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# NEW HYBRID PSO ALGORITHM FOR NON-CONVEX OPTIMAL POWER FLOW PROBLEM

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*Abstract:* **Optimal power flow is an optimizing tool for operation and planning of modern power systems. This OPF problem involves the optimization of various types of objective functions while satisfying a set of operational and physical constraints while keeping the power outputs of generators, bus voltages, shunt capacitors/reactors and transformers tap settings in their limits. In an interconnected power system network obtaining maximum performance, maintaining system stability limits and facilitating efficient system operation are the challenging tasks. This project presents a new hybrid particle swarm optimization algorithm as a modern optimization tool to solve the optimal power flow (OPF) problem. The objective functions considered are the system power losses, fuel cost, valve point effects, ramp-rate limits, prohibited operating zones, and spinning reserves. The proposed algorithm makes use of the PSO, known for its global searching capabilities, to allocate the optimal control settings. PSO algorithm is combined with conventional IPM algorithm to form hybrid PSO algorithm. A hybrid inequality constraint handling mechanism that preserves only feasible solutions is incorporated in the proposed approach. To demonstrate its robustness, the proposed algorithm was tested on the IEEE 30-bus system. Several cases were investigated to test and validate the consistency of detecting optimal solution for each objective. The results show that the proposed hybrid method successfully and efficiently handles the equality and inequality constraints for PSO algorithms.**

*Keywords:* **PSO algorithms, OPF problem, Optimal power flow problem, EEE 30-bus system.**

## I. INTRODUCTION

One of the major problems in the operation of power system is optimal power flow. The aim of this problem is minimizing the fuel cost per unit of production to produce a certain amount of power equal to the demand. The optimal power flow must be done in such a way that the other constraints on production rates and associated constraints will also satisfy. Optimal power flow determines the optimal combination of real power generation, voltage magnitudes, compensator capacitors and transformer tap position to minimize the specific objective function like total generation cost while satisfying load demand and diverse operating constraints of a power systems. In practice, real input-output characteristics present higher order nonlinearities and discontinuities due to valve-point loading effects caused by the sharp increase in losses.

However, generating units may have prohibited operating zones due to faults in the machines themselves or the associated auxiliaries, such as boilers, feed pumps, leading to instabilities in certain ranges of unit loading. Many generating units need the cost function to be modeled as piecewise function, due to their capability of operating with a leading to the problem of determining the most economic fuel to burn. Furthermore, due to the fact that unit generating output cannot be changed instantaneously, the unit in the actual operating processes is restricted by its ramp rate limits. Also, for the security and reliability considerations of power systems, spinning reserve capacity must be sufficient to absorb source contingencies and major load forecast errors without load shedding. The above operating constraints are nonlinearities make the OPF problem a non-smooth optimization problem having complex and non-convex features with heavy equality and inequality constraints. Conventional gradient based optimization methods are not capable to solve efficiently this kind of problems and usually result in inaccurate dispatches causing huge loss of revenue over the time. Recently, as an alternative to the conventional mathematical approaches, modern stochastic optimization techniques have facilitated solving non-smooth and non-convex OPF problems, such as conventional and evolutionary methods. In conventional methods we can go for Newton-Raphson NR) Method, Quadratic Programming (QP) Method, Interior point (IP) Method, Artificial Intelligence (AI) Method. And in Evolutionary Programming we have Fast Evolutionary Programming (FEP) Method, Improved Fast Evolutionary Programming (IFEP) Method, and Particle Swarm Optimization (PSO) Method. Also, some hybridization and combination of these methods have been widely used to solve more effectively this kind of OPF problems.

