Optimal Power Flow Methods: A Comprehensive Survey

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Abstract - Power flow study (load-flow study) is a steady-state analysis whose target is to determine the voltages, currents, and real and reactive power flows in a system under a given load conditions. The objective of an Optimal Power Flow (OPF) study is to find steady state operation point which minimizes generation cost, loss, emission etc. Over the past half-century, OPF has become one of the most important and widely studied nonlinear optimization problems while maintaining an acceptable system performance in terms of limits on generators’ real and reactive powers, line flow limits, output of various compensating devices etc. Traditionally, classical optimization methods were used to effectively solve OPF. But more recently due to incorporation of FACTS devices and deregulation of a power sector, the traditional concepts and practices of power systems are superimposed by an economic market management. Therefore, OPF has become complex. In recent years, Artificial Intelligence (AI) methods have been emerged which can solve highly complex OPF problems. The purpose of this paper is to present a comprehensive survey of various optimization methods like traditional and AI methods used to solve OPF problems.

Index Terms
Artificial Intelligence, Optimal Power Flow

I. INTRODUCTION


II. PROBLEM FORMULATION

The optimal power flow problem is concerned with optimization of steady state power system performance with respect to an objective function while subjected to various equality and inequality constraints. For optimal active power dispatch, the objective function $F$ (total generation cost) is given by the following equation

- Minimize $F_T = \sum_{i=1}^{Ng} a_i + b_i P_i + c_i P_i^2 \quad $$/hr$

Where,
- $F_T$: Total quadratic cost function; it could be also a cubic function
- $P_i$: Real power generated
- $Ng$: Number of generation busses
- $a_i, b_i, c_i$: Fuel cost coefficients for $i$th unit
- Subject to various constraints.

(a) Active power balance in the network

$P_i (V, \delta) - P_{gi} + P_{di} = 0 \quad (i=1, 2, \ldots, NB)$

(b) Reactive power balance in the network

$Q_i (V, \delta) - Q_{gi} + Q_{di} = 0 \quad (i= NV +1, NV + 2, \ldots, NB)$

(c) Security-related constraints called soft constraints.

- Limits on real power generations
  $P_{gimin} \leq P_{gi} \leq P_{gimax} \quad (i=1, 2, NG)$
- Limits on voltage generation
  $V_{imin} \leq V_{i} \leq V_{imax} \quad (i= NV +1, NV + 2, \ldots, NB)$
- Limits on voltage angles

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\[
\delta_{\text{imin}} \leq \delta_i \leq \delta_{\text{imax}} \quad (i=1, 2, \ldots, \text{NB})
\]

- Real power flow equations are:
\[
P_i(V, \delta) = \sum_{j=1}^{\text{NB}} V_j (G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j))
\]

- Reactive power flow equations are:
\[
Q_i(V, \delta) = \sum_{j=1}^{\text{NB}} V_j (G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j))
\]

where \(\text{NG}\) is the number of generator buses, \(\text{NB}\) is number of buses, \(\text{NV}\) is number of voltage controlled buses, \(P_i\) is active power injection into bus \(i\), \(Q_i\) is reactive power injection into bus \(i\), \(P_{di}\) is active load on bus \(i\), \(Q_{di}\) is reactive load on bus \(i\), \(P_{gi}\) is active power generation on bus \(i\), \(Q_{gi}\) is reactive power generation on bus \(i\), \(V_i\) is magnitude of the voltage at \(i\)th bus, \(\delta_i\) is voltage phase angle of bus \(i\), and \(Y_{ij} = G_{ij} + jB_{ij}\) are the elements of admittance matrix.

III. OPTIMAL POWER FLOW METHODS

The optimal power flow solution methods are classified into two categories: Traditional methods and Artificial Intelligence based methods as shown in Fig. 1.

