COMPARATIVE STUDY OF INTELLIGENT TECHNIQUES FOR SOLVING OPF PROBLEM

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ABSTRACT

In the present day scenario, of electrical power system engineering mainly encompasses the problem like optimal power flow. Optimal power flow problem are becoming increasingly stressed, and more difficult to operate. So, it is mandatory to overthrown these problems. This paper focuses on intelligent techniques and their comparative study for solving the optimal power flow problem. These techniques includes Artificial neural network (ANN) , Fuzzy logic(FL) , Genetic algorithm(GA), Particle swarm optimization (PSO) , Ant colony optimization (ACO),Differential evolution(DE) , Artificial bee colony(ABC). This paper first accord a brief review to these techniques then observations on the pros and cons and lastly shows a comparison of all Intelligent Techniques.

Keywords: Ant colony optimization (ACO), Artificial bee colony (ABC), Differential evolution (DE), Genetic algorithm (GA), Intelligent techniques (IT), Optimal power flow (OPF)

I INTRODUCTION

In present day scenario, power engineering require peculiar tools to optimally analyze, monitor and control different conditions of power systems operation and planning. The OPF is the backbone tool that has been extensively researched. The OPF problem is optimized to find the minimum fuel cost of all generating units while maintaining an acceptable system performance in terms of limits on power outputs of generators, bus voltage and line flow. Initially its introduction, uses and methods are given by Carpentier [1] and its definition as OPF by Dommel and Tinney [2]. OPF has been widely used in power system operation and planning. After the electricity sector restructuring, OPF has been used to assess the spatial variation of electricity prices and congestion management and pricing tool [3]-[4]. The OPF is a non-linear, large scale, non-convex, static optimization problem with both continuous and discrete control variables. The OPF problem is non-convex, due to the presence of the non-linear (AC) power flow equality constraints. The existence of discrete control variables such as transformer tap positions, switchable shunt devices and phase shifters, more complicates the problem solution. Researchers have attempted to apply most optimization techniques to solve OPF. Various [5]-[7] conventional optimization techniques were developed to solve the OPF problem. Some most popular i. e. linear programming, generalized reduced gradient method, quadratic programming and the Newton method. Some of these techniques have good convergence characteristics, but due to the following drawbacks:

- Due to presence of qualitative constraints, weak manipulation.
- Poor convergence.

- They can find only a single optimized solution in a single simulation run.
- If number of variables are large, these techniques becomes slow.
- For solution of a large system, calculation becomes more complex.

So it is important to develop new and more general and reliable techniques for dealing with non-linear OPF problem. For solving these types of problems intelligent methods are very useful. Intelligent methods for solving non-linear hard optimization problems have become a very popular research topic in recent years. There are many papers were published based on these techniques. Suharto, M.N. Hassan [8] presents OPF using evolutionary computation techniques in 2011,Metwally [9] also presents a comparative study of some of these techniques in 2008 etc. The purpose of this paper is to present a comparative study of these intelligent techniques for solving the optimal power flow problems.

1.1 Optimal Power Flow Problem

OPF is formulated mathematically as a general constrained optimization problem.

Minimize a function

$$F\ (u,x) \qquad (1)$$

$$\text{Subject to } h\ (u,x) = 0 \qquad (2)$$

$$\text{And} \quad g\ (u,x) \geq 0 \qquad (3)$$

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

II INTELLIGENT TECHNIQUES

It is the science of making intelligent computer program. Intelligent techniques are based on artificial intelligence. These computing techniques are able to work with problems and information which are too large or complicated for humans to handle, peculiarly in a timely fashion. This expertise management system will explain these techniques, the discrepancy between them, and how they help organizations manage knowledge. There are many definitions but most of them can be classified in to the following four categories:

- Systems that think like humans
- Systems that act like humans
- Systems that think rationally
- Systems that act rationally.

2.1 Arificial Neural Network(ANN)

ANN is an interconnected group of artificial neurons that uses a mathematical model or computational model for information processing based on a connectionist approach to computation. Basic concept of ANN “An ANN is a computational model defined by four parameters: type of neurons, connection architecture, learning algorithm, recall algorithm.