Interior – point (IP) method and Particle Swarm Optimization (PSO) algorithms are the two of these recently developed heuristic global search tools. 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. 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. The Hessian matrices in this model are constants and need to be evaluated only once in the entire optimal process. Total calculation time needed for the proposed method is always shorter than that for the conventional model for the seven test cases. PSO belongs to the Ontogeny category in which the adaptation of a special organism to its environment is considered. Particle Swarm Optimization (PSO) is a biologically inspired computational search and optimization method developed by Eberhart and Kennedy in 1995 based on the social behaviors of birds flocking and fish schooling. PSO has proven to be both very fast and effective when applied to a diverse set of optimization problems

PSO may also be trapped in local minima, because it easily loses the diversity of swarm. To overcome the disadvantages of IPM and PSO, an efficient combination strategy of IPM and PSO (termed PSOIPM) is introduced. The contribution of this project is linked with a proposition of a new efficient combined differential evolution and particle swarm optimization (PSOIPM) algorithm for solving practical OPF problems, including all mentioned operational constraints which usually are found simultaneously in realistic power systems. The proposed strategy has been tested on several example problems on optimal power flow and their results have been compared with those obtained by some of the most recent reported methods. The results obtained show that the proposed method is efficient, reliable, robust and has great potential for solving real optimal power flow problems.

**OBJECTIVE OF THE THESIS:**

The main objectives of this Thesis are

- Perform Optimal Power Flow using Conventional PSO to minimize the Fuel Cost, Real Power loss.
- Formulate PSO for Optimal Power Flow to minimize the Fuel Cost, Real Powerless.
- Formulate Hybrid PSO by combining Conventional Interior point Method (IPM)with Evolutionary PSO algorithm (Hybrid PSO-IPM) for Optimal Power Flow to minimize the Fuel Cost, Real Power loss.
- Compare the Hybrid PSO-IPM with conventional PSO under Base case, without considering the constraints, with considering the operational constraints, without violating the equality and inequality constraints.

**CONTRIBUTION TO THE THESIS:**

- OPF using Conventional PSO for minimizing Fuel Cost, Real Power loss, PSO algorithm is tested on standard IEEE 30 bus system to test the ability of the algorithm.
- Formulation of PSO algorithm for OPF
- Hybrid PSO algorithms is used to perform OPF with the specified objective functions and tested on standard IEEE 30 bus system to validate the proposed algorithm.
- Formulation of Hybrid PSO-IPM algorithm for OPF

- Hybrid PSO-IPM algorithms is used to perform OPF with the specified objective functions and tested on standard IEEE 30 bus system to validate the proposed algorithm.
- Compared the results obtained by the proposed algorithms to analyze the performance under base load condition, and base load condition without considering the operational constraints and with considering the operational constraints.

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## 2. POWER FLOW ANALYSIS

Power flow analysis is an integral part of system planning and operation. The electrical system consists of buses with generators and loads that are interconnected by branches and transformers. The steady-state solution of the network determines the bus voltages from which the active and reactive power flow in branches can be calculated.

The power system behavior is often studied taking account of seasonal loading of branches (e.g., at winter peak demand) under specific network conditions including loss of generation, circuit outages, and network upgrades. The loads at each bus are set to representative values derived from minimum, typical, and peak conditions. The assumption that demand is known holds for historic and real-time analysis, while forecast estimates have to be used for any future scenario. To meet load demand, the generation portfolio must be adequate. [1]

The power flow solution determines the steady-state voltage phase and magnitude at all buses, real and reactive power flows in each line, power losses, and reactive power required by the PV buses for specified loading conditions. The common methods which have been widely used in solving the power flow problem are Gauss-Seidel (GS), Newton-Raphson (NR) method and Fast-Decoupled (FD) method which is a modification of the NR method. [2]

Power flow studies are typically used to determine the steady state operating conditions of power systems for a specified set of load and generation, and is one of the most intensely used tools in power engineering. The most common formulation of the power flow problem has all input data specified from a snapshot at a point in time associated with specific system conditions, or from a proper set of "crisp" values that the analyst defines under various assumptions for the system. The power flow solution is then deemed representative of a limited set of system conditions. However, when the input conditions are uncertain, numerous scenarios need to be analyzed to cover the required range of uncertainty. Uncertainties in power flow analysis stem from several sources both internal and external to the power system. Many uncertainties are induced by the complex dynamics of the active and reactive load profiles that can vary in a fast and disordered manner due to many factors such as weather conditions and electricity price.

