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ELD of Power Network in Southwest of Iran (Khuzestan Province) Using JAYA Technique

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***Abstract* - Power load flow studies are the mainstays of analyzing and designing power systems, and doing so is essential for scheduling production between power companies and economic utilization. The distribution of economic load in today's world is the most important goal of energy distribution in dispatching centers. In industry, the production capacity of generators is usually much larger than the loads, so the allocation of loads in the generator can be varied. Since reducing the cost of electricity generation is important and the highest cost of production is related to the cost of fuel, so load sharing must be done economically. Finally, energy distribution professionals must take control of power plant production at the lowest cost. In this paper, the Economic Load Dispatch (ELD) problem of a sample power system is investigated by JAYA effective computational algorithm and the results are compared with Lambda iteration method. Theoretical backgrounds and mathematical formulations for these two methods are also provided. The power system studied in this research is the power network of southwestern Iran (Khuzestan province), which includes eight power plants. These calculations are performed by excluding network losses as well as by continuously assuming the cost function of power plants. Finally, the fuel cost of the power plants of the sample power system is compared using the JAYA algorithm and the classical Lambda iteration method. Comparison of the obtained results shows that these two methods are suitable in providing efficient solutions to economic load distribution problems in large electricity networks. All simulations have been performed in MATLAB software.**

Index Terms - JAYA technique, Lambda iteration, Economic Load Dispatch.

I. INTRODUCTION

In an interconnected power system, the task of supplying the load is the responsibility of different generators, among which the share of each generator in supplying the network load depends on the cost of generating the generators. Properly allocating a share of total demand can actually reduce fuel costs. Determining the actual generating capacity of generators so that the cost of production in the power system is minimized is known as economic load dispatch (ELD) and its purpose is to provide power to the maximum number of subscribers economically. For this purpose, the demand of the load and all the constraints of equality and inequality such as the balance of generation and consumption and the limits of generation are met in a certain period of time [1]. The ELD problem is classified into both convex and non-convex. The convex ELD problem assumes a simple form of objective function that uses linear constraints and constraints to minimize it. Therefore, in this case, the ELD problem is an approximate and simple problem. In the case of non-convex ELD, the cost function is reduced while constraints such as Prohibited Operating Zones (POZ) and the valve-point loading effects are nonlinear assumed. On the other hand, economic load dispatch is an online operation that is performed after every 15-30 minutes or upon request in power control centers, in which the load is dispatched between the production units in parallel with the system in such a way that the total cost of the operation is At least reach. Also, generators are programmed to use low-cost generators as much as possible [2].

Most major generators of electricity are divided into three categories: nuclear, hydropower, and thermal. Nuclear power plants usually have a constant output power and provide the base load. The operating costs of hydroelectric units do not usually change much as the output power changes. Therefore, the problem of economic load dispatch of power systems only applies to thermal units. Thermal power plants generally use basic energy such as gas, coal or diesel to generate electricity. Therefore, the cost of generation in power plants depends on the cost of fuel used by generators. Therefore, the main purpose of the economic performance of the power system is to reduce the cost of fuel for the operation of the power system [3]. Thermal power plants with a capacity of 68,388 MW, equivalent to 81% of Iran's total electricity production in 2019. The study of the capacity of the world's thermal power plants shows that China and the United States are in the first and second ranks, respectively, and Iran is in the ninth rank in the world in terms of thermal power generation [4].

II. RESEARCH LITERATURE

The history of the economic load dispatch of power systems dates back to the 1920s [5]. In the following decades, activists in the field of electricity and mathematics made great strides in this area. Initially, load dispatching meant the distribution of load among the most efficient power plants, this method is called base load. Another method is best point loading, where generators were loaded sequentially according to thermal scores. In the early 1950s, economic load dispatch based on differential equations was introduced, which included transmission line losses and penalty coefficients, and economic planning for offline or online use was introduced in 1955 [6].

