iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** I **Month of publication:** January 2018

DOI: http://doi.org/10.22214/ijraset.2018.1171

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 6 Issue I, January 2018- Available at www.ijraset.com

Particle Swarm Optimization Algorithm with ANFIS for Economic Load Dispatch

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Abstract: Electrical power systems are designed and operated to meet the continuous variation of power demand. The main aim of modern electric power utilities is to provide high-quality reliable power supply to the consumers at the lowest possible cost while meeting the limits and constraints imposed on the generating units and environment. These constraints formulates the economic load dispatch (ELD) problem for finding the optimal combination of the output power of all the online generating units that minimizes the total fuel cost, while satisfying an equality constraint and a set of inequality constraints. This paper proposes application of PSO trained Anfis for solving economic load dispatch problem. Particle swarm optimization (PSO) is a population based stochastic optimization technique, inspired by social behavior of bird flocking or fish schooling. The proposed approach has been examined and tested with the numerical results of optimal scheduling of generation with three and six generating units. The results of the proposed PSO-ANFIS algorithm are compared with that of other techniques such as Lambda-Iteration Method and PSO Method and compared to both cases; the proposed algorithm outperforms the solution.
Keywords: ANFIS, OSG, ELD, PSO, Lambda iteration

I. INTRODUCTION

Optimal scheduling of generation is an important task in the power plants operation which aims to allocate power generations to match load demand at minimal possible cost while satisfying all the power units and system constraints [1]. The complexity of the problem is due to the nonlinear and non-smooth characteristics of the input-output curves of the generators, because of valve-point effect, ramp rate limits and prohibited operating zones. The mathematical programming based optimization methods such as lambda iteration, base point participation method, Gradient and Newton's methods can solve successfully the optimal scheduling problems [2]. But unfortunately, these methods are ineffective to handle the complex optimal scheduling problems with non-differentiable characteristics due to high complexity. Dynamic programming can solve such type of problem, but it suffers from curse of dimensionality. Hence for optimal solution this problem needs a fast, robust and accurate solution methodology. Now days heuristic search methods such as simulated annealing (SA)[3] genetic algorithm (GA) [4]-[5], evolutionary programming (EP) [6], particle swarm optimization (PSO) [7]-[10], Bacteria foraging optimization (BFO) [11], differential evolution (DE) [12] and chaotic ant swarm optimization [13] are employed to solve the optimal scheduling problems All the approaches have achieved success to a certain extent. New optimization algorithms[18-24] can be used for DG placement and economic load dispatch problems.

This paper presents the application of proposed PSO-ANFIS algorithm to optimal scheduling generation problem. The paper is organized as follows. Section II describes mathematical modelling of optimal scheduling generation problem and in section III existing PSO system is described. The proposed PSO-ANFIS algorithm is described in section IV and the description of test systems, results and comparisons of proposed algorithm with other methods are presented in section V. Finally conclusion is given in section VI.

II. ECONOMIC LOAD DISPATCH PROBLEM

The optimal scheduling generation problem is defined as to minimize the total operating cost of a power system while meeting the total load plus transmission losses with in the generator limits. Mathematically, the problem is defined as to minimize equation (1) subjected to the energy balance equation given by (2) and the inequality constraints given by equation (3).

$$F_i(P_i) = \sum_{i=1}^{NG}(a_i P_i^{\,2} + b_i P_i + c_i) \quad (1)$$

$$\sum_{i=1}^{NG} P_i = P_D + P_L \quad (2)$$

$$P_{imin} \le P_i \le P_{imax} \quad \text{(i=1, 2, 3... NG) (3)}$$

Where a_i, b_i and c_i are cost coefficients

P_D is load demand

P_i is real power generation

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P_L is transmission loss
NG is number of generators
One of the important, simple but approximate methods of expressing transmission loss as a function of generator powers is through B- coefficients. The general form of the loss formula using B- coefficients is

$$P_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_i B_{ij} P_j \text{ MW} \quad (4)$$

Where P_i, P_j are real power injections at the *i*th, *j*thbuses B_{ij} are loss coefficients
The above loss formula (4) is known as George's formula. In normal optimal scheduling generation problem the input – output characteristics of a generator are approximated using quadratic functions, under the assumption that the incremental cost curves of the units are monotonically increasing piecewise-linear functions.

$$F_i(P_i) = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i) \quad (5)$$

Wherea_i, b_i, c_i are cost coefficients of *i*th unit.
Mathematically, optimal scheduling generation problem considering valve point loading is defined as minimizing operating cost given by equation (5) subjected to energy balance equation and inequality constraints given by equations (2) and (3) respectively.

