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A Comprehensive Literature Survey on Recent Methods of Optimal Power Flow

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Abstract:*Over the historyof five decades, Optimal Power Flow (OPF) has become one of the most important and extensivelyconsidered nonlinear optimization problems. In general, OPF needs to optimize the operation of electric power generation, transmission and distribution networks subjectedto varioussystem constraints and control limits. However, there is an extremely wide and variety of OPF formulations and solution techniques. Moreover, the character of OPF continues to evolve due to recent electricity markets and renewable resource integration. In this survey, both the conventional, intelligent OPF methods and both in the presence of Flexible Alternating Current Transmission Systems (FACTS) are surveyed in order to present a sound context for the state of the art in OPF formulation and solution methods. The survey contributes a comprehensive conversation of specific optimization techniques that have been applied to OPF, with an emphasis on the merits, drawbacks of each method of both conventional and intelligent methods of OPF.*
Keywords: *Optimal Power Flow, Power System, System Constraints, Intelligent Methods and FACTS.*

I. Introduction:

The Optimal Power Flow (OPF) problem has been one of the most extensively studied subjects in the power system since Carpentier first published a paper in 1962 [1]. The objective of an Optimal Power Flow (OPF) algorithm is to get a steady state solution which minimizes generation cost, system loss etc. or maximizes social welfare or system utilization etc. while maintaining an acceptable system performance in terms of limits on generator's active and reactive powers, line flow limits and maximum output of different compensating devices etc. The general OPF problem is a non-convex, nonlinear, large-scale optimization problem which may contain both continuous and discrete control variables [2]. Several OPF formulations have been developed to address specific instances of the problem, using varying assumptions and selecting different objective functions, system constraints and controls. The consequential optimization problems go by many names depending on the particular objective function being addressed and the constraints under consideration. Regardless of the name, any power systems network optimization problem that includes a set of power flow expressions in the constraints may be classified as a form of OPF.

Many OPF solution methods have also been developed, each with distinct mathematical characteristics and computational necessities. Almost each mathematical programming approach that can be applied to OPF has been attempted and it has taken developers many decades to develop software capable of solving OPF problems reliably [3].Today, OPF studies and methods present flexible and powerful tools which are widely used in industry applications, such as constrained economic dispatch and voltage control problems [4]. However, real-time OPF problems are frequently more significant and challenging than the classically considered problems and OPF methods vary considerably in their adaptability to the modeling and solution needs of different engineering applications. Therefore, there has been no single formulation and solution approach suitable for all the various types of OPF problems.

In this survey,The OPF methods are broadly classified as Conventional and Intelligent methods. The conventional methodologies comprises of well-known techniques like Newton method, Gradient method, Quadratic Programming method, Linear Programming method and Interior point method. Intelligent methodologies include the popular methods developed recently such as artificial neural networks, Fuzzy, Genetic Algorithm, Particle swarm optimization and some of the latest OPF formulations with FACTS devices are presented below.

II. Optimal Power Flow Problem

In an OPF solution methodology, the values of some or all of the control variables arerequire to found so as to optimize (minimize or maximize) a specific objective. It is also important that, the proper problem formulations with clearly declared objectives are to be needed to find the best solution. The superiority of the solution depends on the accuracy of the model considered. Objectives ought to be modeled and its practicality with possible solutions. The OPF problem solution aims to optimize a chosen objective function via optimal adjustment of the power system control variables, while satisfying different equality and inequality constraints. The OPF problem can be formulated mathematically is as follows:

Min J(x,u)

Subject to: g(x,u) =0

$h_{min} \le h(x,u) \le h_{max}$

where J is objective function to be minimized.x is the vector of dependent variables (state vector) u is the vector of independent variables (control variables) consisting of:

1. Generator voltage VG at PV buses.
2. Real power output of generators PG at PV buses except at the slack bus PG_1.
3. Tap settings of transformer T.
4. Shunt VAR compensators.

$u^T = [PG_1 \ldots PG_{NG}, V_{G1} \ldots V_{GNG}, Qc_1 \ldots Qc_{Nc}, T_1 \ldots T_{NT}]$

Where, NT and NC are the number of the tap changing transformers and VAR compensators, respectively.

g is the equality constraints and

h is operating constraints

Some of the most common objectives of OPF can be recognized as:

Active power objectives

1. Economic dispatch such as minimum cost andminimum losses.
2. Environmental dispatch
3. Maximum power transfer

Reactive power objectives

MW and MVAr loss minimization

General goals

1. lowest amount ofvariation from a target schedule
2. least amount of control shifts to alleviate Violations
3. slightest absolute shift approximation of control shift

Among the above, the following objectives are most commonly used:

1. Total generator fuel cost optimization
2. Active power loss minimization
3. VAr planning to minimize the cost of reactive power support.