ELD solution methods can be divided into two categories: classical methods and methods based on intelligent algorithms. In classical methods, the fuel cost function is modeled as a quadratic function, so that the ELD problem becomes a classical convex problem [7]. These methods are based on iteration and include: Lambda iteration method [8], dynamic programming [9], Lagrange method [10], linear programming [11] and quadratic programming [12]. Among the mentioned methods, the Lambda iteration method is more

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popular among researchers. With the increase in the size of power networks and the definition of new nonlinear constraints such as valve prohibited operating zones (POZ) and the valve-point loading effects, it becomes a function of non-convex cost and traditional methods cannot effectively solve the ELD problem [13]. Classical methods in the search space converge to a local optimization and deviate from global optimization points or spend a lot of computational time [14]. Therefore, the use of intelligent algorithms to solve the ELD problem has increased. Commonly used search algorithms include Particle Swarm Optimization Algorithm [15], Genetic Algorithm [16], Simulated Annealing Approach [17], Gravity Search [18], Cuckoo Search [19] and AMTPG-Jaya [20]. Intelligent optimization algorithms are inspired by nature experiments and can effectively find optimal points in non-convex, non-derivative, nonlinear and discrete functions [21, 22].

Chang et al. used a genetic algorithm to evaluate ELD and showed that the lambda iteration method is more efficient, especially in large-scale power systems [23]. As the number of generators increases, the chromosome length also increases and this increases the computation time, so it is suggested that this method be used in microgrids [24]. Dike et al. used the lambda iteration method to solve the problem of ELD. In this paper, losses and increasing generation costs are considered more than demand [25]. In the reference [26], the PSO algorithm is used to solve the ELD and the generation of each unit is presented as output. In the proposed method, the fuel cost equation of the units is considered as quadratic functions and the transmission losses are expressed by the matrix of B coefficients. This method was tested in four different power networks and the obtained answers were compared with genetic algorithms and quadratic programming (QP). The results of the comparison showed that the PSO algorithm, in addition to simplicity, also has a higher convergence speed.

Algorithms based on evolution and particle swarm require common control parameters such as population size, number of generations, elite size, etc. In addition to these parameters, each algorithm needs to determine its own parameters. For example, the PSO algorithm uses the weight of inertia, social and cognitive parameters [15]. The GA uses mutation probability, crossover probability, and selection operator [16]. The artificial bee colony uses the number of observer bees, worker bees, and watch bees [27]. Proper adjustment of these parameters has many effects on the convergence speed of algorithms. Given these drawbacks, R. V. Rao et al. (2013) introduced the Teaching and Learning Based Optimization Algorithm (TLBO) [28]. TLBO is a population-based meta-innovative algorithm that is based primarily on classical learning and teaching phenomena and therefore has two stages, (a) teaching stage and (b) learning stage. TLBO has attracted the attention of researchers in recent years due to its simple structure, easy implementation and high speed of convergence. In fact, TLBO uses teacher teaching and student learning techniques. Here the teacher is a highly qualified person with deep knowledge and always tries to improve the average of his students. Students also interact with each other to learn and improve their knowledge.

Due to the success of the TLBO algorithm, another algorithm called JAYA has been proposed [29]. However, unlike the TLBO method, which has a training phase and a learning phase, the proposed algorithm has only one phase and makes its application relatively simpler. In the present paper, the JAYA optimization method is used because it has a high ability to solve the problem of constrained optimization [29]. This algorithm requires population size parameters and maximum number of iterations. In order to achieve the optimal global in each iteration, the set of answers must move towards the appropriate answer and avoid the inappropriate answer in each iteration. JAYA is a Sanskrit word meaning victory. In reference [30], JAYA has been used to solve OPF and a satisfactory answer has been obtained.

