



TLBO based ELD of IEEE-30 Bus System

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Abstract— A significant reduction in operational costs as well as the amount of fuel used results in a saving in the operation of the power systems. Modern electricity utilities aim mainly to provide consumers with the lowest possible cost of high-quality, reliable energy supply while working to fulfil the limits or constraints on generation units and environmental considerations. These restrictions formulated the problem of economic load dispatch (ELD) to find the optimal combination of the energy output of all online generating units that minimizes the overall cost of fuel while meeting the limitations of equality and the set of inequalities. This problem of an ELD can effectively be resolved by traditional algorithms, such as lambda iteration, baseline participation factor, gradient method, and Newton's process only if the cost of fuel in generation units is piece by piece linear and monotonous. Here in this paper discuss TLBO based ELD for novel application on IEEE-30 bus system. The result is simulated in MATLAB for validating the result.

Keywords—DG, ELD, Lambda Iteration, Taboo Search, Newton-Rapshon Method, PSO, EHM and TLBO etc.

I. INTRODUCTION

It is very important to reduce running energy costs, given The Economic Load Dispatch primarily focuses on to assign electricity to different units in order to meet the units demand for load. The allocation of power together with the minimum transmission and fuel cost is achieved. By examining the economic transmission, it is shown that the online generation of power is available for small connected units. The online generator relates the cost of production to its output [1]. For designing such a generator, the quadratic cost function is used to simplify arithmetical formulation and traditional optimization techniques. These methods determine that the fuel cost curve either constantly increases or decreases in order to achieve the best solution. Techniques such as dynamic programming may or may not suit for large-scale systems because many computations are required to deliver more accurate and reliable results. However, the introduction to optimization algorithms like PSO makes it possible to solve this problem easily through the developmental optimization algorithm using the simplification model and produce precise and quick results [2].

Unit engagement problems are considered to be the problem of dealing with the optimum time each generator takes per hour to effectively meet the user's load requirements. Minimal losses can be maximized while

supplying power to maximize profit [3], with minimum consumption of fuel. In addition to achieving minimum total production costs, a generation schedule requires a fulfilled number of operational constraints. This particular restriction reduced the option to start and shut down generating units. The limits to be satisfied are: capability limits, minimum down time, limit on the status of each generator unit, minimum downtime, limit of 1st or last hour generation, limit of energy balance, limit of ramp rate, restriction of the spinning reserve, restricted group, and so on.

The UC problem was applied to both stochastic and deterministic loads. The results from a deterministic approach are both definite and unique, while they are not accurate from stochastic loads. The analysis of the data envelope for deterministic loads is a non-parametric approach, where variables are first defined input and then output [4].

Teaching-Learning Based Optimization (TLBO) is a population-based way of working, like other naturally-inspired algorithms, on two basic concepts of education called teacher phase and learner phase. The professor is usually a highly qualified person who shares his knowledge with the students. A teacher's quality affects the result of the quality of the marks or grades of the learner. In addition, from the student phase, students also learn from the interaction, which contributes to their findings. Contrary to other techniques of optimization TLBO is parameter free optimization technique hence it is simpler in nature.

In this paper firstly discuss the review of work associated in the field of economic load dispatch for reducing the cost of generation by different researchers. Then discuss the proposed TLBO based economic load dispatch for IEEE-30 bus system.

II. REVIEW WORK BASED ON ELD

In The recent competition in the electricity market has increased. To survive, it is necessary to produce optimum power to minimize total costs. The cost-effective delivery of the energy system determined by the shipment of power generation resources for the delivery of cargo. The ELD's main aim is to minimize overall production costs while meeting operational limitations. There are many researchers work in the field on economic load dispatch to utilize the proper operation of the power plant. In this chapter discuss a brief review of the work associated in the field of ELD.