A further source of uncertainty derives from the increasing number of no dispatch able generators connected to the power system, particularly intermittent energy sources based on wind and solar power. Thus, solar radiation is subject to random coverage of clouds, which makes short-term variations of solar energy difficult to forecast, and similarly, wind speed variations may follow a generally well-known daily or seasonal pattern, but specific short-term, minute-to-minute and hourly changes are hard to predict. The difficulties arising from the prediction and modeling of electricity market behavior, governed mainly by somewhat unpredictable economic dynamics, represents another source of uncertainty in power flow analysis. Further uncertainties derive from variances in the model parameters of transmission system elements, such as resistance, reactance and/or capacitance values. Under such conditions, reliable solution algorithms that incorporate the effect of data uncertainty into the power flow analysis are required. Reliable "interval" power flow algorithms would allow system operators to estimate both the data and the solution tolerance, i.e., uncertainty characterization and uncertainty propagation assessment, thus allowing them to evaluate the level of confidence of power flow studies. [3]

The power flow analysis is one of the most important problems in power system studies The origins of the formulation of the power flow problem and the solution based on the Newton–Raphson‟s technique It is relevant to classify the power flow problems into the following categories:

1) Well-conditioned case: The power flow solution exists and is reachable using a flat initial guess (e.g., all load voltage magnitudes equal to 1 and all bus voltage angles equal to 0) and a standard Newton–Raphson‟s method. This case is the most common situation.

2) Ill-conditioned case: The solution of the power flow problem does exist, but standard solution methods fail to get this solution starting from a flat initial guess. Typically this situation is due to the fact that the region of attraction of the power flow solution is narrow or far away from the initial guess. In this case, the failure of standard power flow solution methods is due to the instability of the numerical method, not of the power flow equations. Robust power flow methods have proved to be efficacious for solving ill conditioned cases.

3) Bifurcation point: The solution of the power flow exists but it is either a saddle-node bifurcation or a limit-induced bifurcation.

a) Saddle-node bifurcations are associated with the maximum loading condition of a system. The solution cannot be obtained using standard or robust power flow methods, since the power flow Jacobian matrix is singular at the solution point.

b) Limited-induced bifurcations are associated with a physical limit of the system, such as a shortage of generator reactive power. Although limit-induced bifurcation can in some cases lead to the voltage collapse of the system, the solution point is typically a well-conditioned case and does not show convergence issues.

c) Unsolvable case: The power flow solution does not exist. Typically, the issue is that the loading level of the network is too high. As in the case of the bifurcation points, a continuation method or an optimal power flow problem allow defining the maximum loading level that the system can supply.[4]

## 3. OPTIMAL POWER FLOW

Optimal power system operations optimize the power system steady-state performance in terms of one or more objective functions by satisfying several equality and inequality constraints. The OPF problem has two sets of constraints, equality and inequality constraints.

- Equality constraints: The equality constraints of the OPF problem are the power flow equations corresponding to real and reactive power balance equations.
- Inequality constraints: The inequality operation constraints in the OPF problem include: Generation constraints: Generator voltages, real power Outputs and reactive power outputs are [10].

Optimal power flow is a tool that has been commonly used within the power systems industry for many years and generally been considered as a deterministic optimization problem [11], [12]. The optimal power flow issue is one of the most important problems faced by dispatching engineers regarding large scale power systems.

