, but the third and fourth objectives are often taken with the first two main objectives to be multi-objective OPF problem in order to obtain more and more modified state variables. In the case of OPF with FACTS devices the objectives are the same as listed above plus the additional objectives made to obtain5) Minimum capacity of the FACTS device(s).6) Optimal values of controlling variables.7) Optimal location of FACTS device(s). The last objective is made based on the sensitivity methods rather than the well-known OPF methods. The last two objectives are done to satisfy one or more of the other objectives, the problem can be extended to contain two or more of the above objectives to be multi-objective OPF. In addition, security constraints optimal power flow scope has the important partition in the OPF researches. However, our review not includes this subject. There are a lot of researches presents a review for OPF focusing on the methods used for solving economic dispatch tried to categorize the methods for OPF suitable for the certain objective(s) and compare the traditional OPF methods with AI methods and presents their advantages and drawbacks. When the effect of the large steam turbine valve is included in economic dispatch the characteristic of the cost has local minimum points and the method solving such problem known as the optimal dynamic dispatch ODD the literature review of the ODD and categorized their study to conventional methods, artificial intelligence methods, and hybrid methods they concluded that traditional methods like newton methods, lambda iteration method etc. are not effective for solving the non-convex and non-smooth problems but AI can obtain global optimization for this problem successfully with sacrificing more time, the hybrid methods can solve the problem faster. A history of OPF focusing on the power flow, economic dispatch, and OPF and review the most elements for solving PF and OPF, the authors concluded that even 50 years ago for the beginning the problem but at yet there is no theory could solve OPF commercially and showed that an approximation in solving the problem reduces consuming time that important for controlling variables but it causes a huge financial impact. All literature reviews acknowledged that covered the most of the bases, used at yet, for solving an optimal power flow. Although our research focusing on OPF with FACTS it is of interest to define the main fields of OPF studies. Economic dispatch calculation (EDC): is performed to dispatch, or schedule, a set of online generating units to collectively produce electricity at a level that satisfies a specified demand in an economical manner. Optimal power flow OPF: refers to full AC power problem solved to optimize real and reactive power flow subject to a certain constraint Multi-objective OPF: refers to optimization (minimize) two or more objective functions simultaneously subject to unignorable constraints DC OPF: refers to single objective OPF under assumption that all voltage magnitudes are fixed and all phase angles are close to zero, it is not refers to the solution of direct current power flow. Dynamic OPF: refers to include the effect of variation in variables in OPF calculation, for example the effect of valves that causes local optimization points On-line OPF: refers to the solution of OPF directly online, the OPF controlling system receives the information as sampling data and sends the commands in order to satisfy the optimization for the objective function. Security constraints SC OPF: refers to satisfy optimization after contingency being happens in the system. A contingency is defined as an event that causes one or more important components such as transmission lines, generators, and transformers to be unexpectedly removed from service.

2. Optimal power flow formulation

OPF is formulated mathematically as a general constrained optimization problem

Minimize a function F(u,x)

(1) Subject to h(u,x) = 0

(2) Devices, etc.

and g(u,x) ≥0 (3)

Where, u is the set of controllable quantities in the system and x is the set of dependent variables. F(u,x) is an objective function which is scalar. Equality constraints (2) are derived from conventional power balance equation. Inequality constraints (3) are the limits on control variables u and the operating limit on the other variables of the system

3. Classical conventional methods

Traditionally, conventional methods are used to effectively solve OPF. The application of these methods had been an area of active research in the recent past. The conventional methods are based on mathematical programming approaches and used to solve different size of OPF problems.

A. Linear programming method

Linear programming formulation requires linearization of objective function as well as constraints with nonnegative variables. T.S. Chung [6] presented recursive linear programming based approach for minimizing line losses and finding the optimal capacitor allocation in a distribution system. E. Lobato [7] proposed LP based OPF for minimization of transmission losses and Generator reactive margins of the Spanish power system. The discrete nature of shunt reactors and capacitors is modeled by integer variables. F. Lima [8] used Mixed Integer Linear Programming to conduct design study on the combinatorial optimal placement of Thyristor Controlled Phase Shifter Transformers (TCPSTs) in large-scale power systems.

B. Newton Rapson method

The necessary conditions of optimality referred to as the Kuhn-Tucker conditions are obtained in this method S. Chen [9] proposed a new algorithm based on Newton-Raphson (NR) method with sensitivity factors incorporated to solve emission dispatch in real-time So the penalty factor and the incremental losses are easily obtained. Execution time is lesser than that of the conventional one. K.L.Lo [10] proposed two Newton-like load flow methods, the Fixed Newton method and the modification of the right-hand-side vector method for line outage simulation that is a part of contingency analysis. X. Tong [11] presented the semi smooth Newton-type algorithms for solving OPF problems. It treated general inequality constraints and bounded constraints separately.

