Journal of
Electrical & Electronic Systems

Alkhayyat and Bashi, J Electr Electron Syst 2016, 5:4
DOI: 10.4172/2332-0796.1000209

Research Article | Open Access

A New Survey for Optimum Power Flow with Facts Devices

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Abstract

Optimal Power flow considered the backbone tool in the complex power system. The expanding in demands lead to increasing in generation that requires increase the transmission capacity, for these reasons the problem of optimal power flow OPF still under many studies in order to minimize the cost, losses, emission of harm gases, etc. FACTS is the main articles of this paper include the last nontraditional OPF methods, hybrid methods, multi-objective OPF, and OPF with FACTS devices. Also there are three Tables contain the recent stander and hybrid methods used, mostly, in solving OPF problems with their advantages, disadvantages, and their applications that may help the researchers in this field, eventually some important points have been concluded.

Keywords: Optimal power flow; FACTS; Artificial intelligence

Introduction

Optimal power flow has an important for solving the complex problems in large power systems at many reality constraints. The problems are nonlinear, non-convex, non-differentiable, and non-smooth, so many researches adopted the modification of theories used for solving OPF based on minimizing the consuming time beside achieving the best fitness. For these reasons it might be of interest to represent the historical survey of the researches dealing with this field. In our work, generally, OPF researches are classified in two categories OPF and OPF with FACTS devices. The objectives of OPF without FACTS devices is made to minimize:

1) Total generation cost of thermal units.

2) Total real power loss of transmission system.

3) Gas emission from thermal units.

4) Voltage deviation of system buses.

The first and second objectives could be taken as the main objectives for all optimization problems and could be considered as the own required objective to be solved, but the third and fourth objectives are often taken with the first two main objectives to be multi-objective OPF problem in order to obtain more and more modified state variables.

In the case of OPF with FACTS devices the objectives are the same as listed above plus the additional objectives made to obtain

5) Minimum capacity of the FACTS device(s).

6) Optimal values of controlling variables.

7) Optimal location of FACTS device(s).

The last objective is made based on the sensitivity methods rather than the well-known OPF methods. The last two objectives are done to satisfy one or more of the other objectives, the problem can be extended to contain two or more of the above objectives to be multi-objective OPF. In addition, security constraints optimal power flow SCOPF has the important partition in the OPF researches. However, our review not includes this subject.

OPF Reviews

There are a lot of researches presents a reviews for OPF focusing on the methods used for solving economic dispatch HAPP [1], IEEE group [2], Carpentier [3], Chowdhury and Rahman [4], Momoh et al. [5]. Pandya and Joshi [6] tried to categorize the methods for OPF suitable for the certain objective(s) and compare the traditional OPF methods with AI methods and presents their advantages and drawbacks. When the effect of the large steam turbine valve is included in economic dispatch the characteristic of the cost has local minimum points and the method solving such problem known as the optimal dynamic dispatch ODD. Xia and Elaiw [7] present the literature review of the ODD and categorized their study to conventional methods, artificial intelligence methods, and hybrid methods they concluded that traditional methods like newton methods, lambda iteration method etc. are not effective for solving the non-convex and non-smooth problems but AI can obtain global optimization for this problem successfully with sacrificing more time, the hybrid methods can solve the problem faster. Mary B Cain et al. [8] presented a history of OPF focusing on the power flow, economic dispatch, and OPF and review the most elements for solving PF and OPF, the authors concluded that even 50 years ago for the beginning the problem but at yet there is no theory could solve OPF commercially and showed that an approximation in solving the problem reduces consuming time that important for controlling variables but it cause a huge financial impact. All literature reviews acknowledged that Carpentier [9] covered the most of the bases, used at yet, for solving an optimal power flow. Although our research focusing on OPF with FACTS it is of interest to define the main fields of OPF studies.

Economic dispatch calculation (EDC): is performed to dispatch, or schedule, a set of online generating units to collectively produce electricity at a level that satisfies a specified demand in an economical manner.