It is a particular mathematical approach of the global power system optimization problem that aims at determining the least control movements to keep power system at the most desired state. Thus, it represents a flexible and powerful tool, which can address a wide range of planning and operation studies. Optimal power flow problem in interconnected power systems has achieved an increasing interest because it results improvements in the power system operation. The OPF provides support to the operator to overcome many problems in the planning, operation and control of power systems. Therefore, it is widely used in many applications, such as constrained economic dispatch and voltage control problems etc. To describe the OPF problem, all variables have to be defined through the following distinct four categories

- Objectives: The main task of the OPF is to optimize the objective function while meeting all constraints. Many common objective functions, such as minimizing fuel cost, or finding a feasible solution with minimum control movement, can be directly expressed as cost functions of the control. However, some other objective functions, such as minimizing the total active power losses as a common objective function, cannot be directly expressed as a cost function of the control

- Constraints: the limits defined by operating procedure that keep the power system within a safe and sustainable operating region. These are the equipment operating and system security limits, such as bus voltage magnitude and line flow limits. Useful by-products of solving the OPF problem are the sensitivities of enforcing these constraints, relative to the objective function. This gives the user an idea about the cost caused by holding each of the constraints at its present value.
- Network: The OPF must satisfy the physical constraints implied by the network definition. Similar to conventional power flow, primary network constraints are the bus real and reactive power mismatch equations.
- Controls: the set of power system controls that can be adjusted to meet the constraints and to optimize the objectives. Examples are the adjustment of transformer tabs, changing the voltages of the generators and switching the reactive power compensators.[13]

In the optimal power flow (OPF) formulation, the generator terminal voltages, among others, are considered as control variables. Their values are adjusted by an optimization algorithm to minimize an objective function, while satisfying some system conditions in The form of equality (PF equations) and inequality (maximum and minimum variables or Function limits) constraints [14]. Optimal power flow (OPF) tools can provide

- Deterministic convergence.
- Accurate computation of nodal prices.
- Support of both smooth and non smooth costing of a variety of resources and Services, such as real energy, reactive energy, voltages support, etc.
- Full active and reactive power flow modeling of large-scale systems and
- Satisfactory worst-case performance that meets the real-time dispatching requirement.[15]

In real-world, power engineers perform optimization, monitoring and control of different aspects of power systems including economic dispatch, state estimation, unit commitment, automatic generation control and optimal power flow (OPF). Among these Tasks, OPF is considered as an important task and has been significantly researched since its introduction. The goal of OPF problem is to evaluate the power system network settings that optimize a certain objective function, while satisfying the power flow equations, security and maintaining equipment operational constraints. In order to achieve maximum asset utilization and autonomous functioning of the power grid, an allocation technique that can carry out decision making for OPF, incorporate distributed generation systems is required.OPF problem is a non-linear optimization problem with a set of constraints and have been solved using both conventional as well as nonconventional methods. The conventional methods used for solving the OPF problem include Newton method, dynamic programming, gradient methods, linear programming and interior-point methods In recent times, non-conventional methods such as evolutionary programming ,Genetic Algorithm , Particle Swarm Optimization, Tabu search and simulated annealing has been used for solving the OPF problem.[16]

**Optimal Power Flow Challenges:**

The demand for an OPF tool has been increasing to assess the state and recommended control actions both for off line and online studies, since the first OPF paper was presented in 60"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 OPF in terms of its potential and abilities. Many challenges are before OPF remain to be answered. They can be listed as given below.

- Because of 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 obtaining optimum solutions.
- 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.
- To cope up with response time requirements, modelling of externalities (loop flow, environmental and simultaneous transfers), practicality and sensitivity for on line use.

- 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.
- Future OPF has to address the gamut of operation and planning environment in providing new generation facilities, unbundled transmission services and other resources allocations.

## 4. OPF SOLUTION METHODOLOGIES

A first comprehensive survey regarding optimal power dispatch was given by H. H. Happ and subsequently an IEEE working group presented bibliography survey of major economic-security functions in 1981. Thereafter in 1985, J. Carpentier presented a survey and classified the OPF algorithms based on their solution methodology. In 1990, B. H. Chowdhury et *al* did a survey on economic dispatch methods. In 1999, J. A. Momoh et *al* presented a review of some selected OPF techniques.