C. Quadrative programming method

It is a special form of nonlinear programming whose objective function is quadratic and constraints are linear J.A.Momoh [12] presented an extension of basic Kuhn-Tucker conditions and employing a generalized Quadratic-Based model for OPF. Computational memory and execution time required have been reduced. N. Grudinin [13] proposed a reactive power optimization model that was based on Successive Quadratic Programming (SQP) methods. SQP methods provide more fast and reliable optimization in comparison with the usual SLP method. SQP methods provide more fast and reliable optimization in comparison with the usual SLP method. G.P. Granelli[14] proposed Security constrained economic dispatch using dual sequential quadratic programming. It is compared with SQP method of NAG routine. It presents limited computation time and sufficiently good accuracy. X. Lin[15] integrated cost analysis and voltage stability analysis using an OPF formulation for competitive market, which was solved using sequential quadratic programming. A. Berizzi[16] presented Security– Constrained Optimal Power Flow (SCOPF) to determine optimal setting and operation mode of UPFC and TCPAR by the use of the HP (Han-Powell) algorithm. It is an efficient method that solves nonlinear problems with nonlinear constraints through the solution of successive quadratic problems with linear constraints.

D. Nonlinear programming method

Nonlinear programming (NLP) deals with problems involving nonlinear objective and/or constraint functions. J.A.Momoh[17] proposed a new nonlinear convex network flow programming (NLCNFP) model and algorithm for solving the security constrained multi-area economic dispatch (MAED) problem. This method has been tested on four interconnected power systems. It is feasible and effective. D.Pudjianto[18] used LP and NLP based reactive OPF for allocating (auctioning) reactive power among competing generators in a deregulated environment. NLP offers a faster computation speed and accuracy for the solution but the convergence could not be guaranteed for every condition. G.L.Torres [18] J.Z.Zhu [18] suggested the methods to calculate the price of reactive power support service in a multi-area power system. A.K. Sharma [20] had proposed a method to determine optimal number and location of TCSC using Mixed Integer Nonlinear

Table 1
Summary of discussion

S. No.	Method	Objective Used for	Merits	Demerits
1	LINEAR PROGRAMMING	Economic dispatch	1) To solve many diverse combination problems 2) Helps in Re-evaluation process- linear programming helps in changing condition of the process or system. 3) Linear programming is adaptive and more flexibility to analyze the problems. 4) The better quality of decision is provided.	1) Linear programming works only with the variables that are linear. 2) The idea is static; it does not consider change and evolution of variables. 3) Nonlinear function cannot be solved over here. 4) Impossibility of solving some problem, which has more than two variables in graphical method.
2	NEWTON RAPSON	Economic dispatch	1) best fastest convergences to the root 2) Apart from the fast convergences, it also converges quadraticly on the root. 3) This method leads to basically 'polish' a root from the other convergence techniques. 4)this method is that it is flexible; it means that it is easier to convert this method to multiple dimensions	1) Each iteration of Newton's method requires solving a large linear system of equations, which for large-scale problems can be prohibitively expensive.
	QUADRATIVE PROGRAMMING	Reactive power optimization and Social welfare	1) execution time required had been reduced 2) more fast and reliable optimization in comparison with the usual SLP method	1) QP problem is to use an extension of the Simplex method or an extension of the Interior Point or Barrier method.
4	NONLINEAR PROGRAMMING	Reactive power optimization and Security constrain	1) It is feasible and effective 2) faster computation speed and accuracy	1)penalty algorithms, i.e. that too large penalty parameters
5	INTERIOR POINT	Reactive power optimization and Security constrain	1) number of iterations is not very sensitive to network size 2) robustness	1)multivariable nonlinear programming problem
6	ARITIFICIAL INTELLEGENCE	Economic dispatch with non-smooth cost function and Optimal location of FACTS device, Reactive power optimization, Congestion management	1) Less Errors: errors are reduced and the chance of reaching accuracy with a greater degree of precision is a possibility.	1)high cost 2)Highly dependent on machines
7	FUZZY LOGIC	Economic – Emission dispatch	1)high precision 2) rapid operation	1) Restricted no of usage of input variables

Programming (MINLP) approach in the deregulated electricity markets.

