ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 11, November 2016

A Comprehensive Literature Review on Load Frequency Control Strategies

MOHAMMAD URFI[1], SUSHIL PRASHAR[2]
[1]STUDENT, DEPARTMENT OF ELECTRICAL ENGINEERING, DAVIET, JALANDHAR
[2] ASSISTANT PROFESSOR, DEPARTMENT OF ELECTRICAL ENGINEERING, DAVIET, JALANDHAR

Abstract

In this paper, an extensive literature survey has been performed on different control strategies of Load Frequency Control (LFC). The survey consists of both conventional and non-conventional control strategies to overcome the different issues of Load frequency control, like voltage variation, frequency variation and Area Control Error (ACE). Also the merits and demerits of these techniques has been shown. Finally some of the modern techniques are compared with the recently published technique, that is, Sine-Cosine Algorithm (SCA).

Keywords: Load Frequency Control (LFC), Automatic Generation Control (AGC), Area Control Error (ACE), Sine-Cosine Algorithm (SCA).

Introduction

In an interconnected power system maintaining the frequency at prescribed value (50 Hz) and control of tie-line power transfer between the neighboring areas become a most challenging task. The frequency deviation from its normal value cause direct impact on power system operation and its reliability. Need of maintaining the system frequency become necessary because (a) speed of AC motors directly depends on frequency, (b) turbine speed changes due to change in the frequency which causes damage to the blades, (c) when frequency becomes less than normal value (>50hz), the core flux of transformer increases and transformer goes into saturation. The real power changes mainly rely on frequency, while the reactive power relies on the voltage magnitude. Therefore they are controlled separately. The above two objectives are met by measuring control error signal, known as Area Control Error (ACE), this is due to real power imbalance between generation and load. Over the last few years, all the connected areas have been connected to an automatic process known as "Automatic Generation Control". To build the ACE close to zero, AGC automatically alters the generation of an area. The main objectives of AGC are,

1. To hold the system frequency at or very near to nominal value,

2. Uphold the value of interchange of power between the areas and

3. Maintain each unit's generation at the most economic value.

From the literature survey, it is revealed that conventional control strategies has some limitations which are, slow and lack of efficiency in handling system errors, optimization of controller gains with conventional/classical techniques is very time consuming and does not give best possible solution, in usual approach large number of parameters cannot be taken simultaneously. To overcome the above limitations, Meta-heuristic techniques come into existence because of their simplicity, flexibility, derivation free mechanism and local optima avoidance. These techniques are classified into three main categories: Evolutionary, Physics based and Swarm Intelligence (SI) algorithm. Evolutionary Algorithm (EA) are usually inspired by the concept of evolution in nature. The very admired algorithm of this branch is Genetic Algorithm (GA). Some of other EA's are Differential Evolution (DE), Evolutionary Programming (EP). Physics based techniques are the second main branch of the meta-heuristic techniques. These techniques are different from EA's in the sense that is, random set of search agents communicate and move throughout search space according to physics rule. Such optimization techniques follow the physical rules. Some of the examples are: Gravitational Local Search Algorithm (GLSA), Big-Bang Big-Crunch (BBBC), Gravitational Search Algorithm (GSA), Charged System Search (CSS). Swarm-Intelligence (SI) techniques are the third class of meta-heuristics techniques. These techniques mostly follow the social behavior of swarms, herds, flocks of birds and fish schooling. Particle Swarm optimization (PSO) technique is best known SI based technique.

Related Work

Traditionally, for issues related to automatic generation control (AGC), the frequency variation is reduced by the flywheel type of governor of synchronous machine. However, there is some problem in achieving significant control for LFC objectives. Therefore, the supplementary control is introduced to the governor via signal directly proportional to the frequency deviation plus its integral action.

Significant work has been done in the LFC using Evolutionary Algorithms (EA).

References [1],[2],[8] and[45] present the automatic generation control (AGC) of two area interconnected power system having diverse sources of power generation, taking into account the generation rate constraint (GRC), dead band, and time delays.