The solution methodologies can be broadly grouped in to two namely:

1. Conventional (classical) methods

2. Intelligent methods

**OPF solution methodologies:**

- Gradient method
- Hessian-based
- Newton-based
- Linear programming
- Quadratic programming
- Interior point
- Artificial neural network.
- Fuzzy logic
- Evolutionary programming
- Ant colony
- Particle swarm optimisation.

**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. To meet the requirements of different objective functions, types of application and nature of constraints Even though, excellent advancements have been made in classical methods, they suffer with the following disadvantages: In most cases, mathematical formulations have to be simplified to get the solutions because of the extremely limited capability to solve real-world large-scale 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.

***Gradient Method:***

The Generalized Reduced Gradient is applied to the OPF problem 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. With the availability of good load flow packages, the sensitivity information needed is provided.

This in turn helps in obtaining a reduced problem in the space of the control variables with the load flow equations and the associated state variables eliminated**.** The Merits and Demerits of Gradient Method are summarized and given below.

***Merits:***

- With the Gradient method, the Optimal Power Flow solution usually requires 10 to 20 computations of the Jacobian matrix formed in the Newton method.
- The Gradient procedure is used to find the optimal power flow solution that is feasible with respect to all relevant inequality constraints. It handles functional inequality constraints by making use of penalty functions.
- Gradient methods are better fitted to highly constrained problems.
- Gradient methods can accommodate non-linearity easily compared to Quadratic method.
- Compact explicit gradient methods are very efficient, reliable, accurate and fast.

This is true when the optimal step in the gradient direction is computed automatically through quadratic developments.

***Demerits:***

- The higher the dimension of the gradient, the higher the accuracy of the OPF solution. However 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.
- Gradient method suffers from the difficulty of handling all the inequality constraints usually encountered in optimum power flow.
- During the problem solving process, the direction of the Gradient has to be changed often and this leads to a very slow convergences. This is predominant, especially during the enforcement of penalty function; the selection of degree of penalty has bearing on the convergence.
- Gradient methods basically exhibit slow convergence characteristics near the optimal solution.
- These methods are difficult to solve in the presence of inequality constraints.

***Newton Method:***

In the area of Power systems, Newton's method is well known for solution of Power Flow. It has been the standard solution algorithm for the power flow problem for a long time The Newton approach is a flexible formulation that can be adopted to develop different OPF algorithms suited to the requirements of different applications. Althoughthe Newton roach exists as a concept entirely apart from any specific method of

implementation, it would not be possible to develop practical OPF programs without employing special sparsity techniques. The concept and the techniques together comprise the given approach. Other Newton-based approaches are possible. Newton's method is a very powerful solution algorithm because of its rapid convergence near the solution. This property is especially useful for power system applications because an initial guess near the solution is easily attained. System voltages will be near rated system values, generator outputs can be estimated from historical data, and transformer tap ratios will be near 1.0 p.u. The Merits and Demerits of Newton Method are summarized and given below.

***Merits:***

- The method has the ability to converge fast.
- It can handle inequality constraints very well.
- In this method, binding inequality constraints are to be identified, which helps in fast convergence.
- For any given set of binding constraints, the process converges to the Kuhn- Tucker conditions in less iteration.
- The Newton approach is a flexible formulation that can be used to develop different OPF algorithms to the requirements of different applications.
- With this method efficient and robust solutions can be obtained for problems of any practical size.
- Solution time varies approximately in proportion to network size and is relatively independent of the number of controls or inequality constraints.
- There is no need of user supplied tuning and scaling factors for the optimisationprocess.

***Demerits:***

- The penalty near the limit is very small by which the optimal solution will tend to the variable to float over the limit
- It is not possible to develop practical OPF programs without employing sparsity techniques.
- Newton based techniques have a drawback of the convergence characteristics that are sensitive to the initial conditions and they may even fail to converge due to inappropriate initial conditions.

***Linear Programming Method:***

Linear Programming (L.P) method treats problems having constraints and objective functions formulated in linear form with non-negative variables. Basically the simplex method is well known to be very effective for solving LP problems.