Traditional methods are called deterministic or conventional optimization methods. 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, the popular conventional methods are further subdivided into the following:

1. Linear Programming
2. Gradient methods
3. Quadratic Programming
4. Newton-Raphson
5. Nonlinear Programming
6. Interior Point

Even though, excellent advancements have been made in classical methods, they suffer from the following disadvantages:

1. Some required linearization
2. Some required differentiability
3. May get stuck at local optimum
4. Poor convergence
5. Weak in handling qualitative constraints
6. Become too slow if number of variables are large
7. Can find only a single optimized solution in a single simulation run

a) LINEAR PROGRAMMING

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

Mukherjee, S.K. [11] presented a linear programming based optimization method for optimal power flow. Results show that a 220 kV five-bus system convergence within only one iteration was achieved with a considerable reduction in CPU time. The technique has been recommended to Florida Power and Light Company’s Power System Control Division and has proved successful for a 15 bus system using real-time data.

T.S. Chung et al. [12] presented a linear programming method for minimizing power loss and finding the optimal location for capacitor in a distribution system. Calculation is carried at 14-bus system and this method does not require any matrix inversion, thus saves computational time and memory space.

E. Lobato et al. [13] presented a linear programming based method for OPF for minimization of
power loss and generator reactive margins for Spanish power system. Shunt reactors and capacitors are discrete, modeled by integer variables. Both the objective function and the constraints are linearized in each iteration.

Rau, N. [14, 15] presented DC power flow formulation which involves simplifying assumptions and linearization with a linear (or linearized) objective function. Since the DC power flow constraint set is fully linear, no further constraint linearization is needed. In contrast to other linearization techniques, DC-OPF is non-iterative; only a single solve is required to yield the optimal solution. Because of its simplicity, speed, and robust nature, DC-OPF is widely used in industry.

b) GRADIENT METHOD

Gradient methods were among the first attempts to solve practical OPF problems at the end of the 1960s. Gradient methods use the 1st order derivative vector of the objective function of a non-linear optimization (that is, the gradient) to determine improving directions for the solution in iterative steps. Gradient methods are reliable, easy to implement, and guaranteed to converge for well-behaved functions. However, gradient methods are slow compared to higher-order methods.

Dommel and Tinney [16] presented a gradient method to OPF problem, using penalty techniques to enforce the limits on the dependent variables and the functional constraints. This work relied on 1st order information of the (nonlinear) objective and the constraints derived from the Jacobian matrix computed from a conventional power flow.

Alsac and Stott [17] extended the work of Dommel and Tinney to security-constrained OPF (SCOPF) by adding predetermined contingency cases to the power flow equations and penalizing security violations of these cases in the objective function.

Peschon et al. [18] presented an application of the Generalized Reduced Gradient (GRC) method to OPF, presenting the benefits of the GRC method. These benefits include the avoidance of penalty terms and the straightforward computation of sensitivities.

c) QUADRATIC PROGRAMMING

Quadratic Programming (QP) is a special form of non-linear programming whose objective function is quadratic and constraints are linear.

J.A. Momoh [19] presented a generalized Quadratic-based model for OPF. The construction of the OPF algorithm includes the conditions for feasibility, convergence and optimality. It is also capable of using hierarchical structures to include multiple objective functions. The 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.

N. Grudinin [20] presented a reactive power optimization model based on Successive Quadratic Programming (SQP) methods. Six other optimization methods were used to test the IEEE 30-bus and 278-bus systems. It is found that the SQP methods provide more fast and reliable optimization in comparison with other classical methods.

Reid and Hasdorff [21] presented QP OPF using the Lagrange multiplier method and Taylor expansion. Economic dispatch problem is formulated as a quadratic programming problem and solved using Wolfe’s algorithm. The method is capable of handling both equality and inequality constraints on p, q, and v and can solve the load flow as well as the economic dispatch problem. Convergence was obtained in three iterations for all test systems considered and solution time is small enough to allow the method to be used for on-line dispatching at practical time intervals.

d) NEWTON – RAPHSON MEHTOD

Newton method is a second order method for unconstrained optimization based on the application of a 2nd order Taylor series expansion about the current candidate solution.