Optimal performance of controller gain can be calculated by Genetic Algorithm (GA). The comparison of GA has been taken with conventional scheme. Reference [24] present the automatic generation control (AGC) of a hydrothermal power system. The effects of nonlinearities were eliminated and the optimization of integral gain ki can be obtained by using GA. Simulation results reveals that the performance of GA optimized controller are better than the conventional controller. Reference [27] presents design and performance analysis of Differential Evolution (DE) algorithm based parallel 2-Degree Freedom of Proportional-Integral-Derivative (2-DOF PID) controller for Load Frequency Control (LFC) of interconnected power system. DE is employed to search for optimal controller parameters. Comparison of DE is done with Craziness based Particle Swarm Optimization (CPSO) for the same interconnected power system.

Reference [46] focuses on Differential Evolution (DE) technique to optimize proportional-derivative-integral controller with derivative filter (PIDF) for automatic generation control problem.

Some work has been done by combining EA and SI based techniques.

Reference [13] presents the limitation of DE that is, “easily drop into the optimum region” which can be overcome by a novel DEPSO algorithm in DE and Particle Swarm Optimization (PSO), from which obtain the advantage of accuracy solving and stable convergence.

Reference [7] considers the 3-control area power system as a test system. The Genetic algorithm (GA) is used to figure out the decentralized control parameters to attain an optimum operating point by considering generation rate constraint (GRC), dead band, and time delay.

Reference [11],[6] presents an Artificial Intelligence based technique, the Bacterial Foraging Optimization Algorithm (BFOA) for the suppression of oscillation and optimize the integral plus double derivative (IDD) controller in the power system consists of two, three and five unequal areas non-reheat thermal system equipped with proportional plus integral (PI) and IDD controllers. In reference [12] BFOA is also used to solve non-convex economic load dispatch (NCELD) problem of thermal plants having 6 and 13 generating units including constraints like transmission losses, valve point loading, ramp rate limits and forbidden operating zones.

Reference [3] has analyzed that the Feedback Error learning (FEL) approach for automatic generation control (AGC) of power system shows a better performance when compared with PID and conventional FEL controllers. Here dynamic neural network (DNN) is used for feed forward controller.

In reference [4] automatic generation control loop with modifications is integrated in simulating automatic generation control (AGC) in modernized power system is presented. Hybrid particle swarm optimization to attain optimal gain parameters for optimal transient performance.

Reference [5] uses fractional-Order (FO) controllers to improve stability and response of LFC and AGC system and shows that FO controllers carry out better than classical integer-order controllers in these systems.

Brief inspection of literature review shows that work has already been reported taking into consideration either classical or non-classical control strategies. Considerable studies include classical controllers for thermal plants, but shockingly in many cases the tie line model has been over simplified by excluding important constraint like generation rate constraint (GRC) and correct choice of speed regulation parameter R for the primary control loop are essential.

Some work has been done on physics based algorithm.

Reference [18], [37] uses a physics based technique, gravitational search algorithm (GSA) for automatic generation control (AGC) of multiarea interconnected power system. And compare the advantages of proposed scheme with recently published algorithms.

Considerable work has been done on Swarm Intelligence based techniques.

Reference [23] author in this uses Artificial Bee Colony (ABC) to tune the parameters of PI and PID controller. System behavior is also investigated with this analysis towards the different cost functions such as integral of absolute error (IAE), integral of squared error (ISE), integral of time weighted squared error (ITSE) and integral of time multiplied absolute error (ITAE)

Reference [25],[30],[31],[33],[38] present and analyzed the Particle Swarm Optimization (PSO) technique to optimize the gain of controller parameters for an interconnected power system. This technique has better dynamic response as compared to other published techniques.

Reference [44] proposed the Firefly algorithm (FA) optimized fuzzy PID controller for Automatic Generation Control (AGC) of multi-area multi-source power system uses an ITAE criterion. The physical constraints such as Time Delay (TD), reheat turbine and Generation Rate Constraint (GRC) are included

Reference [9] highlighted the effect of non-ideal AGC on the performance of the extensively used envelope-detector (ED) serial search acquisition (SSA) scheme, for the performance loss due to non-ideal AGC is considerable. A normalized-energy-detector (NED) SSA scheme is proposed to improve the acquisition performance and remove the effect of AGC. Moreover, the proposed scheme is free from the influence of AGC, and no performance loss can be identify even when using non-ideal AGC for the proposed method.