Selvi, V.A.I. [10] presented, In the deregulated power systems, it is important to know the value of Available Transfer Capability for the smooth operation of the power system. ATC is commonly calculated using repeated load-flow simulations of the interconnected transmission network. This paper presents an ANN based approach for online-ATC estimation for both bilateral and multilateral transactions. The proposed approach uses Feed forward neural network trained by Back Propagation Algorithm (BPA) for estimating ATC under normal and contingency condition. The scheduled method is tested on IEEE 24 bus Reliability Test System (RTS) and results are compared with Repeated Power Flow (RPF) results. The experimental results show the suitability of proposed method for on-line ATC estimation.

Sasaki, H.[11] present how to solve power system generation expansion planning by ANN, specially the Hopfield type network. In the first place, generation expansion planning is formulated as a 0-1 integer programming problem and then mapped onto the modified Hopfield neural network that can handle a large number of inequality constraints. The neural network simulated on a digital computer can solve a fairly large problem of 20 units over 10 periods. Although the network cannot give the optimal solution, the results obtained are quite encouraging.

2.2 Fuzzy Logic (Fl)

FL technique is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical predicate logic. FL is able to create rules by inferring knowledge from imprecise, uncertain, or unreliable information. Programmers use imprecisely defined terms, which are known as membership functions. These membership functions are a series of IF-THEN rules; however, fuzzy logic code requires fewer IF-THEN rules than traditional code, which makes it simpler to use and to write. The computer asks the user all questions, then combines the membership function readings in a weighted manner, and finally makes a decision based on the user's answers to all questions

Zhu. J [12] presented comprehensively deals with various uncertain problems in power system operation such as uncertainty load analysis, probabilistic power flow, fuzzy power flow, economic dispatch with uncertainties, fuzzy economic dispatch, hydrothermal system operation with uncertainty, unit commitment (UC) with uncertainties, VAR optimization with uncertain reactive load, and probabilistic optimal power flow (P-OPF). Probabilistic analysis and fuzzy theory can be used to analyze the uncertainty load. A method of obtaining a stochastic model is to take a deterministic model and transform it into a stochastic model by (1) introducing random variables as inputs or as coefficients or as both; and (2) introducing equation errors as disturbances. The economy of UC of power systems is influenced by approximations in the operation planning methods and by the inaccuracies and uncertainties of input data.

N.P. Padhy [13] presented an efficient hybrid model for congestion management analysis for both real and reactive power transaction under deregulated Fuzzy environment of power system. The proposed model determines the optimal bilateral or multilateral transaction and their corresponding load curtailment in two stages. In the first stage classical gradient descent OPF algorithm has been used to determine the set of feasible curtailment strategies for different amount of real and reactive power transactions. In second stage, fuzzy decision opinion matrix has been used to select the optimal transaction strategy.

2.3 Genetic Algorithm

GA is a search algorithm based on mechanism of natural selection and natural genetics. The objective of genetic algorithm is to find the optimal solution to a problem. the program is designed for problem solving based off the evolution process. The program continually re-adjusts, reorganizes and even mutates to continually find a better solution.

Zhu. J [14] Security-constrained economic dispatch (SCED) is a simplified optimal power flow (OPF) problem. It is widely used in the power industry. This chapter introduces several major approaches to solve the SCED problem, such as linear programming (LP), network flow programming (NFP), and quadratic programming (QP). Then, nonlinear convex network flow programming (NLCNFP) and the genetic algorithm (GA) are added to tackle the SCED problem. It also provides the implementation details of these methods and a number of numerical examples. The chapter presents a new NLCNFP model of economic dispatch control (EDC), which is solved by a combination approach of QP and NFP. It also presents a two-stage economic dispatch (ED) approach according to the practical operation situation of power systems. The first stage involves the classic economic power dispatch without considering network loss. The second stage involves ED considering system power loss and network security constraints.