The minimization problem is subjected to the following two categories of constraints:

Equality Constraints: These are the sets of nonlinear power flow equations that govern the power systems, i.e.,

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i| |V_j| |Y_{ij}| \cos (\theta_{ij} - \delta_i + \delta_j) = 0 \ldots(1)$$

$$Q_{Gi} - Q_{Di} + \sum_{j=1}^{n} |V_i| |V_j| |Y_{ij}| \sin (\theta_{ij} - \delta_i + \delta_j) = 0 \ldots(2)$$

where, $P_{Gi}$and Q_{Gi} are the real and reactive power outputs injected at bus-i respectively, the load demand at the same bus is represented by P_{Di} and Q_{Di}, and elements of the bus admittance matrix are represented by $|Y_{ij}|$.

Inequality Constraints: These are the set of constraints that represent the system operational and security limits like the bounds on the following:

1. Real and reactive power outputs of generators.

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}, i=1,2,\ldots\ldots,N_G \quad \ldots(3)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}, i=1,2,\ldots\ldots,N_G \ldots(4)$$

2. Voltage magnitudes at each bus in the system

$$V_i^{min} \le V_i \le V_i^{max}, i=1,2,\ldots\ldots\ldots,N \ldots(5)$$

3. Tap settings of transformer

$$T_i^{min} \le T_i \le T_i^{max}, i=1,2,\ldots\ldots\ldots,N_T \ldots(6)$$

4. Reactive power injections supplied by capacitor banks

$$Q_{Ci}^{min} \le Q_C \le Q_{Ci}^{max}, i=1,2,\ldots\ldots\ldots,C_S \ldots(7)$$

5. Transmission lines loading

$$S_i \le S_i^{max}, i=1,2,\ldots\ldots\ldots\ldots,N_L \ldots(8)$$

The main goal of a specific OPF is to reduce the costs of meeting the load demand for a power system while keeping the security of the system. From the perspective of an OPF, the preservation of system security requires keeping each device in the power system within its desired operation range at steady-state. This will incorporate maximum and minimum outputs for generators, maximum MVA flows on transmission lines and transformers, as well as keeping networkbus voltages within specified limits.

III. Optimal Power Flow Challenges

The demand for an OPF problem has been increasing to evaluate the state and recommended control measures for both off line and online studies, since the first OPF paper was published in 1960's. The thrust for OPF to solve problems of today's deregulated industry and the unsolved problem in the vertically integrated industry has posed further challenges to OPF to evaluate the capabilities of existing OPFin terms of its potential and abilities. Many challenges are before OPF remain to be answered. They can be listed as given below.

1. As the consideration of large number of variety of constraints and due to non linearity of mathematical models, OPF poses a big challenge for the mathematicians as well as for engineers in getting optimum solutions.
2. The deregulated electricity market seeks answer from OPF, to address a variety of different types of market participants, data model requirements and real time processing and selection of appropriate costing for each unbundled service evaluation.
3. To cope up with response time requirements, modeling of externalities such as loop flow, environmental and simultaneous transfers, practicality and sensitivity for on line use.
4. How well the future OPF provide local or global control measures to support the impact of critical contingencies, which threaten system voltage and angle stability simulated.
5. Future OPF has to address the scope of operation and planning environment in providing new generation facilities, unbundled transmission services and other resources allocations.

2 OPF Solution Methodologies

A first comprehensive survey concerningto optimal power dispatch was given by H.H.Happ [5] and subsequently an IEEE working group [6] presented bibliography survey of major economic-security functions in 1981.The solution methodologies can be broadly classified into two groups namely:

1. Conventional or classical methods
2. Intelligent methods.

Traditionally, conventional methods are effectively used to solve OPF.The classical methods are based on mathematical programming approaches and used to solve different size of OPF problems to meet the requirements of different objective functions, types of application and nature of constraints.Mathematical formulations have to be simplified to get the solutions because of the extremely limited capability to solve real-world largescale power system problems. They are weak in handling qualitative constraints. 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 computationally expensive for solution of a large system.