Optimal power flow OPF: refers to full AC power problem solved to optimize real and reactive power flow subject to a certain constraints.

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Received September 09, 2016; **Accepted** December 22, 2016; **Published** December 29, 2016

Citation: Alkhayyat MT, Bashi SM (2016) A New Survey for Optimum Power Flow with Facts Devices. J Electr Electron Syst 5: 209. doi:10.4172/2332-0796.1000209

Multi-objective OPF: refers to optimization (minimize) two or more objective functions simultaneously subject to unignorable constraints.

DC OPF: refers to single objective OPF under assumption that all voltage magnitudes are fixed and all phase angles are close to zero, it is not refers to the solution of direct current power flow.

Dynamic OPF: refers to include the effect of variation in variables in OPF calculation, for example the effect of valves that causes local optimization points.

On-line OPF: refers to the solution of OPF directly online, the OPF controlling system receives the information as sampling data and sends the commands in order to satisfy the optimization for the objective function.

Security constraints SC OPF: refers to satisfy optimization after contingency being happens in the system. A contingency is defined as an event that causes one or more important components such as transmission lines, generators, and transformers to be unexpectedly removed from service.

OPF with Artificial Intelligence AI Methods

Conventional methods such as Linear Programming, Newton-Raphson and Non-linear Programming, quadratic programming, mixed integer programming, and interior point, methods were previously offered to handle the complexity of the OPF. However, the common barriers for these methods that may closet to local optima because the complicated features of the mathematical functions of the objectives and constraints due to the nature of real OPF that may be nonlinear, non-convex, non-differentiable and non-smooth optimization problem with discontinuous solution space. This kind of optimization problem is very hard, if not impossible, to solve using traditionally deterministic optimization methods, moreover, if the effects of valve-point loading of thermal generators and/or nonlinearity of FACTS devices are included that may increase the possibility for trapping in local optima or premature convergence Abido [10]. 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. Sumpavakup et al. [11] solved OPF using Artificial Bee Colony ABC and compared it with GA and PSO using IEEE 14 and 30 bus test system. The results showed that BC converge faster than the rest methods and give more accurate solution. Seyed Reza Moasheri and Masoud Khazraei [12] modified GA for solve OPF with IEEE 30 bus as test system. They compared the results with PSO, DE, and conventional GA, the results showed that the modified GA gives best fitness.

OPF with Hybrid Methods

The practical and industrial control applications required fast controller system that needs, beside a very high frequency microprocessor, an effective method capable of reaching a best fitness with less iteration or time. For this reason many attempts still at yet not for proposed new method only, but for merge the methods to satisfy this target. Worawat Nakawiro and István Erlich [13] combined GA with ANN for solving OPF and obtain 5 time faster than GA alone maintaining the error less than 5%. In 2011 and 2012 Sumpavakup et al. [14], proposed a hybrid cultural bee colony to solve single objective and multi-objectives OPF respectively, authors tried to prove that the proposed method is faster than some other AI methods. It is observed that their results not always best than the compared methods but depend on the size of the problem. Sivasubramani [15], combined sequential quadratic programming SQP, which is known as traditional method, once with differential evolution DE and then with Harmony Search HS by two ways to overcome the stagnation and premature convergence in both methods and showed that the proposed hybrid method is quite suitable for non-convex problems. Amjady [16] added the DE searching attribute to BF method to enhance its exploration capability. Authors compared the results of the proposed method with about twenty evolution methods showed that it obtains best fitness. If the individuals are conside on the global best and if both the velocity and the weight are not zero, the method suffers from stagnation. The main contribution of Ahmed and Antônio [17] that they added the GA mutation feature to the PSO method (hybrid particle swarm optimizer with mutation HPSOM) to overcome the stagnation problem when solving OPF to minimize active power loss in simple system, the results as compared with PSO gave best fitness and fast convergence. Sai H Ling et al. [18], have the same target for adding the mutation ability to PSO method using wavelet. Authors compared their method with some standard and hybrid PSO methods to show its good performance over them. Karthik and Chandrasekar [19] proposed a hybrid technique for identifying the proper place for fixing the IPFC. The proposed hybrid technique utilizes genetic algorithm and neural network to identify the proper place for fixing the IPFC. The training dataset is generated using the genetic algorithm. For creating training dataset different combinations of buses are taken and their power values are analyzed and the best combination of buses to which the IPFC must be connected to attain maximum system stability is selected. By using this dataset the neural network is trained. This technique identified the proper place for fixing the IPFC, also the losses in the compensated line is decreased.