Reference [10],[36] propose a Superconducting Magnetic Energy Storage (SMES) control scheme for two interconnected area power system. This scheme is competent of controlling both the active and reactive power simultaneously and quickly, growing attention has been focused recently on power system stabilization by SMES control. The proposed self-tuning control scheme is used to apply the automatic generation control for load frequency control application adding to the conventional control configuration

Reference [14] represents the Dynamic responses with PI controller are better than the Integral controller regarding peak deviation and settling time by using close loop control of real and reactive powers generated at the controllable source of the system with the help of conventional controllers and also the response of integral controller is smooth while the response of PI controller is somewhat jerky.

Reference [15] proposed the concept and method of hybrid control to set up an Integrated Coordinated Optimization Control (ICOC) system for AGC and AVC.

Reference [16],[42] presents a comprehensive literature review of the Philosophies of automatic generation control (AGC) of power systems. The survey covers the detail discussion of single area and double area power system and different control strategy that is the control techniques of the conventional power system and soft computing techniques.

In order to maintain the desired frequency and power interchange with neighboring systems references [17],[20],[46] considered the effect of Generation Rate Constraint (GRCs) and other non-linearities.

Considerable work has been done on controllers and freshly Fuzzy set theory has been applied to automatic control of load frequency.

Reference [19] and [32] explained the functioning of Fuzzy Logic Controller in multi areas thermal and hydrothermal scheme and presented the presentation of AGC in comparison with conventional controller either in the presence or in the absence of Generation Rate Constraint.

Reference [20] proposed an optimal output feedback controller, which uses only the output state variables to overcome the cost and difficulty access to all the state variables of a system and also their measurement. And are compared with the full state feedback controller

In reference [21] author proposed the craziness based particle swarm optimization (CRAZYPSO) algorithm to optimize the controller parameters for automatic generation control (AGC) of the two area thermal power system with governor dead-band nonlinearity. Comparison of performance of control system and the performance which is obtained with the classical integral of the squared error (ISE) and the integral of time weighted squared error (ITSE) cost functions has been made.

Reference [22] had examined the application of artificial neural network (ANN) based ANFIS approach to automatic generation control (AGC) of a three unequal area hydrothermal system. The performance of the ANFIS controller is compared with the results of integral squared error (ISE) criterion. Result shows, ANFIS approach satisfies the load frequency control requirements with a reasonable dynamic response.

Reference [26] presented the design and analysis Proportional Integral (PI) and Proportional Integral Derivative (PID) controller employing multi-objective Non-Dominated Shorting Genetic Algorithm-II (NSGA-II) technique for Automatic Generation Control (AGC) of an interconnected system.

Reference [28] investigate the dynamic performance of a more realistic power system with diverse sources in each area and interconnected via parallel AC/DC transmission links for 1% step load disturbance. AC stability improves and also Eigen value study is conducted.
Reference [29] in this a PID controller has been examined for automatic generation control of multi area power system in order to improve the performance of the system.

Reference [34] proposed generalized likelihood ratio test (GLRT) detector AGC-GLRT and formulated for packet detection in the presence of a practical AGC, where the output power in hypothesis H1 (i.e., P) is known previously, but that in hypothesis H0 (i.e., N0) is not.
Reference [35] presented a Dynamic Available AGC (*DAA*) of the Battery Energy Storage System (BESS) and applied in coincidence with the priority and proportional AGC signal distribution strategies.

Reference [39] applied a fractional order (FO) automatic generation control (AGC) scheme for frequency oscillation damping in power system.

Comprehensive studies has been taken out between series flexible AC transmission system (FACTS), thyristor controlled series capacitor (TCSC), thyristor controlled phase shifter (TCPS) and static synchronous series compensator (SSSC) in automatic generation control (AGC) in order to mitigate area frequency and tie-line power oscillations is presented in reference [40] TCSC–AGC yields superior performance.

Reference [41] presented a Differential Game approach to control the load and frequency of the power system and compared with the traditional Proportional–Integral (PI) controller and optimal controller.

Reference [43] uses a feedback sliding mode controller (SMC) for multi area diverse-source interconnected power system and controller gain is optimized by the Teaching and learning based optimization (TLBO) technique and shows superior results when compare with differential evolution, particle swarm optimization and genetic algorithm.

From the Literature Survey following **GAPS** has been framed.