To overcome the shortcomingsof conventional methods, Intelligent methods based on Artificial Intelligence (AI) have been developed in the recent past. The major advantages of the Intelligent methods are that they arerelatively versatile in handling various qualitative constraints, can find multiple optimal solutions in single simulation run.So they are quite suitable in solving multi objective optimization problems. Most of the cases,they can find the global optimum solution. The main advantages of intelligenttechniques are: Learning ability, fast in convergence, appropriate for non-linear modeling, etc. whereas, large dimensionality and the choice of training methodology are some drawbacks.

Gradient Method

The Generalized Reduced Gradient is applied to the OPF problem [7] with the main motivation being the existence of the concept of the state and control variables, with load flow equations providing a nodal basis for the elimination of state variables.

Dommel H.W. and Tinney W.F [7] proposed an Optimal Power Flow solutions using penalty function optimization approach, developed nonlinear programming (NLP) method for minimization of fuel cost and active power loss. The confirmation of boundary, using Lagrange multiplier approach, is achieved and is Capable of solving large size power system problems up to 500 buses. Its drawback is in the modeling of components such as transformer taps that are accounted in the load flow but not in the optimization routine.

O. Alasc and B Stott [8]proposed an Optimum Load Flow with steady state security using a non linear programming approach based on reduced gradient method utilizing the Lagrange multiplier and penalty-function technique to minimize the cost of total active power generation. Steady state security and insecurity constraints are incorporated to make the optimum power flow calculation a powerful and practical tool for system operation and design. It is validated on the IEEE 30- bus test system and solved in 14.3 seconds. The correct choice of gradient step sizes is crucial to the success of the algorithm.

Jamoulle and Dupont [9] provided an overview of the historic development of RG and GRG methods for OPF in a technical report. Furthermore, the authors applied on RG method using a two-level optimization procedure that guarantees feasibility, ensures a monotonically decreasing objective, and enables nearNewton type convergence. Their method is similar to the GRG methods in that they allow variable base.

Merits

1. Gradient methods are better fitted to highly constrained problems.
2. Gradient methods can accommodate non-linearity's easily compared to Quadratic method.
3. Compact explicit gradient methods are very efficient, reliable, accurate and fast.

Demerits

1. Consideration of equality and inequality constraints and penalty factors make the relevant matrices less sparse and hence it complicates the procedure and increases computational time.
2. Suffers from the difficulty of handling all the inequality constraints.
3. These methods are difficult to solve in the presence of inequality constraints.

IV. Newton Raphson Method

Newton's method [10] is a very powerful solution algorithm because of its rapid convergence near the solution.

David I. Sun et al[10] proposed with network sparcity techniques and Lagrange multiplier approaches.A Solution for reactive power optimization based on Newton method was proposed.The Quadratic approximation of the Lagrangian was solved at eachiteration and also validated on an actual 912-bus system. This Approach is suitable for practical large systems due to super-linear convergence to Kuhn-Tucker condition makes.

M. V. F. Pereira et al[11] proposed a method for Decomposition Approach to Security constrained Optimal Power Flow with Post Contingency corrective rescheduling. Solution for Economic dispatch problem with security constraints using Bender's decomposition approach is obtained. In addition, solution is also obtained for dispatch problems like the pure economic dispatch problem, the security-constrained dispatch problem and the

Security-constrained dispatch with re-scheduling problem. This method linearizes AC/DC power flows and performs sensitivity analysis of load variations.

Practical testing of the method has shown encouraging results.

A. Monticelli et al[12] proposed an algorithm based on mathematical programming decomposition, for solving an economic dispatch problem with security constraints is presented. A Separate contingency analysis with generation rescheduling can be done to estimate constraint violation. Preventive control actions are built in and an automatic means of adjusting the controls are included.

WenHsiung E. Liu et al[13] proposed Adaptive Movement Penalty Method for the Newton's Optimal Power Flow. This method introduces an adaptive movement penalties to ensure positive definitiveness and convergence is attained without any negative affect and proved for Handling of penalties are automatic without any tuning. Results are encouraging when tested on the critical 1650 –bus system.

S.Chen et al. [14] proposed a novel algorithm based on Newton-Raphson (NR) method with sensitivity factors incorporated to solve emission dispatch in real-time. The Jacobian matrix and the B-coefficients have been developed in terms of the generalized generation shift distribution factor. So the penalty factor and the incremental losses are easily obtained. Execution time is lesser than that of the conventional one.