S. Chen et al. [22] presented Newton-Raphson (NR) method to solve emission dispatch in real-time with sensitivity factors incorporated. The Jacobian matrix and the coefficients have been developed in terms of the generalized generation shift distribution factor. Penalty factor and the incremental losses are easily obtained. Run time is lesser than that of the conventional one.

K.L. Lo et al. [23] presented 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. These two methods are compared with the Newton-based full AC load flow method and the fast decoupled load flow to show their better convergence characteristics.

H. Ambriz-Pérez [24] presented unified power flow controller (UPFC) modeling within the context of optimal power flow (OPF) by Newton Method. The networks are modified to include several UPFCs are solved with equal reliability. The UPFC model itself is very flexible; it allows the control of active and reactive powers and voltage magnitude simultaneously. It can
also be set to control one or more of these parameters in any combination or to control none of them.

e) **NON LINEAR PROGRAMMING**

Nonlinear programming (NLP) deals with problems involving nonlinear objective and/or constraint functions. The main advantage of NLP formulations for OPF is that they accurately capture power system behavior. However, the computational and theoretical challenges associated with NLP motivated the development of simplified formulations, as discussed below. In addition, certain NLP formulations redefine the problem variables to reduce the degree of nonlinearity.

J.A. Momoh et al. [25] presented a new nonlinear convex network flow programming (NLCNFP) model for solving the multi-area security constrained economic dispatch (MAED) problem. A combined method of quadratic programming and network flow programming used to solve MAED problem. The tie-line security and transfer constraints are considered in each area. Method is tested in four interconnected power systems.

D. Pudjianto et al. [26] presented LP and NLP for reactive OPF for allocating reactive power among generators in a deregulated environment. It was found that the overall cost associated with the system reactive requirement calculated by LP method was reasonably accurate, but the generator’s individual commitment may vary considerably. Whereas, NLP offers a faster computation speed and accuracy for the solution but the convergence could not be guaranteed for every condition.

H. Habibollahzadeh [27] presented hydrothermal OPF based on a combined LP and NLP methods. Hydraulic modeling of systems with considerable share of hydraulic generation is also considered. It used the LP technique to help the Generalized Reduced Gradient technique in a feasibility adjustment step and feasible directions method for solving nonlinear programming problems has been used.

f) **INTERIOR POINT METHOD**

Interior Point Methods (IPMs) are a family of projective scaling algorithms for solving linear and nonlinear optimization problems that constrain the search to the feasible region by introducing barrier terms to the objective function. In general, IPMs attempt to determine and follow a central path through the feasible region to the optimal solution.

Sergio Granville [28] presented IPM to the optimal reactive power dispatch problem. It is based on the primal dual logarithmic. This method was applied on large power systems and it converged in 40 iterations at CPU time 398.9 seconds. IPM advantages are: 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.

Torres, G.L. [29] presented the solution of an optimal power flow (OPF) problem in rectangular form by an IPM for nonlinear programming. OPF problem is solved via a primal-dual IPM for NLP. Objective function and constraints are quadratic. Desirable properties of a quadratic function are: (a) its Hessian is constant, (b) its Taylor expansion terminates at the second-order without error, and (c) the higher-order term is easily evaluated. Such quadratic features allow for ease of matrix setup and inexpensive incorporation of higher order information in a predictor-corrector procedure that reduces the number of IPM iterations to convergence.

Edgardo D. Castronuovo [30] presented new versions of interior point methods applied to the optimal power flow problem. Search for the optimum is based on the combination of two directions: the affine-scaling and the centralization, it is shown that the suitable combination of these directions can increase the potential of the optimization algorithm in terms of speed and reliability. To solve optimization problems through the IPM for Nonlinear Programming (NLP) a perturbation parameter is introduced in the complementarily Karush-Kuhn-Tucker (KKT) condition.