III.PSO ALGORITHM

Particle Swarm Optimization is an approach to problems whose solutions can be represented as a point in an n-dimensional solution space. A number of particles are randomly set into motion through this space. At each iteration, they observe the "fitness" of themselves and their neighbours and "emulate" successful neighbors (those whose current position represents a better solution to the problem than theirs) by moving towards them. Various schemes for grouping particles into competing, semi-independent flocks can be used, or all the particles can belong to a single global flock. This extremely simple approach has been surprisingly effective across a variety of problem domains.
PSO was developed by James Kennedy and Russell Eberhart in 1995 after being inspired by the study of bird flocking behavior by biologist Frank Heppner. It is related to evolution-inspired problem solving techniques such as genetic algorithms.
As stated before, PSO simulates the behaviors of bird flocking. Let us consider a scenario where a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. So what's the best strategy to find the food? The effective one is to follow the bird which is nearest to the food.
PSO learned from this scenario is used to solve the optimization problems. In PSO, each single solution is a "bird" in the search space. We call it " a particle". All of particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles.
PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called p best. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called g best. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called l best. After finding the two best values, the particle updates its velocity and positions with following equation (6) and (7).

v[] = v[] + c1 * rand() * (p best[] - present[]) + c2 * rand() * (g best[] - present[]) (6)

present [] = present[] + v[] (7)

v [] is the particle velocity, present[] is the current particle (solution). P best [] and g best [] are defined as stated before. Rand () is a random number between (0,1). c1, c2 are learning factors. Usually c1 = c2 = 2
While maximum iterations or minimum error criteria is not attained Particles' velocities on each dimension are clamped to a maximum velocity Vmax. If the sum of accelerations would cause the velocity on that dimension to exceed Vmax, which is a parameter specified by the user then the velocity on that dimension is limited to Vmax. Flowchart of PSO algorithm is shown in figure 1.

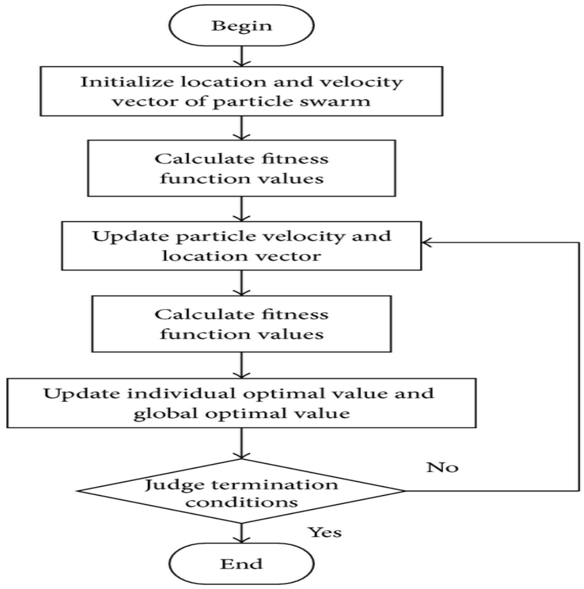

Fig: 1 Flowchart for PSO Algorithm

IV. ADAPTIVE NEURO FUZZY INFERENCE SYSTEM

An adaptive neuro fuzzy inference system (ANFIS) is a kind of artificial neural network that is based on Takagi–Sugeno fuzzy inference system. This technique was developed in the early 1990s. ANFIS integrates both neural networks and fuzzy logic principles and it has the potential to capture the benefits of both in a single framework. It's inference system corresponds to a set of fuzzy "If-Then" rules that have learning capability to approximate nonlinear functions. Hence, ANFIS is considered to be an universal estimator. ANFIS uses a hybrid learning algorithm to tune the parameters of a Sugeno-type fuzzy inference system (FIS). This algorithm uses a combination of the least-squares and back-propagation gradient descent methods to model a training data set. ANFIS also validates models using a checking data set to test for overfitting of the training data. [14].