K. L. Lo et al[15] proposed Newton-likemethod for line outage simulation. In this research paper Fixed Newton method and the modification of the right hand side vector method are presented for simulation of line outage.

Above methods have better convergence characteristics than Fast decoupled load flowmethod and Newton based full AC load flow method.

Merits

1. The method has the ability to converge fast.
2. It can handle inequality constraints very well.
3. Efficient and robust solutions can be obtained for problems of any practical size.
4. Relatively independent of the number of controls or inequality constraints.

Demerits

1. The penalty near the limit is very small by which the optimal solution will tend to the variable to float over the limit.
2. Convergence characteristics that is sensitive to the initial conditions.

V. Linear Programming Method

Linear programming formulation requires linearization of objective function as well as constraints with nonnegative variables.

D. W. Wells developed a Method for Economic Secure Loading of a Power System by a linear programming method to formulate an economical schedule[16], consistent with network security requirements for loading plants in power system. Simplex method was used to solve cost objective and its constraints. Further a scheme was adopted for selecting and updating variables at the buses. It is a decomposition approach based on Dantzig and Wolfe's algorithm. The drawbacks are the optimum results may not be obtained for an infeasible situation and digital computers may create rounding errors by which constraints may be overloaded.

C. M. Shen et al [17] developed a method for power System Load Scheduling with Security Constraints using Dual Linear Programming.The problem formulation has taken to account single-line outages. Revised simplex method was adopted to obtain solutions for both primal and dual problems. Changes in system networks were made based on variation studies of system dispatch load. It was tested on a 23-bus theoretical power systemhas shown encouraging results.

T. S. Chung et al [18] Achieved optimal capacitor allocation and reduction of line losses in a distribution system using recursive linear programming. Cost-benefit calculation is carried out for 14-bus system. As this method does not require any matrix inversion seeks less computational time and memory space.

E. Lobato et al [19] developed an LP-based optimal power flow for transmission losses and generator reactive margins minimization. This LP based OPF was applied for reduction of transmission losses and Generator reactive margins of the system. Integer variables represented the discrete nature of shunt reactors and capacitors. Objective function and the constraints are linearized in each iteration, to yield better results.

F. G. M, Limaet al [20]made a Design analysis on the combinatorial optimal placement of Thyristor Controlled Phase Shifting Transformer (TCPST) in large scale power systems, using Mixed Integer Linear Programming. The number, network location and settings of phase shifters to enhance system load ability are determined under the DC load flow model. Restrictions on the installation investment or total number of TCPSTs are satisfied. Execution time is considerably reduced compared to other available similar cases.

G. Irisarri[21] et al made an attempt with Quasi-Newton linear programming using a variable weights method with multiple objective functions. Hessian matrix was improved by sparcity coding in place of full Hessian. Set of penalty functions with variable weights coefficients are represented as linearized constraints. Feasibility retention and optimum power flow solution is obtained with the use of "Guiding function". This method is tested on 14 and 118-bus systems and performance is comparable to o methods on small-size systems.

S. A. Farghal, M. A. Tantawy et al [22] proposed a method for real time control of power system under emergency conditions. Insecure operating conditions are corrected by using sensitivity parameters. It is achieved through set of control actions based on theoptimal re-dispatch function.It was validated on a 30-bus system for various loads and is appropriate for on-line operation.

R. Mota-Palomino et al[23]Solved constrained Economic Operation Problem using a non-conventional linear programming technique involving a piece-wise differentiable penalty function approach. Objectives of contingency constrained economic technique involving a piece-wise differentiable penalty function approach.Objectives of contingency constrained economic dispatch (CED) with linear constraints were achieved by employing this method.Optimal solution was attained, independent of a feasible starting point and it was verified on a 10-, 23-, and 118-bus systems. At a certain point pseudo gradient of the penalty function is a linear combination of the column of the active set matrix or not, decides the descent direction. The method's optimal step-size was decided by choosing the direction so that the active remain active or feasible and hence only inactive constraints are considered to calculate step size.

Merits

1. The LP method easily handles Non linearity constraints
2. It is efficient in handling of inequalities.
3. Deals effectively with local constraints.
4. It has ability for incorporation of contingency constraints

Demerits

1. It suffers lack of accuracy.
2. Although LP methods are fast and reliable, but they have some disadvantages associated with the piecewise linear cost approximations.