The Linear Programming approach has been advocated on the grounds that

(a) The L.P solution process is completely reliable.

(b) The L.P solutions can be very fast.

(c) The accuracy and scope of linearized model is adequate for most engineering purposes.

It may be noted that point (a) is certainly true while point (b) depends on the specific algorithms and problem formulations. The observation (c) is frequently valid since the transmission network is quasi linear, but it needs to be checked out for any given system and application. The Merits and Demerits of Linear Programming Method are summarized and given below.

***Merits:***

- The LP method easily handles Non linearity constraints.
- It is efficient in handling of inequalities. 15
- Deals effectively with local constraints.
- It has ability for incorporation of contingency constraints.
- The latest LP methods have overcome the difficulties of solving the non-separable loss minimisation problem, limitations on the modelling of generator cost curves.
- There is no requirement to start from a feasible point .The process is entered with a solved or unsolved power flow. If a reactive balance is not initially achievable, the first power flow solution switches in or out the necessary amount of controlled VAR compensation.
- The LP solution is completely reliable.
- It has the ability to detect infeasible solution.
- The LP solution can be very fast.
- The advantages of LP approach such as, complete computational reliability and very high speed enables it, suitable for real time or steady mode purposes.

***Demerits***

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

***Quadratic Programming Method:***

Quadratic Programming (QP) is a special form of NLP. The objective function of QP optimization model is quadratic and the constraints are in linear form. Quadratic Programming has higher accuracy than LP – based approaches. Especially the most often used objective function is a quadratic.

The NLP having the objective function and constraints described in Quadratic form is having lot of practical importance and is referred to as quadratic optimization.

The special case of NLP where the objective function is quadratic (i.e. is involving the square, cross product of one or more variables) and constraints described in linear form is known as quadratic programming. Derivation of the sensitivity method is aimed at solving the NLP on the computer. Apart from being a common form for many important problems, Quadratic Programming is also very important because many of the problems are often solved as a series of QP or Sequential Quadratic Programming (SQP) problems.

Quadratic Programming based optimization is involved in power systems for maintaining a desired 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. Further, the quadratic functions are characterized by the matrices and vectors. The Merits and Demerits of Quadratic Programming Method are summarized and given below.

***Merits:***

- The method is suited to infeasible or divergent starting points.
- Optimum Power Flow in ill conditioned and divergent systems can be solved in most cases.
- The Quadratic Programming method does not require the use of penalty factors or the determination of gradient step size which can cause convergence difficulties.

In this way convergence is very fast.

- The method can solve both the load flow and economic dispatch problems.
- During the optimization phase all intermediate results feasible and the algorithm indicates whether or not a feasible solution is possible.
- The accuracy of QP method is much higher compared to other established methods.

***Demerits:***

- The main problem of using the Quadratic Programming in Reactive Power Optimization is a) Convergence of approximating programming cycle. b) Difficulties in obtaining solution of quadratic programming in large dimension of approximating QP problems. c) Complexity and reliability of quadratic programming algorithms.
- QP based techniques have some disadvantages associated with the piecewise quadratic cost approximations.

***Interior Point Method:***

It has been found that, the projective scaling algorithm for linear programming proposed by N. Karmarkar is characterized by significant speed advantages for large problems reported to be as much as 12:1 when compared to the simplex method. Further,

this method has a polynomial bound on worst-case running time that is better than the ellipsoid algorithms. Karmarkar‟s algorithm is significantly different from Dantzig‟s simplex method. Karmarkar‟s interior point rarely visits too many extreme points before an optimal point is found. In addition, the IP method stays in the interior of the polytope and tries to position a current solution as the "center of the universe" in finding a better direction for the next move. By properly choosing the step lengths, an optimal solution is achieved after a number of iterations. Although this IP approach requires more computational time in finding a moving direction than the traditional simplex method, better moving direction is achieved resulting in less iteration. In this way, the IP approach has become a major rival of the simplex method and has attracted attention in the optimization community. Several variants of interior points have been proposed and successfully applied to optimal power flow. The Interior Point Method (IPM) can solve a large scale linear programming problem by moving through the interior, rather than the boundary as in the simplex method, of the feasible reason to find an optimal solution. The IP method was originally proposed to solve linear programming problems; however later it was implemented to efficiently handle quadratic programming problems. The Merits and Demerits of Interior Point Method are given below