In [5-6] present a hybrid technique a hybrid technique combining differential development with biogeographically optimization (DE / BBO) algorithms for resolving the thermal unit thermal power problems, including the ramp rate limits, valve points, and banned operating zones, of both convex and non-convex economic load dispatch (ELDs). The swarm intelligence hybrid harmony search (HHS) algorithm is used to solve the dynamic displacement problem of economic load [7]. Harmony Search (HS) is an algorithm for derive-free and meta-heurical optimization that has recently been developed and is inspired by the musical search process for a perfect harmonic. The distributed EDP based consensus algorithm is suggested in [8]. The optimization algorithm for ELD is presented in [9]. In this paper convex-type function of the ELD is calculate and by using CPLEX solver to find the optimum ELD. The distributed algorithm [10] is used for solving the transmission line losses and generator constraints on economic power dispatch. The approach proposed is based on two parallel consensus algorithms. A new knapsack type of problem is proposed in the paper [11]. A multi agent based new optimization technique is developed for the muti-micorgird system in [12]. A CEED problem is discussed in [13] for solving the ELD issue. Other optimization algorithms for various energy systems are comparable to results obtained from the FPA proposed in [14]. New strategy on ELD based on for smart grid id developed in [15]. The GWO algorithm for the non-convex solution of the problem of the electrical power system dynamic load delivery (ELDP) solution is presented in [16]. The evolutionary approach to optimization named Gray Wolf Optimization (GWO), based on gray wolves 'behaviour, for the optimal economic load shipment (ELD) operation strategy is discussed in [17]. A newly population-based search algorithm Ant Lion Optimizer (ALO) [18], based on the hunting mechanism of ant lion and five steps of the hunt, i.e. the random walk of ants, building tags, trapping of agneas in traps, catching bearings and reconstruction traps, is the basis. A universal tool

which is being implemented with two dispatch-optimizers for a centralized Energy Management System (CEMS) is presented in [19]. targets.

III. MATHEMATICAL FORMULATION OF ELD

The Economic Load Dispatch (ELD) can be defined as the process of assigning the generation level to the generating system, thus ensuring the complete and economic supply of the system charges. It is necessary to minimize the costs of an interconnected system. In order to define each plant's production level, the economical load dispatch is used to minimize the total cost of the generation and transmission for the specified load schedule. The aim of the economic load dispatch is to minimize overall production costs. For generating units for different charges, the method of economic load shipping must have minimum total fuel cost. Numerous appliances, removable loads, and advanced Communication Networks now feature power systems that increase customer participation in the electricity market. This creates much more challenges for the optimal economic shipment (ED) of future power systems. In order to fully deal with the growing involvement of customers in the electricity sector and the inability of existing practices to address these changes, a sophisticated control is required.

The overall objective function F_T of the economic load dispatch problem is written as:

$$F_T = \min \sum_{i=1}^{N_G} F_i(P_{gi}) \tag{1}$$

Where, $F_i(P_{gi})$ is the cost function of the i^{th} generator and usually expressed as a quadratic polynomial. The ELD problem consists in minimizing the F_T subject to the following constraints:

➤ Real Power Balance Constraint:

$$\sum_{i=1}^{N_G} P_{gi} - (P_d + P_L) = 0 \tag{2}$$

Where, P_d is total power demand by the load, P_L is the transmission loss in the system.

➤ Generator Capacity Constraints:

Within its lower limit, P_{gi}^{\min} and upper limit P_{gi}^{\max} , the power must be generated by every generator:

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \tag{3}$$

➤ Ramp Rate limit Constraint:

At certain intervals, the power generated by the i^{th} generator, $P_{gi,0}$ shall not be more than that of the preceding interval UR_i the up-ramp limit, nor should it be less than that of the previous interval, DR_i , the down-ramp limit. The following limitations arise:

As generation increases

$$P_{gi} - P_{gi,0} \leq UR_i \tag{4}$$

As generation decreases:

$$P_{gi,0} - P_{gi} \leq DR_i \tag{5}$$

$$\max(P_i^{min}, P_{gi,0} - DR_i) \leq (P_i^{max}, P_{gi,0} + UR_i) \tag{6}$$

➤ **Prohibited Operating Zone:**

Feasible operating zone for a unit is expressed in mathematically:

$$P_{i,n_i}^u \leq P_{gi} \leq P_{gi}^{max} \tag{7}$$

Where, j represents the number of prohibited operating zones of unit i . $P_{i,j}^u$ is the upper limit and $P_{i,j}^l$ is the lower limit of the j^{th} prohibited operating zone of the i^{th} unit. The total number of prohibited operating zones of the i^{th} unit is n_j .