VI. Quadratic Programming Method

It is a special form of nonlinear programming whose objective function is quadratic and constraints are linear. Quadratic Programming based optimization is involved in power systems [24] for maintaining adesired voltage profile, maximizing power flow and minimizing generation cost. These quantities are generally controlled by complex power generation which is usually having two limits. Here minimization is considered as maximization can be determined by changing the sign of the objective function.

G. F. Reid and L. Hasdorf [25] implemented quadratic programming method based on Wolf's algorithm specialized to solve the economic dispatch problem. In this Penalty factors or the selection of the gradient step size are not essential. It was developed purely for research purposes; therefore, the model used is limited and employs the classical economic dispatch with voltage, real, and reactive power as constraints. The CPU time is less as convergence is very fast. It increases with system size.

T. C.Giras et al [26] Solved an OPF problem, having an infeasible initial starting point, by Quasi-Newton technique using the Han-Powell algorithm. A decomposition technique using the Berna, Locke, Westberg (BLW) decomposition is adopted. Due to excellent linear convergence qualities of power flow, the execution is fast and was validated on small synthetic systems. The method can be of production grade quality subject to its performance in more rigorous tests.

R.C. Burchett et al[27] developed an optimal power flow by considering four objective functions namely, fuel cost, active and reactive losses, and new shunt capacitors are solved by Quadratic Programming (QP) method. Run time and the robustness of QP method are superior to an augmented Lagrangian method. OPF solutions based on the above methods, for four different systems with a range of 350-,1100-,1600- and 1900-buses, are evaluated and the observations are: The QP method employs the exact second derivatives, while second method adopts an augmented Lagrangian to solve a sequence of sub-problems with a changed objective. The later is based wholly on the first derivative information. By this method a viable solution can be obtained J.A.Momoh [28] presented an extension of basic Kuhn-Tucker conditions and employing a generalized Quadratic-Based model for OPF. The conditions for feasibility, convergence and optimality are included in the construction of the OPF algorithm. It is also capable of using hierarchical structures to include multiple objective functions and selectable constraints. The generalized algorithm using sensitivity of objective functions with optimal adjustments in the constraints yields a global optimal solution. Computational memory and execution time required have been reduced.

X. Lin et al [29] developed an OPF algorithm for competitive market by employing a method based on integrated cost analysis and voltage stability analysis for reactive power minimization. Solution was obtained by using sequential quadratic programming.In this an optimum reactive power dispatch was attained under different voltage stability margin requirements in normal and outage conditions.

Merits

1. Ill conditioned and divergent systems can be solved in most cases.
2. The accuracy of QP method is much higher compared to other established methods.

Demerits.

1. Difficulties in obtaining solution of quadratic programming in large dimension of approximating QP problems.

VII. Interior Point Method

The Interior Point Method [30] is one of the most efficient algorithms. The IP method classification is a relatively new optimization approach that was applied to solve power system optimization problems in the late 1980s and early 1990s and as can be seen from the list of references [31].

Momoh, J. A et al [32] Solved optimal power flow problems, economic dispatch, and VAR planning, by adapting a Quadratic Interior Point (QIP) method and also it also provides solution to linear and quadratic objective functions including linear constraints.

Sergio Granville [33] 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 algorithm was applied on large power systems and it converged in 40 iterations. CPU time was 398.9 seconds. 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 in large scale and ill-conditioned networks.

D.Xia-oying, et al[34] Solved decoupled OPF problem using an Interior Point Branch and Cut Method (IPBCM).Active Power Suboptimal Problem (APSOP) was solved by employing Modern Interior Point Algorithm (MIPA) and adapted IPBCM to iteratively resolve linearization's of Reactive Power Suboptimal

Problem (RPSOP).The RPSOP has fewer variables and limitations than original OPF problem, resulting in improving pace of computation.

Wei Yan, et al [35] developed a new optimal reactive power flow model in rectangular form and its solution by predictor corrector primal dual interior point method. Predictor Corrector Primal Dual Interior Point Method (PCPDIPM) was employed for resolving the problem of the Optimal Reactive Power Flow (ORPF). It also presented a new optimal reactive power flow model in rectangular form. In the complete optimal process, the Hessian matrices are constants and require evaluation only once. The computation time for this method is always less than conventional model in seven test cases.

Merits

1. It is one of most efficient algorithms.
2. Maintains good accuracy while achieving great advantages in speed of convergence reliability, speed and accuracy.