ANFIS is a type of Neuro-fuzzy model. Neural networks and fuzzy systems both are stand-alone systems. With the increase in the complexity of the process being modeled, the difficulty in developing dependable fuzzy rules and membership functions increases. This has led to the development of another approach which is mostly known as ANFIS approach. It has the benefits of both neural networks and fuzzy logic. One of the advantages of fuzzy systems is that they describe fuzzy rules, which fit the description of real-world processes to a greater extent. Another advantage of fuzzy systems is their interpretability; it means that it is possible to explain why a particular value appeared at the output of a fuzzy system. In turn, some of the main disadvantages of fuzzy systems are that expert's knowledge or instructions are needed in order to define fuzzy rules, and that the process of tuning of the parameters of the fuzzy system often requires a relatively long time. [15].

A diametrically opposite situation can be observed in the field of neural networks. It is known that neural networks are trained, but it is extremely difficult to use a prior knowledge about the considered system and it is almost impossible to explain the behavior of the neural network system in a particular situation. In order to compensate the disadvantages of one system with the advantages of another system, several researchers tried to combine fuzzy systems with neural networks. A hybrid system named ANFIS has been proposed. Fuzzy inference in this system is realized with the aid of a training algorithm, which enables to tune the parameters of the fuzzy system.

V. RESULTS

The applicability and efficiency of PSO-ANFIS algorithm for practical applications has been tested on two test cases. The programs are developed using MATLAB 7.9. The Parameters for PSO algorithm considered here are: n=20, c1=2.0,c2=2.0, Wmax=0.9, Wmin=0.4.The proposed PSO algorithm stopping criteria is based on maximum-generation=500.

A. Test case 1:

The system consists of three thermal units [16]. The cost coefficients of all thermal generating units are listed in table (1). The economic load dispatch problem is solved to meet a load demand of 250 MW and 350 MW.

TABLE: 1 COST COEFFICIENTS FOR THREE GENERATING UNITS

Unit	Fuel cost coefficients			P_(G min) (MW)	P_(G max) (MW)
	a_i	b_i	c_i		
G1	0.03546	38.30553	1243.531	50	250
G2	0.02111	36.32782	1658.57	5	150
G3	0.01799	38.27041	1356.659	15	100

TABLE: 2 TRAINING DATA FROM PSO ALGORITHM

Load (MW)	P1 (MW)	P2 (MW)	P3 (MW)	Cost (Rs/h)
300	49.32179	130	125	16378.5891
350	70.30123	156.2673	129.2084	18564.484
400	82.07836	174.9938	150.496	20812.2936
450	93.93744	193.8135	171.8617	23112.3635
500	105.8799	212.728	193.3065	25465.4691
550	117.9073	231.7384	214.8312	27872.4051
600	130.021	250.8462	236.4368	30333.9858
650	142.2227	270.0528	258.1242	32851.0461
700	154.5139	289.3597	279.8944	35424.442
750	166.8963	308.7683	301.7484	38055.0518
800	191.1077	325	315	40750.8418

TABLE 3: COMPARISON OF RESULTS FOR TEST CASE 1

Power Demand (MW)	Fuel Cost (Rs/hr)		
	Lambda Iteration Method	PSO Method	PSO-ANFIS Method
350	18564.48	18564.48	18567.37
400	20812.29	20812.29	20812.13
450	23112.36	23112.36	23111.54
500	25465.47	25465.47	25465.09
550	27872.40	27872.40	27872.71
600	30333.98	30333.99	30334.63
650	32851.04	32851.05	32851.44
700	35424.44	35424.44	35424.22

Table: 3 show the summarized result of all the existing algorithms along with proposed PSO-Anfis algorithm for test case 1. Form Table: 3, it is clear that proposed algorithm gives optimum result in terms of minimum fuel cost compared to other existing algorithms shown.