IV. TEACHING LEARNING BASED OPTIMISATION

A new optimization technique developed by Rao et al. is a teaching-learning optimization algorithm. It is also an optimization process based on the population, like other optimization algorithms, and is inspired in a class between teachers and learners by the teaching-learning process. Professors are regarded as the most expert and always attempt to influence the students to achieve their goal. The teacher's quality influences the students' result. In addition, the students improve their knowledge by discussing it with other students in the classroom. Based on the students' knowledge, the final results of the class is evaluated. Teaching - learning based optimization (TLBO) achieves global solutions with reduced computational and consistent continuous non - linear functions.

Like genetic algorithms, artificial bee colony and the harmony search, teaching learning-based optimization is also a population-based technique implementing the best solution group of solutions. TLBO includes: (i) the teacher phase and (ii) the student phase

➤ **Teacher Phase**

The first part of the algorithm is called the Teacher Phase, where students increase their knowledge by teachers. At this stage, the teacher attempts, depending on his capacity, to increase the mean results of the subject he or she teaches in the class [29]. The best solution defined by the value of its objective function is the teacher from the population. The growth of student knowledge in a course depends on the teacher. However, for a teacher the knowledge in the students cannot be increased equally in practice because each student has different levels of learning. Thus, after learning, the teacher can only somewhat improve the average level of the students in class.

➤ **Lerner Phase**

A student also learns through interaction with other students. The Learner Phase is thus known as the learning phase of the other students of the class. The second phase of the algorithm is Learner, where students enhance their understanding by interacting with each other [29]. If other learners have more knowledge, they further enhance the

quality of their knowledge by comparing their knowledge with other students. So every student will choose another student randomly to interact with him and learn new things from him if he knows better than him.

V. IMPLEMENTATION OF TLBO IN ELD PROBLEM

The procedure for implementing the TLBO algorithm in proposed work has been described in this section to solve ELD problems. This algorithm is also used to address the constraints of ELD equality and inequality. The sequence of steps used to solve the ELD problem in the TLBO algorithm:

➤ **Preparing of Student matrix, X:** Because the ELD problem assessment variables are the actual power output of generators, they represent each learner together. The subject is the study of the corresponding student each single element of a learner, and the actual output power of the generators in ELD is the same. Select the number of generator units for initializations, m , as design variable, D . The total population size of the learner structure is referred to as the 'popsize'.

$$X_i = [X_{i,1}, X_{i,2}, \dots, X_{i,m}] = [P_{g_i,j}]$$

$$= [P_{g_{i,1}}, P_{g_{i,2}}, \dots, P_{g_{i,m}}] \tag{8}$$

➤ **Initialization of the Student:** Each element in the student matrix (X) is randomly initialized within the effective real power operating limits for each element in a given student.

➤ **Evaluation of Objective function:** In the case of ELD problems, each student's objective function is represented by the total cost of fuel for all generators.

Initially chooses the number of generator units m , i.e number of design variables, D , and the total population size i.e number of student "Pop Size". Indicate the maximum and minimum capacity of each generator, B -coefficient matrix for calculation of transmission loss and other input parameter of the proposed system. Now set the maximum iteration number for running the algorithm.

By using the concept of slack generator principle satisfy each student of matrix "X" the equality constraint of equation

Calculate the objective function of the proposed system for each student

Identify the elitist learner who is assigned to teach the learner matrix on the basis of target function values. The elite term is used here to show the student who pays the best amount of fuel.