Demerits

1. Limitation due to starting and terminating conditions.
2. Infeasible solution if step size is chosen improperly.

Intelligent Methodologies

The drawbacks of classical methods can be summarized as three major problems:

1. They may not be able to give optimal solution and usually getting struck at a local optimal.
2. All these methods are based on assumption of continuity and differentiability of objective function which is not practically possible.
3. All these methods cannot be applied with discrete variables such as transformer taps.

It is observed that intelligent techniques aresuitable methods to overcome above drawbacks.

Genetic Algorithms

It is observed that Genetic Algorithm (GA) is anappropriate method to solve OPF problem, whicheliminates the above draw backs [36].

A. Bakritzs et al[37] Solved an Economic dispatch problems using Genetic Algorithm technique. Its merits are, the non restriction of any convexity limitations on the generator cost function and effective coding of GAs to work on parallel machines.GA is superior to Dynamic programming, as per the performance observed in Economic dispatch problem. The run time of the second GA solution i.e. EGA method proportionately increases with size of the system.

Po-H.Chen et al. [38] proposed a novel genetic algorithm for solving the Economic Dispatch (ED) problem in large-scale systems. A new encoding method is developed in which the chromosome contains only an encoding of the normalized system incremental cost. So the whole number of bits of chromosome is entirely independent of the number of units. The approach can take network losses, ramp rate limits and prohibited zone avoidance into account. It converges more rapidly than lambda – iteration method in large systems.

L. L. Lai et al [39] provided a solution by employing Improved Genetic Algorithm for optimal power flow in regular and contingent environment. The approach provides better performance and thrown out operational and insecure violations. The dynamical hierarchy of the coding procedure designed in this approach, enables to code numerous control variables in a practical system within suitable size of string length. This method is therefore able to regulate the active power outputs of generation, bus voltages, shunt capacitors / reactors and transformer tap settings for fuel cost minimization. IGA obtains better optimal fuel cost of the normal case and global optimal point compared to gradient based conventional method.

Liladhur G. et al [40] proposeda solution for Economic Dispatch with valve point effect using Genetic Algorithm.In this method, four Genetic Algorithms namely, Simple Genetic Algorithm (SGA), SGA with generation – apart elitism, SGA through atavism and Atavistic Genetic Algorithm (AGA) are employed to obtainsolution on three test systems: 3–generator, 13–generator systems and the standard IEEE 30-bus test system. From the comparison of the results, it is observed that all GA methods mentioned aboveare better than Lagrangian method with no valve effect. With valve point effect and ramping characteristics of generators, AGA is superior to other GAs and the Tabu search. Further, the AGA alone circumvents entrapment in local solution. It is attributed to equilibrium in selective pressure and population diversity.

L.J.Cai et al. [41] proposed optimal selection and allocation of FACTS devices in multi-machine power systems using genetic algorithm. The objective is to achieve the power system economic generation allocation and dispatch in deregulated electricity market. The locations of the FACTS devices, their types and ratings are optimized simultaneously. UPFC, TCSC, TCPST and SVC are modeled and their investment costs are also considered.

Merits

1. GAs can provide a globally optimum solution as it can avoid the trap of local optima.
2. GAs can deal with the non-smooth, non continuous, non-convex and non differentiable functions
3. Adaptable to change, ability to generate large number of solutions and rapid convergence.

Demerits

1. GAs are stochastic algorithms and the solution they provide to the OPF problem is not guaranteed to be optimum.
2. The run time and the quality of the solution, weakens with the raise of the chromosome length, i.e., the OPF problem size.
3. If the size of the power system is increasing, the GA method can produce more in feasible springs which may guide to wastage of computational efforts.

VIII. Evolutionary Programming (EP)

It is a subset of evolutionary computation, a generic population based meta-heuristic optimization algorithm.

P.Somasundaram et al. [42] proposed an algorithm for solving security constrained OPF problem with the application of EP. The controllable system parameters in the base-case are optimized to minimize some defined objective function subject to the base-case operating constraints as well as the contingencycase security constraints. Fitness function converges efficiently without any noticeableoscillations.

W.Ongsakul et al. [43] developed an Evolutionary Programming based algorithm tofind out the optimal allocation of FACTS devices for maximizing the Total Transfer Capability (TTC) of power system between source and load areas in deregulated power system. EP simultaneously searches location for FACTS devices, FACTS parameters, real power generations except slack bus in source area, real power loads in sink area and generation bus voltages.