Multiobjective MO OPF

About 50 years ago, as mentioned in previous section, Carpentier established the main basics for solving OPF adopted at yet and became a traditional way for solution. It is of convenient to use optimal active power flow, optimal reactive power flow, and optimal active and reactive power flow for solving various objective functions. OPF with single objective had been studied by many authors. However, due to the fact that real life problems involve several objectives and the decision maker would like to find solution, which gives compromise between the selected objectives [20]. Firstly, MOOPF solved by weighting the objectives and combined them as a single objective, this approach has the disadvantage of finding only a single solution and it cannot find trade-off between the different objectives in single run [M10], and requires multiple runs as many times as the number of desired Pareto-optimal solutions [21]. Debjani Chakraborti et al. [22] used GA with fuzzy goal programming for solving MOOPF, the objectives are the fuel cost, gas emission, and voltage deviation, these objectives are described fuzzily and incorporate the power loss in an equality constraint equation, the properties of Particle Swarm Optimization PSO technique are fast convergence, less parameters to tune, easier searching in very large problem spaces, and effectively optimizes the multidimensional discontinuous nonlinearities. However, the tuning of its parameters needs some experience. Yong Zhang [23], proposed a bare bone PSO that has the ability for self-tuning parameters and applied the proposed method in IEEE 30 bus for solving environmental/economic dispatch multi-objective function and compare the results with families of GA and PSO methods, the results proved the efficient of this method.