Hua Wei et al. [31] presented a new interior point nonlinear programming algorithm for optimal power flow problems (OPF) based on the perturbed KKT conditions of the primal problem. Through the concept of the centering direction, authors extend this algorithm to classical power flow (PF) and approximate OPF problems. Compared with the conventional data structure of Newton OPF, the number of fill-ins of the proposed scheme is roughly halved and CPU time is reduced by about 15% for large scale systems. The proposed algorithm includes four kinds of objective functions and two different data structures. Extensive numerical simulations on test systems that range in size from 14 to 1047 buses have shown that the proposed method is very promising for large scale application due to its robustness and fast execution time.

V. **ARTIFICIAL INTELLIGENCE METHODS**
The intelligent search has become a very important technique in searching the global or near-global optimal solution. It also called Non-deterministic or stochastic method, major advantages of these methods are:
1. Able to handle various qualitative constraints
2. Can find multiple optimal solutions in single simulation run
3. Suitable in solving multi-objective optimization problems
4. Can find the global optimum solution

Number of non-deterministic optimization methods have been developed and applied to global optimization problems to overcome the weak global search capabilities of many conventional deterministic optimization algorithms. Many of these techniques have been applied to OPF problems like:
1. Genetic algorithm
2. Particle swarm
3. Artificial neural network
4. Bee colony optimization
5. Differential evolution
6. Grey wolf optimizer
7. Shuffled frog-leaping

a) GENETIC ALGORITHM

Genetic Algorithm (GA) operates on the encoded binary string of the problem parameters rather than the actual parameters of the system. Each string can be thought of as a chromosome that completely describes one candidate solution to the problem. A simple Genetic Algorithm is an iterative procedure. During each iteration step (generation) three genetic operators (Selection, crossover, and mutation) are performing to generate new populations (offspring).

Bakritz, V. [32] presented economic dispatch problems using genetic algorithm method. 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 (EGA method) proportionately increases with size of the system.

Po-Hung Chen [33] presented a large scale economic dispatch problem by GA. He designed new encoding technique where in, the chromosome has only an encoding normalized incremental cost. There is no correlation between total number of bits in the chromosome and number of units. The unique characteristic of Genetic Approach is significant in big and intricate systems which other approaches fails to accomplish. Dispatch is made more practical by flexibility in GA, due to consideration of network losses, ramp rate limits and prohibited zone’s avoidance. This method takes lesser time compared to Lambda –iteration method in big systems.

M. Younes and M. Rahl [34] presented hybrid Genetic Algorithm (combination of GA and Mat power) that was used to solve OPF including active and reactive power dispatches. The method uses GA to get a close to global solution and the package of MATLAB m files for solving power flow and optimal power flow problem (mat power) to decide the optimal global solution. Mat power is employed to adjust the control variables to attain the global solution. The method was validated on the modified IEEE 57-bus system and the results show that the hybrid approach provides a good solution as compared to GA or Mat power alone.

M. Sailaja Kumari [35] presented OPF problem formulated as a multi-objective optimization problem, where optimal control settings for simultaneous minimization of fuel cost and loss, loss and voltage stability index, fuel cost and voltage stability index and finally fuel cost, loss and voltage stability index are obtained, it combines a new Decoupled Quadratic Load Flow (DQLF) solution with Enhanced Genetic Algorithm (EGA) to solve the OPF problem. A Strength Pareto Evolutionary Algorithm (SPEA) based approach with strongly dominated set of solutions is used to form the pareto-optimal set.

b) PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a population-based stochastic optimization Technique. PSO is based on processes arising naturally in socially organized colonies such as flocks of birds and schools of fish. PSO exploits a population of individuals to explore promising regions within the search space. In the search procedure, each individual (particle) moves within the decision space over time and changes its position in accordance with its own best experience and the current best particle according to the model shown in Fig. 2.
El-Gallad et al. [37] presented PSO to solve the traditional economic dispatch problem. The objective function was formulated as a combination of piecewise quadratic cost functions with non-differential regions, instead of adopting a single convex function for each generating unit. This innovation in problem formulation is due to the incorporation of practical operating conditions, like valve-point effects and fuel types where system demand and the balance of power, with network losses incorporated and the generating capacity limits.