T.Jayabarathi et al. [44] proposed the application of Classical Evolutionary Programming (EP), Fast EP(FEP) and Improved FEP(IFEP) methods to solve all types of economic dispatch problems such as ED of generators with prohibited operating zones (POZ), ED of generators with piecewise quadratic cost function (PQCF), combined economic and environmental dispatch (CEED) and multi-area economic dispatch (MAED). Generating capacity, power balance, prohibited operating zones; area power balance, generation limits and tie-line limit constraints are the considered constraints.

IX. Ant Colony Optimization (ACO)

It is based on the thoughts of ant foraging by pheromone communication to make path.

I.K.Yu et al. [45] presented a novel co-operative agents approach, Ant Colony Search Algorithm (ACSA)-based method, for solving a short-term generation scheduling problem of thermal power systems. The state transition rule, global and local updating regulations are also introduced to ensure the optimal solution. Once all the ants have accomplished their tours, a global pheromone-updating rule is then applied and the process is iterated until the stop criterion is satisfied. The feasibility of the algorithm in large systems with more complicated constraints is yet to be investigated.

Libao Shi et al.[46] developed ant colony optimization algorithm with random perturbation manner (RPACO) based on amalgamation of general ant colony optimization and stochasticmethod is developed for the solution of optimal unit commitment(UC) with probabilistic spinning reserve determination. Total production fuel costs, start-up costs of units in stage t, the penalty cost imposed when any of constraints are violated and the total accumulated cost from stage 0 to stage t. are incorporated in objective function. The security function approach is also applied to evaluate the desired level of system security.

R.Meziane et al. [47] used ACO to work out the allocation problem involving the selection of electrical devices and the appropriate levels of redundancy to maximize system reliability of series-parallel topology, under performance and cost constraints. A universal moment generating function (UMGF) method is used by the ACO to find out the optimal electrical power network topology.

X. Particle Swarm Optimisation.

Particle swarm optimization (PSO) is a population based stochastic optimization methodmotivated by social behavior of bird flocking or fish schooling[48].

M.A. Abido [49] proposed the Particle swarm optimization (PSO), to solve Optimal Power Flow problem. In this,PSO algorithm is used for optimal position of OPF problem control variables. Presumptions forced on the optimized objective functions are considerably removed by this optimization technique in solving OPF problem. Validation was done for various objective functions such as fuel cost minimization, enhancement of voltage profile and voltage stability. Observationsconfirm that this method is better than the conventional methods and Genetic Algorithms in respect of efficiency and robustness.

Jong-Bae Park et al. [50] suggested a Modified Particle Swarm Optimization (MPSO) for economic dispatch with non-smooth fuel cost functions. A position adjustment strategy is proposed to provide the solutions satisfying the inequality constraints. The equality constraint is resolved by dropping the degree of freedom by one at random. Dynamic search-space reduction approach is devised to accelerate the process. The results attained from the proposed method are compared with those obtained by GA, TS, EP, MHNN, AHNN and NM methods. It has shown its superiority to the conventional methods.

Jong-Bae Park et al[51] developed an improved particle swarm optimization for solving the non-convex economic dispatch problems. It improved the performance of the conventional PSO by adopting this approach which uses the chaotic sequences and the crossover operation. The global searching ability and getaway from local minimum is enhanced by uniting, the chaotic sequences with the linearly decreasing inertia weights. Further, the diversity of the population is distended by adding the crossover operation. The global searching ability as well as preventing the solution from entrapment in local optima, by the above approaches.

Merits

1. PSO is one of the modern heuristic algorithms capable to solve large-scale non convex optimization problems like OPF.
2. The main advantages of PSO algorithms are: simple concept, easy implementation, relative robustness to control parameters and computational efficiency.
3. The prominent merit of PSO is its fast convergence speed.
4. Flexibility to control the balance between the global and local exploration of the search space.

Demerits

1. Slow convergence in refined search stage (weak local search ability).

XI. Optimal Power Flow With FACTS Devices.

Various algorithms have been reported in the literature to solve power flow and optimal power flow (OPF) for power systems equipment with various FACTS devices. Several papers have been published originating with OPF incorporating FACTS devices for power flow control.

M.Saravanan et al. [52] proposed the application of Particle Swarm Optimization to find the optimal location, settings, type and number of FACTS devices to minimize their cost of installation and to improve system loadability for single and multi-type FACTS devices. While finding the optimal location, the thermal limit for the lines and voltage limit for the buses are taken as constraints. TCSC, UPFC and SVC were considered.