B. Test case 2

The six unit test system chosen in this thesis is the IEEE 30 bus system [17] in which cost coefficients of the generating units, generating capacity of each are specified. The test system comprises of 6 generators, 41 transmission lines and 30 buses. The IEEE 30 bus system has a minimum generation capacity of 117 MW and a maximum generation capacity of 435 MW. The economic load dispatch problem is solved to meet a load demand of 250 MW and 350 MW.

TABLE 4: COST COEFFICIENTS FOR SIX GENERATING UNITS

Unit	Fuel cost coefficients			$P_{G\,min}$ (MW)	$P_{G\,max}$ (MW)
	a_i	b_i	c_i		
G1	0.1524	38.53	756.79886	10	125
G2	0.10587	46.15916	451.32513	10	150
G3	0.02803	40.39655	1049.9977	35	225
G4	0.03546	38.30553	1243.5311	35	210
G5	0.02111	36.32782	1658.5696	130	325
G6	0.01799	38.27041	1356.6592	125	315

TABLE 5: TRAINING DATA FROM PSO ALGORITHM

LOAD	P1	P2	P3	P4	P5	P6	COST
400	14.76745	10	35	63.20802	155.6134	125	22831.57
450	18.86115	10	35	80.57687	185.054	125	25045.4
500	18.62118	10	56.31067	77.3453	182.0797	161.3248	27254.49
550	22.74596	10	84.31418	35	212.056	192.5923	29624.37
600	22.72662	10	78.9887	93.57175	211.1886	191.802	31819.68
650	24.77192	10	89.11953	101.6324	225.6671	208.5631	34156.51
700	26.86407	10	99.28232	109.5938	240.2361	225.3786	36529.75
750	28.95601	10	109.4691	117.5769	254.8244	242.2554	38939.65
800	31.05444	10	119.6633	125.5675	269.4596	259.1906	41386.49
850	33.16138	10	129.8688	133.565	284.1432	276.1784	43870.54
900	35.27709	10	140.0881	141.571	298.875	293.2152	46392.07
950	37.40155	10	150.3213	149.5849	313.6556	310.3023	48951.37
1000	41.15337	10	168.7391	163.9197	325	315	51555.73
1050	46.58271	10	195.5023	184.6723	325	315	54243.37
1100	49.19618	24.15205	206.8554	210	325	315	56997.95
1150	63.9863	44.60215	225	210	325	315	59868.36
1200	86.39384	75.63354	225	210	325	315	63072.65
1250	108.8455	106.7536	225	210	325	315	66643.13
1300	124.9988	144.5736	225	210	325	315	70593.24

TABLE: 6 COMPARISON OF RESULTS FOR TEST CASE 2

Power Demand (MW)	Fuel Cost (Rs/hr)		
	Lambda Iteration Method	PSO Method	PSO-ANFIS Method
600	31839.89265	31819.68831	31818.99
650	34180.73802	34156.51368	34162.32
700	36558.42788	36529.84137	36522.11
750	38973.25018	38939.65071	38943.55
800	41425.50478	41386.48877	41390.75
850	43915.48051	43870.53654	43862.84
900	46443.4753	46392.07068	43862.84
950	49009.79797	48951.9641	48949.96

Table: 6 show the summarized result of all the existing algorithms along with proposed PSO-Anfis algorithm for test case 2. Form Table: 6, it is clear that proposed algorithm gives optimum result in terms of minimum fuel cost compared to other algorithms shown.

VI. CONCLUSION

In this paper, a new PSO-ANFIS algorithm has been proposed. In order to prove the effectiveness of algorithm it is applied to economic load dispatch problem with three and six generating units. The results obtained by proposed method were compared to those obtained by conventional method and PSO. The comparison shows that PSO-ANFIS algorithm performs better than above mentioned methods. Therefore, this results shows that PSO-ANFIS optimization is a promising technique for solving complicated problems in power system.