Djillani Ben Attous [38] presented economic dispatch problem with a valve point effects. A valve point effects is the rippling effects added to the generating unit curve when each steam admission valve in a turbine starts to open. Proposed method using PSO has been examined and tested for standard IEEE 30-bus system, it has been found that PSO method is highly competitive for its better general convergence performance.

Sanjeev Kumar [39] presented PSO and integration of GA-fuzzy and PSO-fuzzy optimization to calculate optimal power flow. The four algorithms GA, GA-fuzzy, PSO, and FPSO are tested for solving modified IEEE 30 bus test system. It is found that integration of fuzzy with Genetic Algorithm and particle swarm optimization techniques improve the performance of average fitness obtained with the help of optimal power flow method. The results of integrated GA-Fuzzy and PSO-fuzzy are compared with simple GA and PSO and found synergetic approaches are better.

T. Saravanan [40] presented the application of PSO technique to solve OPF with inequality constraints on line flow. Algorithm is implemented on a six-unit system and the results are compared with linear programming method.

J. Praveen and B. Srinivasa Rao [41] presented optimization problem solved by PSO with power injection model of the FACTS device. The proposed methodology is tested on standard IEEE 30-bus test system and the results are compared for single objective optimization with and without FACTS device.

c) ARTIFICIAL NEURAL NETWORK

Artificial neural network (ANN) is an interconnected group of artificial neurons that use a mathematical model or computational model for information processing based on a connectionist approach to computation. Mat Syai’in [42] presented a novel algorithm of an optimal power flow (OPF). The proposed algorithm uses neural networks (NNs) to model the generator capability curves and set them as the output power constraints of the generators. In addition, it also uses NNs to replace an OPF based on the particle swarm optimization (PSO) method so as to run in real time. Also, in order for the proposed algorithm to be able to account for various load conditions, a 500 kV Java-Bali power system consisting of 23 buses is used as a benchmark system to validate the proposed NN-based OPF. The simulation results show that that the values obtained from the proposed algorithm are in great agreement with those calculated from the PSO-OPF. Method procedure is shown in Fig. 3.

Nakawiro and Erlich [43] presented a speedup strategy for OPF that uses a dedicated ANN to perform the function of a power flow program. The ANN is combined with a GA, which performs the optimization. Tests show that their method significantly speeds up the solution process compared to GAs alone, while providing solutions of similar quality.
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It stays on a food source and provides the neighborhood of the source in its memory.

2. Onlooker bee
It gets the information of food sources from the employed bees in the hive and selects one of the food.

3. Scout bee
It is responsible for finding new food, the new nectar sources. The process is shown in Fig. 4.

Fig. 4 - Foraging behavior of honeybees to find food sources [45]

Sumpavakup et al. [46] presented ABC to solve the optimal power flow problems. The effectiveness of the Bees Algorithm was verified by testing with IEEE-14 and IEEE-30 bus system. The technique was also compared with other swarm intelligence techniques namely, Genetic Algorithms and Particle Swarm Optimization and its simulation results show that Bees Algorithm can converge towards the better solution slightly faster than the rest methods.

Khorsandi [47] presented a fuzzy based modified artificial bee colony (MABC) algorithm to solve discrete optimal power flow (OPF) problem that has both discrete and continuous variables considering valve point effects. The OPF problem is formulated as a multi-objective mixed-integer nonlinear problem, where optimal settings of the OPF control variables for simultaneous minimization of total fuel cost of thermal units, total emission, total real power losses, and voltage deviation are obtained. The proposed approach is applied to the OPF problem on IEEE 30-bus and IEEE 118-bus test systems. The performance and operation of the proposed approach is compared with the conventional methods. The results confirm that the MABC algorithm is more effective in global search exploration and faster than the other algorithms.