The mean value of each design variable, i.e. the mean value of the individual generator output column wise, should be calculated from the student matrix (X)

Change every student, i.e. the generator power output. Check the feasibility of the Modified “X” matrix for each newly developed student. The operational limit of the generator must be met by individual components of each modified learner. If a student's element violates either upper or lower operating limits, X is the value of the corresponding student elements at the limit they reach.

Calculate each learner modular of the learner matrix's objective function values. If the new value of a student's objective function is superior to the previous, take the new student and replace the old one. Otherwise, keep the old student unmodified.

For each student, X_i ($i=1,2,\dots,D$), randomly choose for any student X_j from the student matrix. Compare the target function of X_i and X_j . If the value of the objective function of X_i is less than that of X_j , modify the i^{th} student.

Individual elements must meet their generator constraints for each modern student. If any element of a modernizer breaches either upper or lower operating limits, x the values of the elements of the corresponding student at their reach.

The values of the objective function also change as individual learners of the learner matrix change. Calculate each newly generated student's objective function. If a new value of a given learner's objective function is better than its former value, the new learner will accept it and replace it. Otherwise, keep the old student without changing.

When the maximum number of iterations has been reached or the level of accuracy is specified, the iterative process must be terminated.

VI.RESULT

In this section discuss the proposed teacher learning based optimization technique for IEEE 30 bus system with 6 generators

Here in the proposed system generators are connected at bus number 1, 2, 5, 8, 11 and 13. Table 1 shows the Bus data which is used for validating the proposed TLBO for cost optimization purpose.

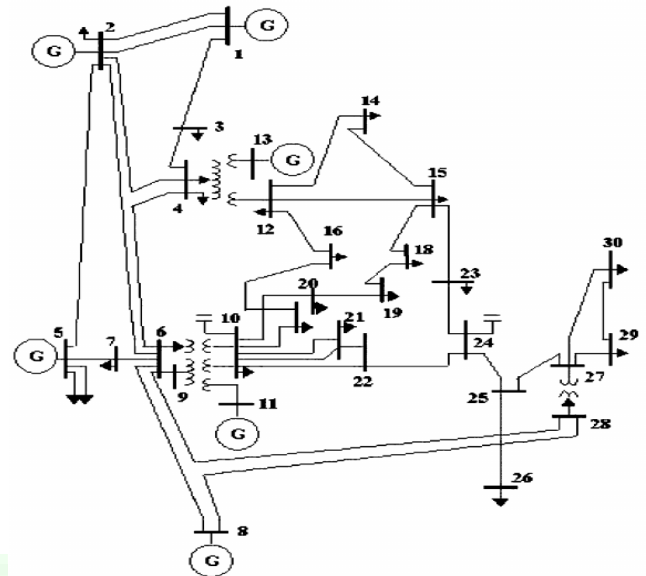


Figure 1: IEEE-30 Bus Standard System with 6 generator

Table 1: Bus Data of Proposed IEEE-30 Bus System

Bus No	Typ e	V	P _{gi}	Q _{gi}	P _{di}	Q _{di}	Q _{mi} _n	Q _{ma} _x
1	1	1.0 6	30	0	0	0	0	0
2	2	1.0 4	40	50	21. 7	12. 7	-40	50
3	3	1	0	0	2.4	1.2	0	0
4	3	1.0 6	0	0	7.6	1.6	0	0
5	2	1.0 1	55	37	94. 2	19	-40	40
6	3	1	0	0	0	0	0	0
7	3	1	0	0	22. 8	10. 9	0	0
8	2	1.0 1	45	37. 3	30	30	-10	40
9	3	1	0	0	0	0	0	0
10	3	1	0	19	5.8	2	0	0
11	2	1.0 8	225	16. 2	0	0	-6	24
12	3	1	0	0	11. 2	7.5	0	0
13	2	1.0 7	200	10. 6	0	0	-6	24
14	3	1	0	0	6.2	1.6	0	0
15	3	1	0	0	8.2	2.5	0	0
16	3	1	0	0	3.5	1.8	0	0
17	3	1	0	0	9	5.8	0	0
18	3	1	0	0	3. 2	0.9	0	0

