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A Review Of Artificial Intelligence Based Optimization Techniques For Optimal Power Flow

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Abstract — *This paper presents a review of different Artificial Intelligence (AI) methods which are one of the latest computational intelligent techniques to solve optimal power flow (OPF) problems. 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 (LP), Newton Raphson (NR) and Non- Linear Programming were previously offered to tackle the complexity of the OPF. However, with emergence of AI methods, many novel techniques such as Artificial neural network (ANN), Fuzzy Logic (FL), Genetic Algorithm (GA), Evolutionary Programming (EP), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Bacterial Foraging Algorithm (BFA), and Artificial Bee Colony (ABC) have also received great attention. This paper gives detailed discussion of AI based optimization techniques to solve OPF problem which are more effective.*

Keywords- *Flexible AC Transmission System (FACTS),Optimal Power Flow(OPF),Artificial Intelligence (AI), Artificial neural network (ANN), Fuzzy Logic (FL), Genetic Algorithm (GA), Evolutionary Programming (EP), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Bacterial Foraging Algorithm (BFA), and Artificial Bee Colony (ABC)*

I. INTRODUCTION

Optimal power flow (OPF) is considered as the backbone tool that has been widely researched since introducing its concept by Carpentier [1]. The OPF optimizes a power system operating objective function (such as the fuel cost of thermal generators) while satisfying the constraints of the components and system [1]. The security engineer monitors the power flow which induced contingencies to withstand any case of overload and voltage violations. Dommel et al.[2] have sketched a detailed survey on Load flow algorithms, the first credits for Load flows undoubtedly goes for Carpentair [4]. All the considerable developments in power flow algorithms are listed in the survey paper of Carpentier [1] and Huneault et al. [3]. 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:

- Weak in handling qualitative constraints.
- 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, they are computationally expensive.

So it is important to develop new and more general and reliable techniques for dealing with non-linear OPF. 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 study of these AI techniques for solving the optimal power flow problems.

II. OPTIMAL POWER FLOW FORMULATION

OPF is formulated mathematically as a general constrained optimization problem.

Minimize a function $F(u, x)$ (1)

Subject to $h(u, x) = 0$ (2)

and $g(u, x) \geq 0$ (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.

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Inequality constraints (3) are the limits on control variables u and the operating limit on the other variables of the system.

III. ARTIFICIAL INTELLIGENCE (AI) METHODS

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.

A. ARTIFICIAL NEUTRAL 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.

Chowdhury [10] had suggested concept of Integrated Security Constrained Optimal Dispatch (ISCOD) which could solve the OPF problem when it was constrained by both static and dynamic security. ISCOD utilized the diagnostic and decision making capabilities of Knowledge Base System (KBS), massive parallel lisms and learning features of an ANN along with conventional power system network solution methodologies to provide real-time control and optimization. The KBS and the ANN are used in different configuration for adding the dispatch or in making control decisions.

N.I.Santoso *et al.* [11] presented a two-stage Artificial Neural Network to control in real time the multi tap capacitors installed on a distribution system for a nonconforming load profile such that the system losses are minimized. The required input data are directly obtained from on-line measurements which include the active and reactive line power flows, voltage magnitudes and the current capacitor settings at certain buses. Inequality constraint consists of limits on capacitor rating. The application of the proposed capacitor control will be limited by the computation time required for the learning process which in turn depends on the number of conforming load groups and capacitors installed rather than the number of system buses.

Selvi, V.A.I. [12] 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.[13] 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.

B. 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 [14] 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;

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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.

Miranda *et al.* [15] gave a fuzzy model to represent uncertainty in loads and generation as fuzzy numbers. While uncertain injections were dealt with D.C. fuzzy power flow model. System optimal operation was calculated with Dantzing- Wolfe decomposition technique and dual simplex method. Among the results, fuzzy cost value for system operation and possibility distribution of branch power flows and power generation were obtained.

V.C.Ramesh *et al.* [16] presented a Fuzzy Logic approach for the contingency constrained OPF problem formulated in a decomposed form that allows for post-contingency corrective rescheduling. Linear membership function is used. The formulation treats the minimization of both the base case (pre-contingency) operating cost and of the post-contingency correction times as conflicting but fuzzy goals. The proposed approach can yield Pareto curves that can guide the system operator regarding the tradeoff between cost and security against contingencies. However, choice of a suitable metric for measuring correction time is unclear.

N.P.Padhy [17] 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.

C. GENETIC ALGORITHM (GA) METHOD

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 [18] 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. *et al.* K.[19] 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.