OPF with Facts Devices

With continuous increase in power demand many problems arises due to the need for extended generation units and additional transmission lines. An expanding in transmission system consumes long time and facing the right of way problem. In addition, the transmission system becomes more complex with additional interconnected between buses, for this reasons a powerful controlling system is invented by Hingorani et al. [24]. FACTS devices are used in power system for controlling power, increase transmission capacity near their thermal limits, enhance system stability and hence its security, reduced reactive power flow, thereby permitting greater active power flow, and reduced cost of energy received due to enhanced line capacity. Direct current transmission system is one of the powerful controller device used in power system to transfer a huge power for long distance and improving the stability of the system. However, in this paper we focusing on the new version of controlling devices, so called, FACTS. Many authors investigate the problem of OPF in presence of FACTS devices. Referring to the equation of power transfers, most of the controlling devices depend on variation of phase angle between the two buses of transmission line and its impedance [25], in this research an attention is closest on three categories, OPF methods with FACTS dvices, hybrid methods and multi-objective OPF, incorporating the last version of controlling devices (UPFC and IPFC) an OPF can be achieved without re-dispatching active power of generator [26], the IPFC has an effect on the voltage profile of the buses neighboring to the compensating bus [27], efficient for minimizing TL loss and reducing reactive power flow [28,29], and it is more efficient compared with UPFC for improving available transfer capability ATC of TL [26]. Many efforts had been done for modeling and simulation of FACTS devices with OPF study and their contribution circulating about the common targets for accelerating the convergence using modified models [30], and adaptive and flexible method [31], PSO is more efficient for solving optimization problems [32]. Moreover, OPF control method used to obtain the minimum of total required capacity of FACTS devices inserted in the system [33]. Although long time ago for the first application of Newton-Raphson method in power flow analysis, it is still extensively used at yet for solving power flow and optimum power flow, Marcos Pereira and Luiz Cera Zanetta [34] used a new current injected model for simulating UPFC and solving the problem with Newton-Raphson NR method. Some authors used NR method with AI method for solving OPF with FACTS [35]. Sreejith et al. [36] used TCSC with OPF and showed that differential evolution DE is more efficient than Lagrangian method. E.S. Ali, S.M. Abd-Elazim [37], used bacterial foraging BF method for optimization the simultaneous tuning of TCSC controller, the results give robust damping performance over a wide range of operating conditions in compare to optimized TCSC controller based on GA. With the increment in power flow controlling devices, additional problems may appear and require a suitable coordination between them [20], authors, pointed out some problems associated with increasing the number of FACTS devices. The voltage-sourced converter (VSC)-based Interline Power Flow Controller (IPFC) was first proposed in 1998, as the latest component of the Flexible AC Transmission System (FACTS) device family [26]. Its unique capability of simultaneously compensating multiple transmission lines at a given substation has since aroused great interest of researchers and power industries around the world, especially when now manufacturing of VSCs are becoming more economical. Like Unified Power Flow Controller (UPFC), the IPFC is a kind of combined compensators, in which at least two Static Synchronous Series Compensators (SSSCs) are combined via a common DC voltage link. If there is no energy storage system installed in the apparatus, this DC voltage link is usually modeled as a DC capacitor. It is this link that provides the IPFC with the path through which different transmission lines can exchange active power. Teerathana et al. [33] proposed the utilization of the IPFC to mitigate overload problem with Optimal Power Flow (OPF) control method. The OPF control method for a satisfied solution of the minimum cost and the entire power flow balance was also discussed. Radhakrishnan and Rathika [38] deals with the development of IPFC using fuzzy technology. In the proposed scheme, series and shunt configuration employing an interline power flow controller using fuzzy technology is designed. Most of the compensation is provided by series controller. In case of excess real power demand shunt controller is used. The authors proved that the offset time required for the oscillations to settle down after compensation has reduced when using FL controller instead of PI controller. Karthik and Chandrasekar [39] presented the Separated IPFC, which eliminates the common DC link of the IPFC and enable the separate installation of the converters. Without location constrain, more power lines can be equipped with the S-IPFC, which gives more control capability of the power flow control. Instead of the common dc link, the exchange active power between the converters is through the same ac transmission line at 3rd harmonic frequency. Every converter has its own dc capacitor to provide the dc voltage. The ‘master’ converter can adjust the voltage magnitude, transmission angle, and line impedance. The ‘slave’ converter provides the active power for ‘master’ converter and at the same time adjusts its own line reactance. However, the active power loss in the line is increased also the authors did not show the practical validity of this method. EL-Sadek, et al. [40], incorporated the IPFC by PQ/PQ/PQ IPFC model and by the injection power flow IPFC model. The two models are incorporated in a MATLAB power flow program based on N-R algorithm. These IPFC power flow models are modified to set control of power flows of multiline. Based on these models it is possible to estimate the IPFC control variables and its ratings. Numerical comparisons between PQ/PQ/PQ IPFC model and the injection power flow IPFC model are presented. Irusapparajan and Rama Reddy [41], modeled and simulated the 30 bus systems with and without IPFC using Matlab/Simulink. The voltage profile is improved by adding IPFC. The authors showed that the IPFC pushes more power to the buses with higher load and the real and reactive power can be easily controlled with the help of IPFC. Sankar and Ramareddy [42], described interline Power flow controller in power system. The different controller’s circuits are simulated using PSPICE software package. IPFC is used to improve the power flow and to provide a power balance of a transmission system. Circuit model with phase difference and voltage difference were simulated to study the real and reactive power flows. The circuit model for open loop and closed loop systems are presented. The authors observed that the real and reactive powers are increased by the presence of IPFC. Naresh Babu and Sivanagaraju [43], proposed a new intelligent search evolution algorithm (ISEA) to minimize the generator fuel cost in optimal power flow (OPF) control with IPFC. In the proposed algorithm, the two-steps initialization process had been adopted which eliminates the mutation operation and also it gives optimal solution with less number of generations. The proposed algorithm has been examined and tested on a standard IEEE-30 bus system without and with IPFC. The results reveal that the generation cost is less with IPFC. Hans Glavitsch and Rainer Bacher [44] attempted to review various optimization methods used to solve OPF problems. A new powerful technique to implement FACTS devices is presented in this paper for the congestion management in the open power market. The merits of this method are that there is no requirement to modify the power mismatch equations to implement the FACTS devices. Application of this technique to Optimal Power Flow has been explored and tested. The simulation results show that this simple algorithm can give a good