19	3	1	0	0	9.5	3.4	0	0
20	3	1	0	0	2.2	0.7	0	0
21	3	1	0	0	17.5	11.2	0	0
22	3	1	0	0	0	0	0	0
23	3	1	0	0	32	1.6	0	0
24	3	1	0	4.3	8.7	6.7	0	0
25	3	1	0	0	0	0	0	0
26	3	1	0	0	3.5	2.3	0	0
27	3	1	0	0	0	0	0	0
28	3	1	0	0	0	0	0	0
29	3	1	0	0	2.4	0.9	0	0
30	3	1	0	0	10.6	1.9	0	0

14	15	0.221	0.19	0	1
16	17	0.082	0.19	0	1
15	18	0.107	0.21	0	1
18	19	0.063	0.12	0	1
19	20	0.034	0.06	0	1
10	20	0.093	0.20	0	1
10	17	0.032	0.08	0	1
10	21	0.034	0.07	0	1
10	22	0.072	0.14	0	1
21	23	0.011	0.02	0	1
15	23	0.1	0.20	0	1
22	24	0.115	0.17	0	1
23	24	0.132	0.27	0	1
24	25	0.188	0.32	0	1
25	26	0.254	0.38	0	1
25	27	0.109	0.20	0	1
28	27	0	0.39	0	0.968
27	29	0.219	0.41	0	1
27	30	0.320	0.60	0	1
29	30	0.239	0.45	0	1
8	28	0.063	0.2	0.0214	1
6	28	0.016	0.05	0.065	1

Table 2 shows the line data of the IEEE-30 bus standard data of the line. In this system there is 41 branches is consider for proposing optimal economic load dispatch.

Table 2: Line Data for IEEE-30 Bus System

From Bus	To Bus	R (pu)	X(pu)	B/2 (pu)	X'mer TAP
1	2	0.019	0.05	0.0264	1
1	3	0.045	0.16	0.0204	1
2	4	0.057	0.17	0.0184	1
3	4	0.013	0.03	0.0042	1
2	5	0.047	0.19	0.0209	1
2	6	0.058	0.17	0.0187	1
4	6	0.011	0.04	0.0045	1
5	7	0.046	0.11	0.0102	1
6	7	0.027	0.08	0.0085	1
6	8	0.012	0.04	0.0045	1
6	9	0	0.20	0	0.978
6	10	0	0.55	0	0.969
9	11	0	0.20	0	1
9	10	0	0.11	0	1
4	12	0	0.25	0	0.932
12	13	0	0.14	0	1
12	14	0.123	0.25	0	1
12	15	0.066	0.13	0	1
12	16	0.094	0.19	0	1

For validating the proposed system here in this uses standard IEEE-30 bus system. The TLBO is applying on this to find the optimal economic load dispatch of the system. Here for this uses 6 generators of different generation of the bus with total load demand of 283.4 MW. The parameter here used in per unit system with base value 100 MVA. The whole system operated in MATLAB environment to find the optimum fuel cost of the generation and also optimize the power generation to fulfil the load.

The result obtained by the running of TLBO for cost minimization of the entire IEEE-30 bus system. The total iteration is taken here for finding result is 100 and after running the best cost is found is 19980.1434 Rs/kWhr as shown in figure 2.