A. N. Afandi and H. Miyauchi [48] developed a Harvest Season Artificial Bee Colony algorithm to improve performance in terms of the search mechanism...
and convergence speed. The effectiveness of the proposed method was tested on IEEE-62 bus system and compared to those obtained by ABC, SFABC, SBABC, MOABC and IABC. The numerical results showed that the proposed method reduced the number of iterations.

e) DIFFERENTIAL EVOLUTION
Differential Evolution (DE) is a population-based, direct stochastic search algorithm. DE combines simple arithmetic operators with the classical evolutionary operators of crossover, mutation and selection to evolve from a randomly generated starting population to a final solution. DE uses a greedy, rather than stochastic, approach to solve the problem. DE procedure is shown in Fig. 5.

Fig. 5 - DE flow chart [48]

Coelho and Mariani [49] presented improved DE algorithms to solve economic dispatch problems of electric energy that takes into account nonlinear generator features such as ramp rate limits and prohibited operating zones. Two economic dispatch problems with 6 and 15 thermal units with ramp rate limits and prohibited operating zones in the power system operation and transmission loss are employed to demonstrate the performance of this method. DE algorithms offer potential advantages: they find the true global minimum regardless of the initial parameter values, and they display fast convergence and use few control parameters.

M. A. Abido [50] presented a multi-objective differential-evolution-based approach to solve the optimal power flow (OPF) problem where different objective functions and operational constraints have been considered and also clustering algorithm is applied to manage the size of the Pareto. An algorithm based on fuzzy set theory is used to extract the best compromise solution. Results on IEEE 30-bus and IEEE 118-bus standard test systems show the effectiveness of the proposed approach in solving true multi-objective OPF and also finding well-distributed Pareto-optimal solutions.

Sayah and Zehar [51] presented DE for solving OPF with non-smooth and non-convex generator fuel cost curves. They consider effective modifications in the mutation, enhancing the convergence rate while improving the solution quality. They also showed that their modified DE algorithm outperforms the classical DE algorithms in global convergence speed and obtains similar results compared to Evolutionary Programming and Tabu Search methods.

f) GREY WOLF OPTIMIZER
Grey wolf optimizer (GWO) is a population based heuristics algorithm simulates the leadership hierarchy and hunting mechanism of gray wolves in nature. Privileged wolves are alpha wolves – decision makers, then beta wolves – alpha assistant, and then delta wolves - lowest ranking and omega are inferior wolves preceded by scoffed kappa and lambda as in Fig. 6.

Fig. 6 - The hierarchy of the grey wolves

El-Fergany and Hasanien [52] presented the grey wolf optimizer to solve the optimal power flow (OPF) problem. The indicator of the static line stability index is incorporated into the OPF problem. The fuzzy-based Pareto front method is tested to find the best compromise point of multi-objective functions. Algorithm used to determine the optimal values of the continuous and discrete control variables. These algorithms are applied to the standard IEEE 30-bus and 118-bus systems with different scenarios.

Sulaiman et al. [53] presented GWO in solving the optimal reactive power dispatch (ORPD) problem. Two case studies of IEEE 30-bus system and IEEE 118-bus system are used to show the effectiveness of GWO technique compared to other techniques. The results of this research show that GWO is able to achieve less
power loss and voltage deviation than those determined by other techniques.

g) **SHUFFLED FROG-LEAPING**

Shuffled frog Leaping algorithm (SFLA) is memetic heuristic that is designed to seek a global optimal solution by performing a heuristic search based on the evolution of memes carried by individuals and a global exchange of information among the population. It combines the benefits of the local search tool of the particle swarm optimization and the idea of mixing information from parallel local searches to move toward a global solution. Shuffling of frogs in memeplexes is shown in Fig. 7.

![Shuffled behavior of leaping frogs in search of food](image)

**Fig. 7 - Shuffled behavior of leaping frogs in search of food [54]**

R. Jahani [55] presented a new method based on shuffled frog leaping algorithm for distributing the power optimized distribution to minimize power production costs and to optimize allocation of every powerhouse share in addition to providing required power for a network. An inferior purpose function is expressed via the basis of units’ productive power and restrictions are modeled in the form of linear equalities and inequality equation. The presented method is simulated on a standard IEEE 30-bus system. Results demonstrate that the algorithm has great potential in functions optimization.