Kilic, U. ; Ayan, K.[15] Optimal reactive power flow (ORPF) is one of the known problems of the power systems. Many numerical and heuristic methods were used to solve this problem so far. As seen from these studies in literature, heuristic methods are more effective and faster than numerical methods. This case is to make more attractive and mandatory the using of heuristic methods in optimal power flow solution of High Voltage Direct Current (HVDC) systems. In this study, ORPF solution of multi-terminal HVDC systems is accomplished by using the genetic algorithm (GA) that is one of the heuristic methods. A new approach is used in opposition to the current-balancing method used mostly in literature for the first time. The proposed approach is tested on the modified IEEE 14-bus test system. The obtained results are compared to that reported in the literature to show validity and effectiveness of the new approach.

2.4 Particle Swarm Optimization (PSO)

PSO is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling. It basically work in three steps :

- Evaluate
- Compare
- Imitate

An organism , a bird in PSO evaluate its neighbors , compare itself to other in the population and then imitates only those neighbor who are superior.so they behave with two kind of information i.e. own experience , and other is knowledge of how other individual performed.

Zhu, j.[16] selects several classic optimal power flow (OPF) algorithms and describes their implementation details. These algorithms include traditional methods such as Newton method, gradient method, linear programming, as well as the latest methods such as modified interior point (IP) method, analytic hierarchy process (AHP), and particle swarm optimization (PSO) method. The goal of OPF is to find the optimal settings of a given power system network that optimizes the system objective functions such as total generation cost, system loss, bus voltage deviation, emission of generating units, number of control actions, and load shedding while satisfying its power flow equations, system security, and equipment operating limits. The phase shifters are adjusted sequentially and their direction of adjustments are governed by the impact on the primary objective function of minimal line overload, in the search technique. This chapter focuses on applying PSO methods to solve the OPF problem.

Anumod, D.M. ; Devesh Raj, M.[17] describes optimal power flow based on particle swarm optimization in which the power transmission loss function is used as the problem objective. Although most of optimal power flow problems involve the total production cost of the entire power system, in some cases some different objective may be chosen. In this paper, to minimize the overall power losses four types of decision variables are participated. They are i) power generated by power plants, ii) specified voltage magnitude at control substations, iii) tap position of on-load tap-changing transformers and iv) reactive power injection from reactive power compensators. Particle swarm optimization (PSO) is well-known and widely accepted as a potential intelligent search methods for solving such a problem. Therefore, PSO-based optimal power flow is formulated and tested in comparison with quasi-Newton method (BFGS), genetic-based (GA-based) optimal power flow. For test, a 6-bus and 30-bus IEEE power system are employed. As a result, the PSO-based optimal power flow gives the best solutions over the BFGS and the GA-based optimal power flow methods.

Jong-Bae Park *et al.* [18] suggested a Modified Particle Swarm Optimization (MPSO) for
economic dispatch with non-smooth cost functions. A position adjustment strategy is proposed to provide the solutions satisfying the inequality constraints. The equality constraint is resolved by reducing the degree of freedom by one at random. Dynamic search-space reduction strategy is devised to accelerate the process. The results obtained from the proposed method are compared with those obtained by GA, TS, EP, MHNN, AHNN and NM methods. It has shown superiority to the conventional methods.

2.5 Ant Colony Optimization (ACO)

ACO is a class of optimization algorithm modeled on the actions of an ant colony. It is a probabilistic technique useful in problems that deals with finding better path through graphs. It is based on the ideas of ant foraging by pheromone communication to make path.

I.K.Yu *et al.* [19] presented a novel co-operative agents approach, Ant Colony Search Algorithm (ACSA)-based scheme, for solving a short-term generation scheduling problem of thermal power systems. The state transition rule, global and local updating rules are also introduced to ensure the optimal solution. Once all the ants have completed their tours, a global pheromone-updating rule is then applied and the process is iterated until the stop condition is satisfied. The feasibility of the algorithm in large systems with more complicated constraints is yet to be investigated.