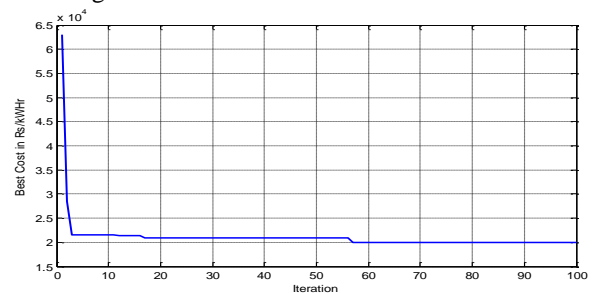


Figure 2: Best Fuel Cost of the Proposed System with TLBO

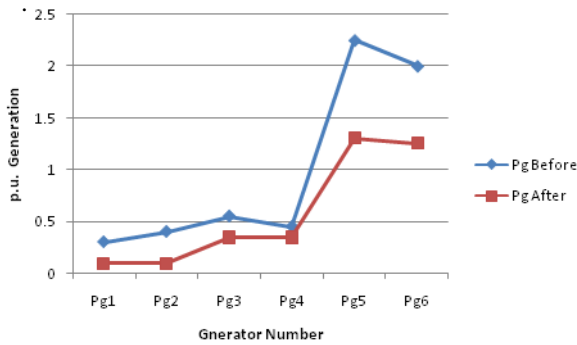


Figure 3: Cost optimized Result of the generation before and after TLBO

Figure 3 shows the generation before and after optimization of the cost for the proposed IEEE-30 bus with 6 generator system. Table 3 shows the generation optimization with the fuel cost minimization with proposed TLBO in IEEE-30 bus system.

Table 3: Optimization of Generation cost of IEEE-30 bus data with TLBO

Gen	Pg (pu)	Pg_Ne w (pu)	Fuel Cost Coefficient			Fuel cost (Rs/kW Hr)
			ai	bi	ci	
Pg1	0.3	0.1	0.1524	38.53	756.79	1157.42
Pg2	0.4	0.22	0.1058	46.15	451.32	923.497
Pg3	0.55	0.35	0.0280	40.39	1049.9	2498.18
Pg4	0.45	0.35	0.0354	38.30	1243.5	2627.64
Pg5	2.25	1.3	0.0211	36.32	1658.5	6737.82
Pg6	2	1.25	0.0179	38.27	1356.6	6421.49

Table 4 shows the emission of the generation side due to fuel combustion at the generating end bus.

Table 4: Optimization of emission of IEEE-30 Bus data with TLBO

Gen	Pg (pu)	Pg_Ne w (pu)	Emission Coefficient			Emission (Tons/Hr)
			alpha	beta	gama	
Pg1	0.3	0.1	0.004	0.327 67	13.859	17.554 7
Pg2	0.4	0.1	0.004 19	0.3 2767	13.859	17.554 7

Pg3	0.55	0.35	.0068	0.545 51	40.266	29.5399
Pg4	0.45	0.35	0.006 83	0.5 4551	40.266	29.5399
Pg5	2.25	1.3	0.004 61	0.5 1116	42.895	54.3532
Pg6	2	1.25	0.004 61	0.5 1116	42.895	51.03125

VII. CONCLUSION

Mathematical programming and Optimization techniques apply many traditional methods for solving ELD problems. The most common methods are the lambda iteration method, method of base point and participatory factor, method of gradient, etc. The lambda iteration method frequently uses all these methods and this can also be used easily. For linear cost approximation all of these methods may only be feasible. In this paper looks up off many researchers work in different field of economic load dispatch in modern power system. A new type of optimization technique based on teacher student relationship is discussed and implemented in the ELD problem. The work is simulated in MATLAB software and result is discussed for 6 generator based IEEE-30 bus system.

References

- [1]. Revathy K, "Economic load Dispatch using particle Swarm otimization", ijareeie, vol 3(4), Pp 59-67, 2015
- [2]. M. Sudhakaran, P. Ajay - D - Vimal Raj and T.G. Palanivelu, 2007, "Application of Particle Swarm Optimization for Economic Load Dispatch Problems", ISAP,, Pp 668-674, 2007
- [3]. Jong-Bae Park, Ki-Song Lee, Joong-Rin Shin, and Kwang Y. Lee, FEBRUARY 2005, "A Particle Swarm Optimization for Economic Dispatch with No smooth Cost Functions", IEEE, vol 20(1), Pp 34-42, 2005
- [4]. Samir SAYAH, "Economic Load Dispatch with Security Constraints of the Algerian Power System uses Successive Linear Programming Method", researchgate, 2004
- [5]. Aniruddha Bhattacharya ; Pranab Kumar Chattopadhyay, "Hybrid Differential Evolution With Biogeography-Based Optimization for Solution of Economic Load Dispatch", IEEE Transactions on Power Systems (Volume: 25 , Issue: 4 , Nov. 2010)
- [6]. Aniruddha Bhattacharya ; Pranab Kumar Chattopadhyay, "Closure to Discussion of "Hybrid Differential Evolution With Biogeography-Based Optimization for Solution of Economic Load Dispatch"", IEEE Transactions on Power Systems , Volume: 27 , Issue: 1 , Feb. 2012
- [7]. V.Ravikumar Pandi, Bijaya KetanPanigrahi, "Dynamic economic load dispatch using hybrid swarm intelligence based harmony search algorithm", Expert