Taher Niknam [56] presented a modified shuffle frog leaping algorithm for multi-objective optimal power flow by considering the emission issue. A modified SLFA called MSLFA algorithm which profits from a mutation in order to reduce the processing time and improve the quality of solutions, particularly to avoid being trapped in local optima. MSLFA algorithm is applied to the 30-bus IEEE test system. The results showed that MSFLA method is capable of obtaining accurate and acceptable solutions.

K. Lenin [57] presented an algorithm based on Modified Shuffled Frog-Leaping Optimization for solving the multi-objective reactive power dispatch problem considering various generator constraints in a power system. This method formulates reactive power dispatch problem as a mixed integer non-linear optimization problem and determines control strategy with continuous and discrete control variables. This paper introduces a new search-acceleration parameter into the formulation of the original shuffled frog leaping algorithm to create a modified form of the shuffled frog algorithm.

**VI. CONCLUSION**

This paper presents a review for various optimization methods used to solve OPF problems. Even though excellent advancements have been made in classical methods they suffer from the following disadvantages: some required linearization and differentiability, may get stuck at local optimum, poor convergence, weak in handling qualitative constraints and become too slow if number of variables are large whereas, the major advantage of the AI methods is that they are relatively versatile for handling various qualitative constraints. AI 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. Table 1 shows advantages and disadvantages of AI methods presented in this survey. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references as well as the previous work done in the field of OPF methods, so that further research work can be carried out.

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Table 1 - Advantages and disadvantages of AI methods [57]-[62]

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<tr>
<th>AI method</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Genetic algorithm</td>
<td>- Capability of solving any optimization problem based on chromosome approach&lt;br&gt;- Capability to handle multiple solution search spaces&lt;br&gt;- Less complex and more straightforward compared to other algorithms</td>
<td>- Does not always come with global optimum all the time.&lt;br&gt;- A tool is dependent on computers speed and only real time application can produce quick respond time.&lt;br&gt;- To a non-professional, the return encoded result maybe not be able to understand</td>
</tr>
<tr>
<td>Particle swarm optimization</td>
<td>- Simple concept and easy implementation&lt;br&gt;- Robust in controlling the few parameters, computationally efficient and requires less memory&lt;br&gt;- It can be easily applied to nonlinear non-continuous optimization problem</td>
<td>- It gets trapped in local optima when handling heavily constraint problems due to limited local/global searching capabilities&lt;br&gt;- Updating is performed without considering quality of solutions and the distance between solutions</td>
</tr>
<tr>
<td>Artificial neural network</td>
<td>- Less formal statistical training,&lt;br&gt;- Ability to detect all possible interactions&lt;br&gt;- Availability of multiple training algorithms.</td>
<td>- Its “black box” nature&lt;br&gt;- Greater computational burden, proneness to over-fitting&lt;br&gt;- The empirical nature of model development.</td>
</tr>
<tr>
<td>Bee colony optimization</td>
<td>- It has few parameters&lt;br&gt;- It is a global optimizer&lt;br&gt;- Flexible</td>
<td>- High computational time</td>
</tr>
<tr>
<td>Differential evolution</td>
<td>- Few control variables and fast convergence&lt;br&gt;- Stable and simple</td>
<td>- The convergence to proper target is very late</td>
</tr>
<tr>
<td>Grey wolf optimizer</td>
<td>- Easy to implement due to its simple structure&lt;br&gt;- Faster convergence&lt;br&gt;- Few parameters to control&lt;br&gt;- Avoids local optima</td>
<td>- The algorithm is still under research and development</td>
</tr>
<tr>
<td>Shuffled frog-leaping</td>
<td>- Robust, accurate, efficient and fast&lt;br&gt;- It combines the profits of the local search tool of PSO and the idea of mixing information from parallel local searches to move toward a global solution</td>
<td>- It gets trapped in local optima&lt;br&gt;- The convergence to proper target is very late</td>
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