Libao Shi *et al.* [20] presented ant colony optimization algorithm with random perturbation behavior (RPACO) based on combination of general ant colony optimization and stochastic mechanism 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 ,the penalty cost imposed when any of constraints are violated and the total accumulated cost from stage 0 to stage t. are included in objective function. The security function approach is also applied to evaluate the desired level of system security.

R.Meziane *et al.* [21] used ACO to solve 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) approach is used by the ACO to determine the optimal electrical power network topology.

2.6 Differential Evolutionary (DE)

DE is a method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Such methods are commonly known as meta-heuristics as they make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. However, meta-heuristics such as DE do not guarantee an optimal solution is ever found.

Nayak, M.R. ; Krishnanand, K.R. ; Rout, P.K.[22] presents an algorithm for solving optimal power flow problem through the application of a modified differential evolution algorithm(MDE). The objective of an optimal Power Flow(OPF) is to find steady state operation point which minimizes total generating unit (thermal) fuel cost and total load bus voltage deviation from a specified point while maintaining an acceptable system performance in terms of limits on generator real and reactive power outputs, bus voltages, transformer taps, output of various compensating devices and power flow of transmission lines. Differential Evolution (DE) is one of evolutionary algorithms, which has been used in many optimization problems due to its simplicity and efficiency. The proposed MDE is in the framework of differential evolution owning new mutation operator and selection mechanism. To test the efficacy of the algorithm, it is applied to IEEE 30-bus power system with two different objective functions. The optimal power flow results obtained using MDE are compared with other evolutionary methods. The simulation results reveal that the MDE optimization technique provides better results compared to other methods recently published in the literature as demonstrated by simulation results.

Jithendranath, J. ; Babu, B.Y.[23] presents a significant evolutionary based algorithm for solving conventional Optimal Reactive Power Dispatch (ORPD) problem in power system. This problem was designed as a Multi-Objective case with loss minimization and voltage stability as objectives and Generator terminal voltages, tap setting of transformers and reactive power generation of capacitor banks were taken as optimization variables. Modal analysis method is adopted to assess the voltage stability of system. The above presented problem was solved on basis of efficient and reliable technique among all evolutionary based algorithms, the Differential Evolution Technique. The proposed method has been tested on IEEE 30 bus system where the obtained results were found satisfactorily to a large extent that of reported earlier.

2.7 Arificial Bee Colony (ABC)

It is a meta-heuristic algorithm and simulates the foraging behavior of honey bees. The ABC algorithm has three phases:

- Employed bee
- Onlooker bee
- Scout bee

The solution of the optimization problem is represented by the location of a food source and the quality of the solution is represented by the nectar amount of the source (fitness).

Sumpavakup, C. ; Srikun, I. ; Chusanapiputt, S.[24] Optimal Power Flow (OPF) is one of the most vital tools for power system operation analysis, which requires a complex mathematical formulation to find the best solution. Conventional methods such as Linear Programming, Newton-Raphson and Non-linear Programming were previously offered to tackle the complexity of the OPF. However, with the emergence of artificial intelligence, many novel techniques such as Artificial Neural Networks, Genetic Algorithms, Particle Swarm Optimization and other Swarm Intelligence techniques have also received great attention. This paper described the use of ABC, which is one of the latest computational intelligence to solve the OPF problems. The results show that solving the OPF problem by the ABC can be as effective as other swarm intelligence methods in the literature.

III TABLE

3.1 The given table shows the advantages and disadvantages of all the AI techniques:

Intelligent Techniques	Advantages	Disadvantages
Artificial Neural Network	• Can be used for classification or regression. •Able to represent Boolean Functions (AND, OR, NOT). • Tolerant of noisy inputs. • Instances can be classified by more than one output.	• Difficult to understand structure of algorithm. • Too many attributes can result in Over fitting. • Optimal network structure can only be Determine.
Fuzzy Logic	• Different stochastic relationships can be identified to describe properties. •Accurately represents the operational constraints and fuzzified constraints are softer than traditional constraints.	• Priori knowledge is very important to get good results. • Precise solutions are not obtained if the direction of decision is not clear.