E. Interior point method

Karmarkar proposed a new method in 1984 for solving large-scale linear programming problems very efficiently. It is known as an interior method since it finds improved search directions strictly in the interior of the feasible space. Sergio Granville [18] presented application of an Interior Point Method to the optimal reactive power dispatch problem. It is based on the primaldual logarithmic barrier method as described by Monteiro and Adler. The proposed method has the following advantages: number of iterations is not very sensitive to network size or number of control variables, numerical robustness, hot starting capability, no active set identification difficulties and effectiveness in dealing with optimal reactive allocation and loss reduction problems. Whei-Min Lin[20] presented the use of Predictor-Corrector Interior-Point Nonlinear Programming (PCIPNLP) algorithm to solve social welfare maximization problem incorporating FACTS devices in a deregulated market structure. The advantage of the method is the inequality–constraint handling capabilities. Ding Xiaoying [20] presented an Interior Point Branch and Cut Method (IPBCM) to solve decoupled OPF problem. The Modern Interior Point Algorithm (MIPA) is used to solve Active Power Suboptimal Problem (APSOP) and use IPBCM to iteratively solve linearizations of Reactive Power Suboptimal Problem (RPSOP). The advantages of the proposed method are: The variables and constraints of RPSOP are lesser than that of original OPF problem, which will enhance the calculation speed. Wei Yan[20] presented the solution of the Optimal Reactive Power Flow (ORPF) problem by the Predictor Corrector Primal Dual Interior Point Method (PCPDIPM). Total calculation time needed for the proposed method is always shorter than that for the conventional model.

F. Artificial intelligence method

To overcome the limitations and deficiencies in analytical methods, Intelligent methods based on Artificial Intelligence (AI) techniques have been developed.

1) Artificial neural network

ANN is an interconnected group of artificial neurons that uses a mathematical model or computational model for information processing based on a connectionist approach to computation. Chowdhury [19] had suggested concept of Integrated Security Constrained Optimal Dispatch (ISCOD) which could solve the OPF problem when it was constrained by both static and dynamic security. N.I. Santoso et al. [26] presented a two-stage Artificial Neural Network to control in real time the multi tap capacitors installed on a distribution system for a nonconforming load profile such that the system losses are minimized.

2) Fuzzy logic method

It is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical predicate logic. Miranda et al. [27] gave a fuzzy model to represent uncertainty in loads and generation as fuzzy numbers. While uncertain injections were dealt with D.C. fuzzy power flow model. System optimal operation was calculated with Dantzing Wolfe decomposition technique and dual simplex method. V.C. Ramesh et al. [28] presented a Fuzzy Logic approach for the contingency constrained OPF problem formulated in a decomposed form that allows for post-contingency corrective rescheduling. N.P.Padhy [29] presented an efficient hybrid model for congestion management analysis for both real and reactive power transaction under deregulated Fuzzy environment of power system. The proposed model determines the optimal bilateral or multilateral transaction and their corresponding load curtailment in two stages. In the first stage classical gradient descent OPF algorithm has been used to determine the set of feasible curtailment strategies for different amount of real and reactive power transactions. In second stage, fuzzy decision opinion matrix has been used to select the optimal transaction strategy.

3) Miscellaneous AI methods

Chowdhury et al. [34] proposed Expert System (ES) which was used in combination with a transmission constrained economic dispatch to provide real time security. The ES then determines the best possible control measure using rules on voltage and line flow control. The purpose of the expert system is to expeditiously remediate voltage and branch over load problems. H.Mori et al. [35] presented a Parallel Tabu Search (PTS) based method for determining optimal allocation of FACTS devices in competitive power systems. Available Transfer Capability (ATC) was maximized with the FACTS devices.

4. Summary of the discussion

The following table shows the suitable methods for solving the various optimization problems with their merits and demerits listed in the Table 1.

5. Conclusion

Different improvement techniques used to take care of OPF issues. Despite the fact that, astounding headways have been made in established strategies, they endure with the accompanying inconveniences: In many cases, numerical definitions must be streamlined to get the arrangements in light of the amazingly restricted ability to tackle genuine expansive scale control framework issues. They are powerless in dealing with subjective limitations. They have poor convergence, may get stuck at local optimum, they can find only a single optimized solution in a single simulation run, they become too slow if number of variables are large and they are computational extensive and they are computationally costly for arrangement of an expansive framework. Computer based intelligence strategies can locate numerous ideal arrangements in single reproduction run. So they are very reasonable in taking care of multi-target streamlining issues. By and large, they can locate the worldwide ideal arrangement. The fundamental points of interest of ANN are: Possesses learning capacity, quick, appropriate for non-linear modeling, etc.

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