1. Classical techniques most of the times are divert from optimal solution and are very time consuming.
2. Classical techniques are suffer from premature convergence
3. Genetic algorithm is less sensitive to local minima and modifies the illustration of probable solution rather than solution itself.
4. PSO has been popular in different fields. But, it also has some critical problems such as premature convergence and easily drops into regional optimum.
5. The Artificial Neural Network (ANN) method has the advantages of giving good solution quality and rapid convergence, but it requires lot of data for training purpose, which is a dreary task.
6. BFOA has lack a mechanism to deal with the constraints of a problem.
7. GWO also suffers from premature convergence which causes degradation of computational efficacy and search capability.

Sine Cosine Algorithm (SCA)

In order to overcome the above GAPS to the larger extent, Sine Cosine algorithm has been developed. SCA is population based optimization technique, initiates the optimization process with a set of random solution. These random solutions are repeatedly evaluated over the course of iterations by an objective function. With large number of random solutions the probability of finding global optima is increased.

$$X^{t+1}_i = X^t_i + r_1 \times \sin(r_2) \times r_3 P^t_i - X^t_i \ldots\ldots\ldots\ldots\ldots (1)$$

$$X^{t+1}_i = X^t_i + r_1 \times cos(r_2) \times r_3 P^t_i - X^t_{ii} \ldots\ldots\ldots\ldots.. (2)$$

Where X^t_i is the position of current solution in i-th dimension at t-th iteration, r1/r2/r3 are the random numbers, Pi is position of the destination point in the i-th dimension.

$$X^{t+1}_i = \begin{cases} X^t_i + r_1 \times \sin(r_2) \times r_3 P^t_i - X^t_i & r4 < 0.5 \\ X^t_i + r_1 \times cos(r_2) \times r_3 P^t_i - X^t_{ii} & r4 > 0.5 \end{cases} \ldots\ldots\ldots (3)$$

Where r4 is a random number in [0,1]

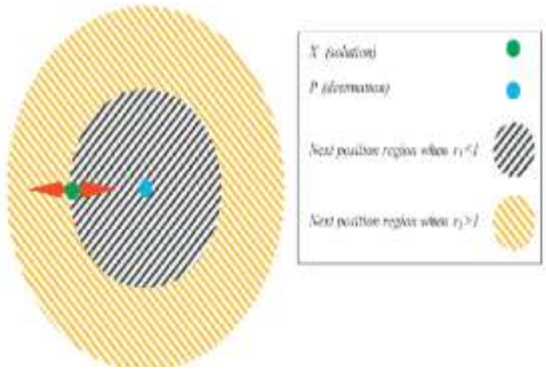

Fig.1

Effect of sine cosine in eqn. (1) and (2)

In the above equations there are four main parameters r1,r2,r3 and r4. The parameters r1 tells that the next position region between solution and destination or outside it. Parameter r2 dictates how far the movement should be towards or outwards the destination. The parameter r3 brings the random weight for destination in order to stochastically force (r3 > 1) or deemphasize (r3 < 1) the effect of destination in defining the distance. And parameter r4 equally switches between sine and cosine component in eqn. (3)

Fig. 1 shows that how the space between the two solutions in the search space is define by the proposed equations. The cyclic pattern of sine and cosine function defines the position of solution around another solution. Also this can provide guarantee exploitation of the space between two solutions. By changing the range of sine and cosine function we can explore the search space.

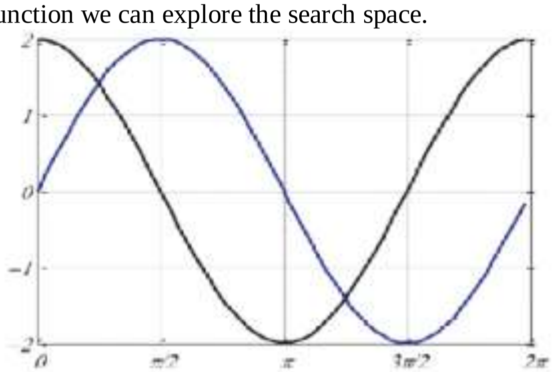

Fig.2 sine cosine with ranges of [-2,2]

The effects of sine and cosine function with ranges [-2,2] is illustrated by the conceptual model as shown in the fig.3. This figure tells that how position of solution can be updated by changing the range of sine and cosine function. This can guarantees exploration and exploitation of the search space respectively.