III. Formulation

In this research, the problem of ELD is formulated by ignoring the losses of the transmission line. This assumption is usually made if a bunch of generators are connected to a bus, such as the generating units of a power plant, or when these units are too close together. Constraints on Prohibited Operating Zones (POZ) and the valve-point loading effects are also waived. The cost function of thermal power plants is described by quadratic algebraic functions and is given in Equations (1, 2).

$$C_i(P_i) = a_i * P_i^2 + b_i * P_i + c_i \tag{1}$$

$$Z = \left[P_1, P_2, P_3, \ldots., P_{N_g}\right] \tag{2}$$

There, Z is the vector of decision variables and P_i is the output power of the i^{th} power plant, and the fixed maintenance costs of the power plant (manpower, equipment, etc.) and the cost of fuel are indicated by a, b and c, respectively. In thermal units, the change in fuel cost depends on the output power of the unit. Therefore, it is necessary to consider the fuel cost characteristic of generators to find optimal outputs. Figure (1) shows the fuel cost-output power characteristic, Input is in Btu/h while output is in MW. $Pmin$ and $Pmax$ are the low and high power output ranges of the units. Figure (2) shows a thermal power plant. Where n is the thermal unit connected to a bus. C_T is the sum of the cost functions of all thermal units in a power system, so it can be expressed as Equation (3).

$$C_T = C_1(P_1) + C_2(P_2) + \cdots + C_n(P_n) = \sum_{i=1}^{n} C_i(P_i) \tag{3}$$

The fitness function is considered to minimize Equation (3). Hence, the fitness function can be formulated as a mathematical problem [31] Equation (4):

$$C_T = Min \sum_{i=1}^{n} C_i\,(P_i) \tag{4}$$

The fitness function must be optimized under the condition of supplying the electric load in the network according to Equation (5) and the condition of minimum and maximum power plant production according to Equation (6).

$$\sum_{i=1}^{n} P_{Gi} = P_D \tag{5}$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}, \quad i = 1,2,\dots,n \tag{6}$$

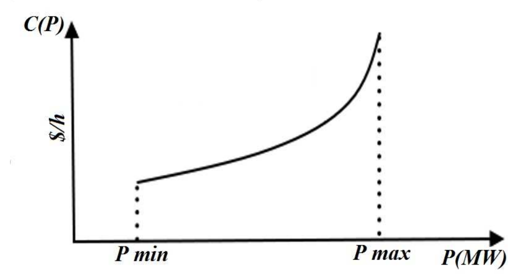

Fig1. Fuel cost function curve

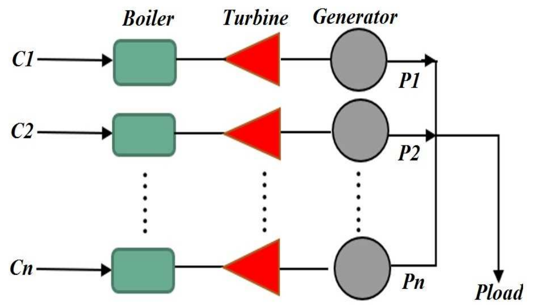

Fig. 2 Thermal power plant

IV. Economic Load Dispatch (ELD)

A. Lambda iteration method

One of the most widely used classical methods for optimizing nonlinear functions is the Lambda iteration method. This method is more popular among other methods due to its proper control of constraints, simple structure and high convergence speed [8]. In this method, Lagrange coefficient (λ) is used, so the ELD problem is defined as Equation (7) [32].

$$L(P_{Gi}, \lambda) = C_i(P_{Gi}) + \lambda\left(P_D - \sum_{i=1}^{n_g} P_{Gi}\right) \tag{7}$$

To find the optimal points of the function $C_i(P_{Gi})$, it is sufficient to set the partial derivative of the function to zero with respect to P_{Gi} and λ, according to Equations (8, 9).