- Systems with Applications Volume 38, Issue 7, July 2011, Pages 8509-8514
- [8]. Shiping Yang ; Sicong Tan ; Jian-Xin Xu , "Consensus Based Approach for Economic Dispatch Problem in a Smart Grid", IEEE Transactions on Power Systems, Volume: 28 , Issue: 4 , Nov. 2013
- [9]. Mostafa Modiri-Delshad ; Sam Koohi-Kamali ; Ehsan Taslimi ; S. Hr. Aghay Kaboli ; N. A. Rahim, "Economic dispatch in a microgrid through an iterated-based algorithm", 2013 IEEE Conference on Clean Energy and Technology (CEAT), Lankgwawi, Malaysia
- [10]. Giulio Binetti ; Ali Davoudi ; Frank L. Lewis ; David Naso ; Biagio Turchiano, "Distributed Consensus-Based Economic Dispatch With Transmission Losses", IEEE Transactions on Power Systems , Volume: 29 , Issue: 4 , July 2014
- [11]. Yinliang Xu ; Wei Zhang ; Wenxin Liu, "Distributed Dynamic Programming-Based Approach for Economic Dispatch in Smart Grids", IEEE Transactions on Industrial Informatics, Volume: 11 , Issue: 1 , Feb. 2015
- [12]. Nima Nikmehr ; Sajad Najafi Ravadanegh , "Optimal Power Dispatch of Multi-Microgrids at Future Smart Distribution Grids", IEEE Transactions on Smart Grid, Volume: 6 , Issue: 4 , July 2015
- [13]. A.Y.Abdelaziz, E.S.Ali, S.M.Abd Elazim, "Implementation of flower pollination algorithm for solving economic load dispatch and combined economic emission dispatch problems in power systems", Energy Volume 101, 15 April 2016, Pages 506-518
- [14]. Fanghong Guo ; Changyun Wen ; Jianfeng Mao ; Yong-Duan Song , "Distributed Economic Dispatch for Smart Grids With Random Wind Power", IEEE Transactions on Smart Grid, Volume: 7 , Issue: 3 , May 2016
- [15]. Vikram Kumar Kamboj, S. K. Bath, J. S. Dhillon, "Solution of non-convex economic load dispatch problem using Grey Wolf Optimizer", Neural Computing and Applications , Springer July 2016, Volume 27, Issue 5, pp 1301–1316
- [16]. B.R.Adarsh, T.Raghunathan, T.Jayabarathi, Xin-SheYang, "Economic dispatch using chaotic bat algorithm", Energy Volume 96, 1 February 2016, Pages 666-675
- [17]. Moumita Pradhan, Provas Kumar Roy, Tandra Pal, "Grey wolf optimization applied to economic load dispatch problems", International Journal of Electrical Power & Energy Systems Volume 83, December 2016, Pages 325-334
- [18]. Vikram Kumar Kamboj, Ashutosh Bhadoria, S. K. Bath, "Solution of non-convex economic load dispatch problem for small-scale power systems using ant lion optimizer", Neural Computing and Applications , Springer, August 2017, Volume 28, Issue 8, pp 2181–2192
- [19]. Mohsen Nemati, Martin Braun, Stefan Tenbohlen, "Optimization of unit commitment and economic dispatch in microgrids based on genetic algorithm and mixed integer linear programming", Applied Energy Volume 210, 15 January 2018, Pages 944-963
Convers Manage 2011;52:2854–60