No.	Theory	Advantages	Drawbacks	Applications
1	Classical methods	Reliable and fast convergence	1-Weak in handling constraints 2-Poor convergence 3-Convergence becomes too slow. if the numbers of variables are large	
2	Stochastic methods			
3	Artificial Neural Network ANN	1-Fast 2-Appropriate for non-linear models	1-Large dimensionality 2-The choice of training methodology	1-Real time control 2-Optimization
4	Fuzzy Logic FL	Represents constraints more accurate		1-Real time control
5	Genetic Algorithm GA	Rarely trapped in local optima	Consumes long time for global convergence	
6	Evolutionary programming EP	1-Adaptability to change, 2-Ability to generate good solutions 3-Rapid convergence		
7	Bacterial Foraging BF			
8	Bee Colony BC			
9	Ant Colony AC	1-Positive feedback for recovery of good solutions, 2-Robust against premature convergence.		1-To find shorter rout in TLs 2-Dispatching Gens. 3-Optimal unit commitments
10	Particle swarm optimization PSO	1-Fast convergence 2-More accurate and robust for global convergence 3-Less parameters need adjustment 4-Able to search in large problem with non-differentiable	1-Need experience for adjusting parameters 2-Sometimes suffers from stagnation	1 large area optimization 2 multi-objective OPF
11	Simulating Annealing SA			
12	Deferential Evolution DE		1-Stagnation 2-Premature convergence	
13	Tabu search TS		1-trapped in local optima 2-converge to global optima in long time	
14	Honey bee mating HBM			
15	Harmony search HS		1-Stagnation 2-Premature convergence	

Table 1: AI theories advantages/drawbacks, and applications.

No.	Hybrid theory		Advanced features	Application
1	ANN	Fuzzy		
2	GA	ANN	Minimize iterations to reaching best fitness	Optimization and optimal location
3	GA	PSO		
4	DE	SQP	Overcome the premature convergence and stagnation	
5	HS	SQP	Overcome the premature convergence	
6	BF	GA	Enhance the exploration capability	

Table 2: Hybrid AI theories features and applications.

result using only simple modifications. Finally, Tables 1 and 2 illustrates some advantages, draw backs, and applications of various AI methods and hybrid methods respectively.

Conclusion

The competition between OPF methods, regarding they impact with the same problem or objective, to reach best fitness with minimal time depends on:

1) Modifications of methods.

2) The proposed model of FACTS device(s) when these devices incorporated in the PS.

3) The Selected methods combined as a hybrid method.

4) The size of the problem.

Factors effect for obtaining advanced results.

1) Transfer the constraint optimization problem into unconstraint.

2) The size of the problem.

At yet there is no method can solve OPF for global problems and obtain best fitness precisely with minimal time, but the modified and hybrid methods success in achieved more accurate results and less solving time. In many optimization formulas solving multi-objective OPF, the minimization of this objectives cannot precisely have obtained simultaneously, for example if the process intended to minimized cost, the loss may increase, this is depending on the objectives coefficients. It is of important to note that MOOPF approaches not always means the combination of two or more of the known objectives like cost, losses, and gas emission, but in some researches the single objective with transformed constraints is known as MOOPF. When the number of FACTS devices is increased, the new problems may appear and need a suitable coordination between them that lead to an increase the complication in controller system.

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