***Merits:***

- The Interior Point Method is one of the most efficient algorithms. Maintains good accuracy while achieving great advantages in speed of convergence of as much as 12:1 in some cases when compared with other known linear programming techniques.
- The Interior Point Method can solve a large scale linear programming problem by moving through the interior, rather than the boundary as in the simplex method, of the feasible region to find an optimal solution.
- The Interior Point Method is preferably adapted to OPF due to its reliability, speed and accuracy.
- Automatic objective selection (Economic Dispatch, VAR planning and Loss Minimization options) based on system analysis.
- IP provides user interaction in the selection of constraints.

***Demerits:***

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

**Intelligent Methods:**

To overcome the limitations and deficiencies in analytical methods, Intelligent methods based on Artificial Intelligence (AI) techniques have been developed in the recent past. The major advantage of the intelligent methods is that they are relatively versatile for handling various qualitative constraints. These methods can find multiple optimal solutions in single simulation run. So they are quite suitable in solving multi objective optimization problems. In most cases, they can find the global optimum solution. The main advantages of intelligent methods are: Possesses learning ability, fast, appropriate for non-linear modeling, etc. whereas, large dimensionality and the choice of training methodology are some disadvantages of intelligent methods.

***Binary Coded Genetic Algorithm Method:***

GAs differs from other optimization and search procedures. GAs work with a coding of the parameter set, not the parameters themselves. Therefore GAs can easily handle the integer or discrete variables. GAs search within a population of points, not a single point. Therefore GAs can provide a globally optimal solution. GAs use only objective function information, not derivatives or other auxiliary knowledge. Therefore GAs can deal with non-smooth, non-continuous and non-differentiable functions which are actually exist in a practical optimization problem. GAs use probabilistic transition rules, not deterministic rules. We use GA because the features of GA are different from other search techniques in several aspects, such as: First, the algorithm is a multipath that searches many peaks in parallel and hence reducing the possibility of local minimum trapping. Secondly, GA works with a coding of parameters instead of the parameters themselves. The coding of parameter will help the genetic operator to evolve the current state into the next state with minimum computations. Thirdly, GA evaluates the fitness of each string to guide its search instead of the optimization function. The Merits and Demerits of Genetic Algorithm are summarized and given below.

***Merits:***

- GAs can handle the Integer or discrete variables.
- GAs can provide a globally optimum solution as it can avoid the trap of local optima.
- GAs can deal with the non-smooth, non-continuous, non-convex and non-differentiable functions which actually exist in practical optimization problems.
- GAs has the potential to find solutions in many different areas of the search space simultaneously, there by multiple objectives can be achieved in single run.
- GAs is adaptable to change, ability to generate large number of solutions and rapid convergence.
- GAs can be easily coded to work on parallel computers.

***De Merits:***

- GAs is stochastic algorithms and the solution they provide to the OPF problem is not guaranteed to be optimum.
- The execution time and the quality of the solution, deteriorate with the increase of the chromosome length, i.e., the OPF problem size. If the size of the power system is increasing, the GA approach can produce more in feasible off springs which may lead to wastage of computational efforts.

***Particle Swarm Optimization Method:***

Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling. The Merits and Demerits of PSO Method are given below

***Merits:***

- PSO is one of the modern heuristic algorithms capable to solve large-scale non convex optimization problems like OPF.
- The main advantages of PSO algorithms are: simple concept, easy implementation, relative robustness to control parameters and computational efficiency.
- The prominent merit of PSO is its fast convergence speed.
- PSO algorithm can be realized simply for less parameter adjusting.
- PSO can easily deal with non-differentiable and non-convex objective functions.
- PSO has the flexibility to control the balance between the global and local exploration of the search space.