For make balance between exploration and exploitation, the range of sine and cosine in eqn. (1) to (3) is changed adaptively using equation:

$$\mathbf{r_1 = a - t\, a/T}$$

where **t** is current iteration, **T** is maximum number of iterations and **a** is constant.

SCA explores the search space when ranges of sine and cosine function are in (1,2] and [-2,-1] and exploits the search space when ranges are in [-1,1].

Discussion

Many researchers test this algorithm on many test cases with different characteristic. The set of cases studies employed includes three families of test functions: uni-model, multi-model and composite test functions [47-50]. SCA algorithm is compared with recently published techniques as shown in the table 1 and 2. Since the single run result might be unreliable. Therefore these algorithms are run 30 times and statistical results are taken and shown in table 1. In order to decide about the significance of results, Wilcoxon ranksum test is performed as well. The p-values obtained from this statistical test are shown in table 2.

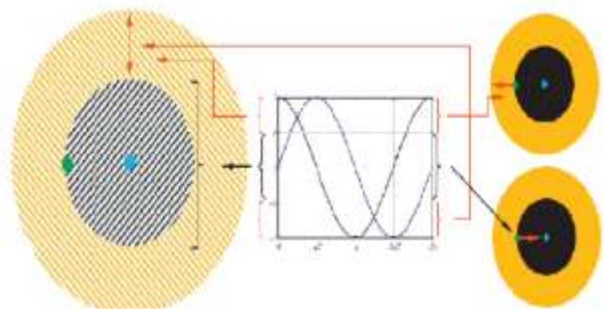

Fig.3 Sine and Cosine with the ranges in [-2,2] to go around the destination

The superiority of SCA algorithm on majority of test cases are shown in table 1. Initially, SCA algorithm shows best results on 3 out of 6 unimodel test functions. The p-values in table 2 shows significant statistical superiority. Due to characteristic of unimodel test function, these results show that the SCA algorithm has a high exploitation and convergence. Secondly, SCA algorithm gives better results than all other algorithms employed on the majority of multi- model test function. The p- values in table 2 also shows the better results of SCA statistically. These results confirm that that the SCA algorithm has high exploration and local optima avoidance. Finally, the results of SCA on composite test functions in table 1 and 2 reveal the merits of SCA algorithm in solving problems with challenging search space.

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Table 1
Results on benchmark functions.

F	SCA		PSO		GA		BA		FPA		FA		GSA
	ave	*std*	*ave*	*std*	*ave*	*std*	*ave*	*std*	*ave*	*std*	*ave*	*std*	*ave*
F1	0.0000	0.0000	0.0003	0.0011	0.8078	0.4393	1.0000	1.0000	0.2111	0.0717	0.0004	0.0002	0.0000
F2	0.0000	0.0001	0.0693	0.2164	0.5406	0.2363	1.0000	1.0000	0.9190	0.7804	0.0177	0.0179	0.0100
F3	0.0371	0.1372	0.0157	0.0158	0.5323	0.2423	1.0000	1.0000	0.2016	0.1225	0.0000	0.0004	0.0016
F4	0.0965	0.5823	0.0936	0.4282	0.8837	0.7528	1.0000	1.0000	0.8160	0.5618	0.0000	0.0107	0.1177
F5	0.0005	0.0017	0.0000	0.0000	0.6677	0.4334	1.0000	1.0000	0.0813	0.0426	0.0000	0.0000	0.0000
F6	0.0002	0.0001	0.0004	0.0033	0.7618	0.7443	1.0000	1.0000	0.2168	0.1742	0.0004	0.0002	0.0000
F7	0.0000	0.0014	0.0398	0.0634	0.5080	0.1125	1.0000	1.0000	0.3587	0.2104	0.0009	0.0022	0.0021
F8	1.0000	0.0036	1.0000	0.0036	1.0000	0.0055	0.0000	1.0000	1.0000	0.0029	1.0000	0.0168	1.0000
F9	0.0000	0.7303	0.3582	0.8795	1.0000	0.6881	0.4248	1.0000	0.8714	0.8665	0.0190	0.3298	0.0222
F10	0.3804	1.0000	0.1045	0.0541	0.8323	0.0686	0.8205	0.0796	1.0000	0.0162	0.0000	0.0079	0.1569
F11	0.0000	0.0051	0.0521	0.0448	0.7679	0.2776	1.0000	1.0000	0.2678	0.0706	0.0074	0.0001	0.4011
F12	0.0000	0.0000	0.0000	0.0000	0.4573	0.4222	1.0000	1.0000	0.0008	0.0015	0.0000	0.0000	0.0000
F13	0.0000	0.0000	0.0000	0.0000	0.6554	0.8209	1.0000	1.0000	0.0187	0.0375	0.0000	0.0000	0.0000
F14	0.3908	0.1924	0.1816	1.0000	0.4201	0.1610	1.0000	0.6977	0.3786	0.1716	0.0000	0.9571	0.0961
F15	0.0230	0.0676	0.3016	1.0000	0.0000	0.0779	1.0000	0.7614	0.2235	0.4252	0.4395	0.9135	0.2926
F16	0.0497	0.4921	0.0427	0.7228	0.0000	0.2422	0.3572	0.7629	0.2652	0.6012	0.5298	1.0000	1.0000
F17	0.0000	0.1105	0.0249	1.0000	0.1093	0.1873	0.8189	0.7754	0.5197	0.4847	0.7093	0.8842	0.7887
F18	0.0129	0.0134	0.1772	0.4289	0.0000	0.0538	1.0000	0.2855	0.1310	0.0429	0.0723	0.2069	0.8018
F19	0.0000	0.2001	0.7727	1.0000	0.0192	0.0312	1.0000	0.2142	0.3192	0.4635	0.8176	0.7924	0.9950
Sum	1.9911	3.5379	3.2346	6.8619	9.9634	5.9972	16.4214	15.5767	7.8004	5.1479	3.6143	5.1403	5.6858