Genetic Algorithm	• Can be used in feature classification and feature selection • Primarily used in optimization always finds a "good" solution (not always the best solution) • Can handle large, complex, non-differentiable and Multimodal spaces. • Efficient search method for a complex problem space. • Good at refining irrelevant and noisy features selected for	• Computation or development of scoring function is Nontrivial. • Not the most efficient method to find some optima, rather than global • Complications involved in the representation of training/output data. • High computation time. • Cannot be applied on continuous variables.
Particle Swarm Optimization	• Solve complex optimization problem which are non-linear, non-convex, non -differentiable and multi model. • Fast convergence speed. • Used to solve bi-objective generation scheduling. • Minimum total cost of power generation. • Simple concept, easy implementation, relative robustness to control parameters and computational efficiency. • PSO algorithm can be realized simply for less parameter adjusting. • PSO has the flexibility to control the balance between the global and local exploration of the search space.	• The candidate solutions in PSO are coded as a set of real numbers. But, most of the control variables such as transformer tap settings and switchable shunt capacitors change in discrete manner. Real coding of these variables represents a limitation of round-off calculations may lead to significant errors. • Slow convergence in refined search stage (weak local search ability).

Ant Colony Optimization	• Positive feedback for recovery of good solution. • Distributed computation which avoid premature convergence.	• It is mainly used only for finding the shortest route in transmission network.
Differential Algorithm	• It is applicable in continuous variables. • The method of differential evolution can be applied to real-valued problems over a continuous space with much more ease than a genetic algorithm.	• It has mutation and crossover but do not have the global best solution in its search equations.
Artificial Bee Colony	• Applicable for both continuous or discrete variables. • Simplicity, flexibility and robustness. • Use of fewer control parameters compared to many other search techniques. • Ease of hybridization with other optimization algorithms. • Ability to handle the objective cost with stochastic nature. • Ease of implementation with basic mathematical and logical operations.	• Data clustering. • Generalized assignment. • Discrete optimum design of truss structure.

3.2 This table shows the comparative study of intelligent techniques:

Features	ANN	FL	GA	PSO	ACO	DE	ABC
Based on	Neurons	Fuzzy set	Chromosomes Or biological systems	Nature inspired or based on social behavior of birds	Action of an ant colony	Same as GA, uses multi-agents to carry out search	Action of bees for searching of food

Applicable to	Non - linear physical series	Continuous variables	Discrete variables only	Continuous variables only		Continuous variables only	Both continuous or discrete variables
Evolution operator	No	No	Crossover and mutation	no	no	Crossover and mutation	No
New solution produce by	Adjusting weight		Crossover	Updating velocities	Pheromone trail	crossover	By its parents
Modification done by			Mutation process			Mutation process	Same as DE and GE, By whole solution in the population is removed.
Solution obtained		Best optimal result in non-inferior domain	No guarantee to find the optimum, but able to find good solution	Gives optimal solution	Gives optimal solution	Do not have global best solution in contrast with PSO	Better performance in term of global optimization
Control parameters	Training set, fine tuning set, test set		Crossover rate, mutation and generation gap	Cognitive and social factors, inertia weight		Crossover rate , scaling factor	Maximum cycle number(MCN),colon-y size (SN)

IV CONCLUSION

In this paper an attempt has been made to review various intelligent techniques used to solve OPF problems. 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. These techniques mainly used to solve Bi-objective generation scheduling, optimal reactive power dispatch and to minimize total cost, to solve Security constrained OPF, Contingency constrained OPF e. t. c. of a deregulated system are explored out. A lot of work has been done on these techniques, there still remain significantly challenging tasks for the research community to address for the realization of many existing and most of the emerging area in technology. In particular, there are great opportunities in examining a new approach/algorithm. For this it requires collaboration of researchers from different communities like artificial intelligence e. t. c. Intelligent techniques are among the most powerful techniques for optimization which is going to have a wide impact on future generation computing.

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