Po-H.Chen *et al.* [20] proposed a new genetic algorithm for solving the Economic Dispatch (ED) problem in large-scale systems. A new encoding method is developed in which the chromosome contains only an encoding of the normalized system incremental cost. So the total number of bits of chromosome is entirely independent of the number of units. The approach can take network losses, ramp rate limits and prohibited zone avoidance into account. It is faster than lambda – iteration method in large systems.

T.S.Chung *et al.* [21] presented a Hybrid Genetic Algorithm (GA) method to solve OPF incorporating FACTS devices. GA is integrated with conventional OPF to select the best control parameters to minimize the total generation fuel cost and keep the power flows within the security limits. TCPS and TCSC are modeled. The proposed method was applied on modified IEEE 14 bus system and it converged in a few iterations.

L.J.Cai *et al.* [22] proposed optimal choice and allocation of FACTS devices in multimachine power systems using genetic algorithm. The objective is to achieve the power system economic generation allocation and dispatch in deregulated electricity market. The locations of the FACTS devices, their types and ratings are optimized simultaneously. UPFC, TCSC, TCPST and SVC are modeled and their investment costs are also considered.

D. EVOLUTIONARY PROGRAMMING (EP)

It is a subset of evolutionary computation, a generic population based metaheuristic optimization algorithm.

P.Somasundaram *et al.* [23] proposed an algorithm for solving security constrained optimal power flow problem through the application of EP. The controllable system quantities in the base-case state are optimized to minimize some

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defined objective function subject to the base-case operating constraints as well as the contingency- case security constraints. Fitness function converges smoothly without any oscillations.

W.Ongsakul *et al.* [24] proposed Evolutionary Programming (EP) to determine the optimal allocation of FACTS devices for maximizing the total transfer capability (TTC) of power transactions between source and sink areas in deregulated power system. EP simultaneously searches for FACTS locations, FACTS parameters, real power generations except slack bus in source area, real power loads in sink area and generation bus voltages.

P.Attaviriyanupap *et al.* [25] presented a new bidding strategy for a day-ahead energy and reserve markets based on an EP. The optimal bidding parameters for both markets are determined by solving an optimization problem that takes unit commitment constraints such as generating limits and unit minimum up/down time constraints into account. The proposed algorithm is developed from the view point of a generation company wishing to maximize a profit as a participant in the deregulated power and reserve markets. Separate power and reserve markets are considered, both are operated by clearing price auction system.

T.Jayabarathi *et al.* [26] proposed the application of Classical Evolutionary Programming (EP), Fast EP and Improved FEP methods to solve all kinds of economic dispatch problems such as ED of generators with prohibited operating zones (POZ), ED of generators with piecewise quadratic cost function (PQCF), combined economic-environmental dispatch (CEED) and multi-area economic dispatch (MAED). The constraints considered are the power balance, generating capacity, prohibited operating zones, area power balance, generation limits and tieline limits constraints.

E. ANT COLONY OPTIMIZATION (ACO)

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

I.K.Yu *et al.* [27] 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.* [28] 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 t, 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.* [29] 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.

F. PARTICLE SWARM OPTIMIZATION (PSO)

It is based on the ideas of social behavior of organisms such as animal flocking and fish schooling.

H.Yoshida *et al.* [30] proposed a Particle Swarm Optimization (PSO) for reactive power and Voltage/VAR Control (VVC) considering voltage security assessment. It determines an on-line VVC strategy with continuous and discrete control variables such as AVR operating values of generators, tap positions of OLTC of transformers and the number of reactive power compensation equipment.

Jong-Bae Park *et al.* [31] suggested a Modified Particle Swarm Optimization (MPSO) for economic dispatch with nonsmooth 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.

Cui-Ru Wang *et al.* [32] presented a Modified Particle Swarm Optimization (MPSO) algorithm to solve economic dispatch problem. In the new algorithm, particles not only studies from itself and the best one but also from other individuals. By this enhanced study behavior, the opportunity to find the global optimum is increased and the influence of the initial position of the particles is decreased. The particle also adjusts its velocity according to two extremes. One is the best position of its own and the other is not always the best one of the group, but selected randomly from the group.

J.G.Vlachogiannis *et al.* [33] formulated the contributions of generators to the power flows in transmission lines as a multiobjective optimization problem and calculated using a Parallel Vector Evaluated Particle Swarm Optimization (VEPSO) algorithm. VEPSO accounts for nonlinear characteristics of the generators and lines. The contributions of generators are modeled as positions of agents in swarms. Generator constraints such as prohibited operating zones and

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line thermal limits are considered. It can obtain precise solutions compared to analytical methods.