Taranto et al. [53] have proposed a decomposition method for representing FACTS devices in optimal power flow (OPF) model. The proposed approach was first proposed to solve the optimal active power flow dispatch problem incorporating FACTS devices. This methodology is based on mathematical decomposition and network compensation techniques. A linearized network model (DC power flow) was used. This method can deal with the representation of series compensators and phase shifters, but this method did not consider the specified line flow constraints.

Hiyama, et al. [54], presented an application of a fuzzy logic control scheme for TCSC module to enhance overall stability of electric power systems and also to increase the maximum power transmission through the existing AC transmission lines.

Galiana et al. [55] proposed to systematically evaluate the impact of FACTS on the steady state .behavior of power systems through the concept of generalized security regions and through scalar measure of these regions obtained from optimal power flow (OPF) simulation.

Nabavi and Iravani [56] proposed a way to handle UPFC with power flow algorithms by removing the UPFC and assigning the ends of UPFC by the P-Q bus or P- V bus.

Fang and Ngan [57] presented the optimal location of unified power flow controllers using the method of augmented Lagrange multipliers. Chung and Li [58] presented an improved genetic algorithm (GA) to solve optimal power flow (OPF) problems in power system with flexible AC transmission systems (FACTS). In this two types of FACTS devices are considered to control power flow such as Thyristor controlled phase shifter and Thyristor controlled series compensator. In the process of solution, GA is together with full AC power flow, selects the best regulation to minimize the total generation fuel cost and keep the power flows within their secure limits. The optimization process with GA is presented with case study examples of an IEEE test system to demonstrate its feasibility and effectiveness.

Lu and Abur [59] presented a systematic procedure to place and operate TCSC in a power system. First the "Single Contingency Sensitivity (SCS)" criterion for a given branch flow is defined. This condition is then utilized to develop a branch's prioritizing index in order to rank branches for possible placement of TCSC. Finally, optimal settings of TCSC parameters are determined for important contingencies. IEEE 14-bus test system was used to demonstrate the proposed approach

XII. Conclusions

In this Paper various popular techniquesin Optimum Power Flow, covering both Conventional, Intelligent methodologies as well as with FACTS have presented. To begin with, the Mathematical representation of optimal power flow problem is described byexplaining the objective function along with non linear equality and inequality constraints.

For each of the Conventional and Intelligent methodology, the contribution by Researchers in each of the methodology has been covered with a lucid presentation. This helps the reader to quickly get to know the significant contributions and salient features of the contribution made by Researchers as per the Ref. No. mentioned in the list of References.

The conventional methods include Gradient method, Newton method, Linear Programming method, Quadratic Programming method and Interior Point method. Among these methods, the Interior Point method (IP) is found to be the most efficient algorithm. It maintains good accuracy while achieving the speed of convergence of as much as 12:1 in some cases when compared to other known linear programming methods.

The deterministic methods surveyed suffer from two common shortcomings: All are local solvers only and cannot guarantee global optimality except in the case of a convex problem.This is because of the Kuhn-Tucker conditions are not sufficient for a global optimum in general. Since the OPF problem is inherently non-convex, multiple local optima may exist. This issue has long been recognized, although in practice the various deterministic methods tend to converge to the same optimal solution in any given problem.The majority are continuous solvers: they cannot readily handle binary or integer variables. As a result, switching controls in the power system cannot be accurately modeled. This limits the scope of OPF problems that may be effectively solved with deterministic solvers. These two shortcomings have motivated significant work in the area of non-deterministic, that is, heuristic, optimization methods for OPF, including methods that hybridize multiple approaches.

As a counter to the shortcomings of the deterministic methods, Intelligenttechniques have been widely applied to various OPF problems. These techniques have outstanding global search characteristics, and some have been shown to approach global optimality for a given sufficient search time and appropriate selection of control parameters. The Intelligent methods covered are GA,EP, ANTOCOLONY and PSO methods. These methods are suitable in solving multiple objective problems as they are versatile in handling qualitative constraints. The advantages of the intelligent methods include learning ability, fast convergence and their suitability for non linear modeling.

From the FACTS viewpoint, future prospects are mostly dependable on a number of practical applications of the FACTS-controllers. In future increased number of their installations are expected, raised concern appears within their co- ordination in overall planning and operational procedures. Systems with several FACTS devices are to be analyzed. Possible overlapping or interactions between control systems are to be investigated. Value-added increase of transmission capacity by using FACTS device is to be compared with other solutions. So it is suggested that solutions of power flow and optimal power flow must be developed incorporating advanced facts devices.

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