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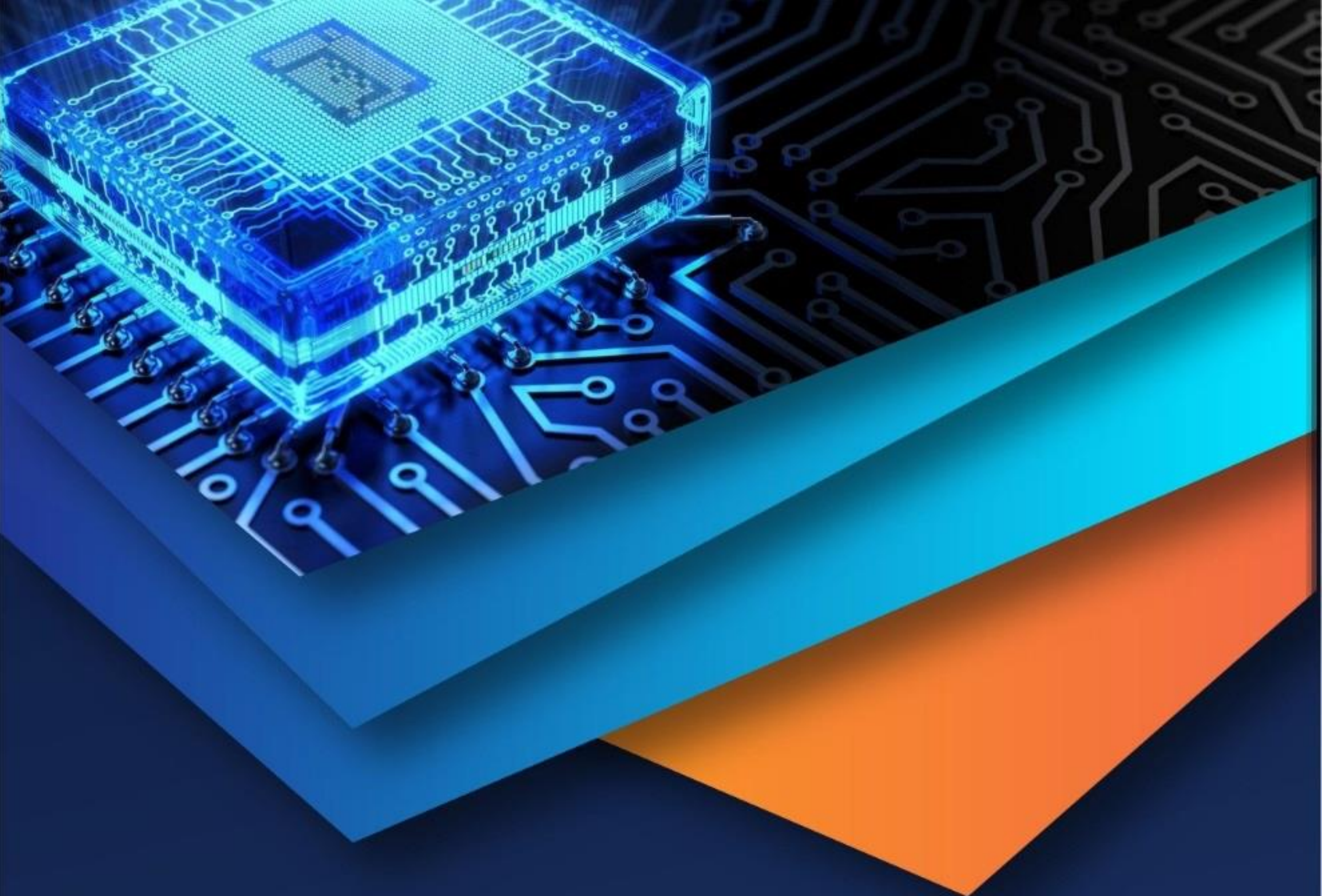

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