M.Saravanan *et al.* [34] proposed the application of Particle Swarm Optimization to find the optimal location, settings, type and number of FACTS devices to minimize their cost of installation and to improve system loadability for single and multi-type FACTS devices. While finding the optimal location, the thermal limit for the lines and voltage limit for the buses are taken as constraints. TCSC, UPFC and SVC were considered.

Zhu, j.[35] 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. *et al.* [36] 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.* [37] suggested a Modified Particle Swarm Optimization (MPSO) foreconomic 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.

G. BACTERIAL FORAGING ALGORITHM (BFA)

Bacterial Foraging optimization (BFO) is a swarm intelligence technique used to solve problem in power systems. The algorithm is based on the group foraging behaviour of Escherichia coli (E-Coli) bacteria present in human intestine. This social foraging behaviour of E.coli bacteria has been used to solve optimization problems.

H.Vahedi *et al*.[38].The paper proposes a novel Bacterial Foraging Algorithm (BFA) for solving optimal power flow (OPF) problems with considering transmission security for practical application. The objective of OPF is to minimize total generation cost, enhance transmission security, reduce transmission loss and improve the bus voltage profile under normal or contingent states. Moreover, the valve-point loading effect of thermal units should be taken into consideration. The effectiveness of the proposed method is demonstrated for a 26-bus and the IEEE 30-bus systems, and it is compared with the PSO-RO algorithm in terms of solution quality and evolutionary computing efficiency.

Nima *et al.* [39] proposed a new solution method, which is an improved version of bacterial foraging (BF) technique, used for optimal power flow under security constraints (OPF-SC) problem. The OPF-SC is a nonlinear programming optimization problem with complex discontinuous solution space. BF is a recently developed advanced stochastic search technique owning high exploitation and local search capabilities to search the promising areas of the solution space with high resolution. Saving the advantages of BF, the exploration capability and diversity of the search process of BF are enhanced in the proposed improved version of BF (IBF) to cover different areas of the solution space avoiding the trap of local minima. The solution strategy to solve the OPF-SC problem is illustrated on 30-bus and 118-bus systems.

H. ARTIFICIAL 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

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- 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 *et al.* [40] solve the Optimal Power Flow using Artificial Bee Colony algorithm.

I. MISCELLANEOUS METHODS

Chowdhury *et al.* [41] proposed Expert System (ES) which was used in combination with a transmission constrained economic dispatch to provide real time security. The strategy for combining the ES with an economic dispatch which identifies the constraint violations in bus voltage magnitudes and in line flows, as well as the set of optimal generations. The ES then determines the best possible control measure using rules on voltage and line flow control. The purpose of the expert system is to expeditiously remediate voltage and branch over load problems.

H.Mori *et al.* [42] presented a Parallel Tabu Search (PTS) based method for determining optimal allocation of FACTS devices in competitive power systems. Available Transfer Capability (ATC) was maximized with the FACTS devices. UPFC was modeled and concept of incremental load rate was used. The proposed method was compared with Simulated Annealing, GA and Tabu Search methods. It is 1.95 and 2.68 times faster than TS and GA respectively. It is not affected by the initial conditions and gave higher quality solutions.

IV. CONCLUSION

In this paper an attempt has been made to review various optimization methods 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. In most cases, they can find the global optimum solution.

The main advantages of ANN are: Possesses learning ability, fast, appropriate for non-linear modeling, etc. whereas, large dimensionality and the choice of training methodology are some disadvantages of ANN. The advantages of Fuzzy method are: Accurately represents the operational constraints and fuzzified constraints are softer than traditional constraints. The advantages of GA methods are: It only uses the values of the objective function and less likely to get trapped at a local optimum. Higher computational time is its disadvantage. The advantages of EP are adaptability to change, ability to generate good enough solutions and rapid convergence. ACO and PSO are the latest entry in the field of optimization. The main advantages of ACO are positive feedback for recovery of good solutions, distributed computation, which avoids premature convergence. It has been mainly used in finding the shortest route in transmission network, short- term generation scheduling and optimal unit commitment.

PSO can be used to solve complex optimization problems, which are non-linear, non- differentiable and multi-model. The main merits of PSO are its fast convergence speed and it can be realized simply for less parameters need adjusting. PSO has been mainly used to solve Bi-objective generation scheduling, optimal reactive power dispatch and to minimize total cost of power generation. Yet, the applications of ACO and PSO to solve Security constrained OPF, Contingency constrained OPF, Congestion management incorporating FACTS devices etc. of a deregulated power system are to be explored out. Artificial Bee Colony applicable for both continuous or discrete variables. It has ability to handle objective cost with stochastic nature. Also easy to implement with basic mathematical and logical operations. Its disadvantage is data clustering and discrete optimum design of truss structure.

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. AI 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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