***Demerits***:

- The candidate solutions in PSO are coded as a set of real numbers. But, most of the control variables such as transformer taps settings and switchable shunt capacitors change in discrete manner. Real coding of these variables represents a limitation of PSO methods as simple round-off calculations may lead to significant errors.
- Slow convergence in refined search stage (weak local search ability).

**Particle Swarm Optimisation:**

Optimal power flow subject to power system security constraints is solved in [23] with PSO. Optimal power flow problem by incorporation of penalty function using improved particle swam optimization algorithm is proposed in [24].

A hybrid algorithm is developed in [25] using linear interior point algorithm and the chaos optimization algorithm for optimal power flow. In [26], a hybrid algorithm with SLP and chaos optimization for optimal power flow problems with multimodal characteristic is considered. The results conveyed were promising and inspiring for further research in this direction.

The PSO algorithms by Constriction Factor Approach (CFA) and Inertia Weight Approach (IWA) are the same except the calculation of velocity. Unlike other Evolutionary Computation methods, Particle Swarm Optimization with Constriction Factor Approach ensures the convergence of the search procedures based on mathematical theory [27].

Evolutionary Particle Swarm Optimization (EPSO), which combines evolutionary strategy with conventional Particle swarm optimization algorithm and it can be used to solve diversity of problems in any scientific area [28].

The inherent drawbacks of PSO are: increasing the chances of getting trapped in local minima instead of global minimum if the initialized particles are located in a local space as the initialization process is done randomly, depending the speed of search on the particle separations [29].

To overcome the drawbacks in PSO, various some improved PSO and hybrid methods are addressed.

Improved PSO (IPSO): It uses a combination of chaotic sequences and conventional linearly decreasing inertia weights and crossover operation to increase both exploration and exploitation capability of PSO [30].

New PSO (NPSO): In this method, the particle is modified in order to remember its worst position. This modification is improved to explore the search space very effectively [31].

NPSO with local random search (NPSO-LRS): Integrating a simple random search (LRS) procedure with NPSO, guaranties that the promising solution region is exploited well [31]. LRS is a modification of direct search technique.

Modified PSO (MPSO): This approach is a mechanism to cope with the equality and inequality constraints. Furthermore, a dynamic search-space reduction strategy is employed to accelerate the optimization process [32].

Self-Organizing Hierarchical Particle Swarm Optimization (SOH-PSO): In this method when population stagnates at local optima, the particle velocities are reinitialized [32].

Simulated Annealing PSO (SA-PSO): This plan could effectively prevent gaining impracticable solution by use of stochastic search methods [33].

HPSO: This approach is a blend of Binary Particle Swarm Optimization (BPSO) [34] and Real Coded PSO (RCPSO) [35].

PSO with Differentially perturbed Velocity (PSO-DV): The particle velocities are perturbed by a new term containing the weighted difference of the position vectors of any two distinct particles randomly chosen from the swarm [36].

APSO-DV: employs differentially perturbed velocity with adaptive acceleration coefficient for updating the positions of particles for the PSO [36].

PSO-MASF: In this parallel algorithm, the range within which the random cognitive and social learning parameters are to be chosen is bounded [37].

PSO-RVM: A method of incorporating a real-valued mutation (RVM) operator into the PSO algorithms, aimed at enhancing global search capability [38].

HPA (hybrid PSO ANFIS (Adaptive Network based Fuzzy Inference System)): The PSO is used to train the parameters associated with the membership functions of fuzzy inference system [39].

In this project work, new hybrid optimization algorithms to overcome the limitations of both conventional and evolutionary algorithms are proposed for effective optimal power flow. It begins with applying conventional method to obtain optimal solutions by taking all the initial randomly generated solutions as inputs, and then the outputs are introduced into initial populations for evolutionary algorithms.

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