Table 2
p-Values of the Wilcoxon ranksum test over all runs ($p >= 0.05$ have been underlined).

F	SCA	PSO	GA	BA	FPA	FA	GSA
F1	N/A	0.002165	0.002165	0.002165	0.002165	0.002165	0.002165
F2	N/A	0.002165	0.002165	0.002165	0.002165	0.002165	0.002165
F3	0.004329	0.002165	0.002165	0.002165	0.002165	N/A	0.008658
F4	0.002165	0.002165	0.002165	0.002165	0.002165	N/A	0.002165
F5	N/A	0.002165	0.002165	0.002165	0.002165	0.002165	0.681818
F6	0.002165	0.002165	0.002165	0.002165	0.002165	0.002165	N/A
F7	N/A	0.002165	0.002165	0.002165	0.002165	0.24026	0.002165
F8	0.002165	0.002165	0.002165	N/A	0.002165	0.002165	0.002165
F9	N/A	0.002165	0.002165	0.002165	0.002165	0.484848	0.818182
F10	1.000000	0.002165	0.002165	0.002165	0.002165	N/A	0.093074
F11	N/A	0.002165	0.002165	0.002165	0.002165	0.002165	0.002165
F12	N/A	0.015152	0.002165	0.002165	0.002165	0.064935	0.064935
F13	0.002165	0.002165	0.002165	0.002165	0.002165	N/A	0.393939
F14	0.064935	0.588745	0.064935	0.041126	0.064935	N/A	0.132035
F15	0.179654	0.064935	N/A	0.002165	0.008658	0.008658	0.002165
F16	0.818182	0.937229	N/A	0.002165	0.002165	0.002165	0.002165
F17	N/A	1.000000	0.015152	0.002165	0.002165	0.002165	0.002165
F18	0.818182	0.393939	N/A	0.002165	0.002165	0.699134	0.025974
F19	N/A	0.064935	0.699134	0.002165	0.041126	0.041126	0.002165

Conclusion

In this paper, an extensive literature survey has been done on the different techniques of Load Frequency Control/ Automatic Generation Control in order to optimize the gain of controller. Merits and demerits of different algorithms are present. Some of these techniques are compared with freshly developed SCA algorithm for different test functions. Firstly, the set of well known test cases covering uni model, multi-model and composite test functions were made to test exploration, exploitation, local optima avoidance and convergence of proposed algorithm. Secondly, the two dimensional versions of some of the test functions were taken and resolved by SCA. From this paper it can be concluded that the SCA is very suitable option compared with the recently published techniques for solving different optimization problems. Therefore, this algorithm is used in different fields.

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