The incremental cost of the i^th generator can be calculated from Equation (10).

$$\frac{\partial L(P_{Gi}, \lambda)}{\partial P_{Gi}} = \frac{\partial C_i(P_{Gi}, \lambda)}{\partial P_{Gi}} - \lambda = 0 \Rightarrow \frac{\partial C_i(P_{Gi}, \lambda)}{\partial P_{Gi}} = \lambda \tag{8}$$

$$\frac{\partial L(P_{Gi}, \lambda)}{\partial \lambda} = P_D - \sum_{i=1}^{n} P_{Gi} = 0 \tag{9}$$

$$\frac{\partial C_i(P_{Gi}, \lambda)}{\partial P_{Gi}} = 2\, a_i\, P_{Gi} + b_i \Rightarrow 2a_i\, P_{Gi} + b_i = \lambda \Rightarrow P_{Gi} = \frac{\lambda - b_i}{2a_i} \tag{10}$$

By placing the P_{Gi} obtained in Equation (9), Equation (11) is obtained.

$$\sum\nolimits_{i=1}^{n} \frac{\lambda - b_i}{2a_i} = P_D \tag{11}$$

The load changes of the power system are also described using Equation (12).

$$\Delta P_D(k) = P_D - \sum_{i=1}^{n} P_{Gi} \tag{12}$$

Ignoring losses in a power system, all units must operate with a value of λ while meeting the equality constraint given by (9). Using equations (9) and (10), an analytical solution λ is obtained as equations (13) and (14):

$$\lambda = \frac{P_D + \sum_{i=1}^{n} \frac{b_i}{2a_i}}{\sum_{i=1}^{n} \frac{1}{2a_i}} \tag{13}$$

$$\Delta\lambda(k) = \frac{\Delta P(k)}{\sum_{i=1}^{n} \frac{1}{2a_i}} \tag{14}$$

The following is the Lambda algorithm for solving ELD [25].

1) *Initial guess of the value of* λ
2) *Calculate* P_{Gi} *using Equation (10).*
3) *Investigation of non-deviation from the upper and lower production limits in generators.*
4) *If* $P_{Gi} \ge P_{Gi}^{max}$ *then put* $P_{Gi} = P_{Gi}^{max}$ *and if* $P_{Gi} \le P_{Gi}^{min}$ *then put* $P_{Gi} = P_{Gi}^{min}$.
5) *Power deviation is calculated using Equation (12).*
6) *Calculate* $\Delta\lambda(k)$ *using Equation (14).*
7) *If* $\Delta\lambda(k) \le \varepsilon$ *the algorithm terminates and the values of* λ *and* P_{Gi} *are displayed.*

8) λ is updated by the relation $\Delta\lambda(k+1) = \lambda(k) + \Delta\lambda(k)$.

9) Repeat from step 2.

B. JAYA optimization technique

The JAYA algorithm seeks to find the optimal points of the fitness function " $C(p)$". In this algorithm " i " number of iterations$(i = 1, 2, \ldots, maxgen.)$, " var " decision variable $(s = 1, 2, \ldots, var)$ and " pop " is proposed solutions$(k = 1, 2, \ldots, pop)$. Among all the candidate solutions, the best candidate gets the best value of $C(p)$ and the worst candidate gets the worst $C(p)$, If $P_{s,k,i}$ is the value of the S[th] variable from the kth member of the set of possible solutions during iteration i, this value is calculated by Equation (18):

$$P_{s,k,i}^{new} = P_{s,k,i} + r_{1,s,i}\left(P_{s,best,i} - |P_{s,k,i}|\right) - r_{2,s,i}\left(P_{s,worst,i} - |P_{s,k,i}|\right) \quad (15)$$

Where $P_{s,best,i}$ and $P_{s,worst,i}$ are the S values for the best and worst candidate of the possible solutions, respectively. $P_{s,k,i}$ is the updated value of P for the i[th] iteration, and $r_{1,s,i}$ and $r_{2,s,i}$ are two random numbers in the range [0-1]. If $P_{s,k,i}^{new}$ performs better, then it is considered. At the end of each iteration, the new value obtained represents its share in total generation and is updated again according to Equation (16) [33]. If P_i is the output power of the generators and G_T is the total generation of the power system, the updated values of the output power of the generators are P_i^{new}.

$$P_i^{new} = P_i - \left({P_i}/{G_T}\right) * (G_T - P_D) \quad (16)$$

These updates may violate the inequality constraint, in which case they will be updated again by Equation (17). Figure (3) shows the flowchart of the JAYA algorithm.

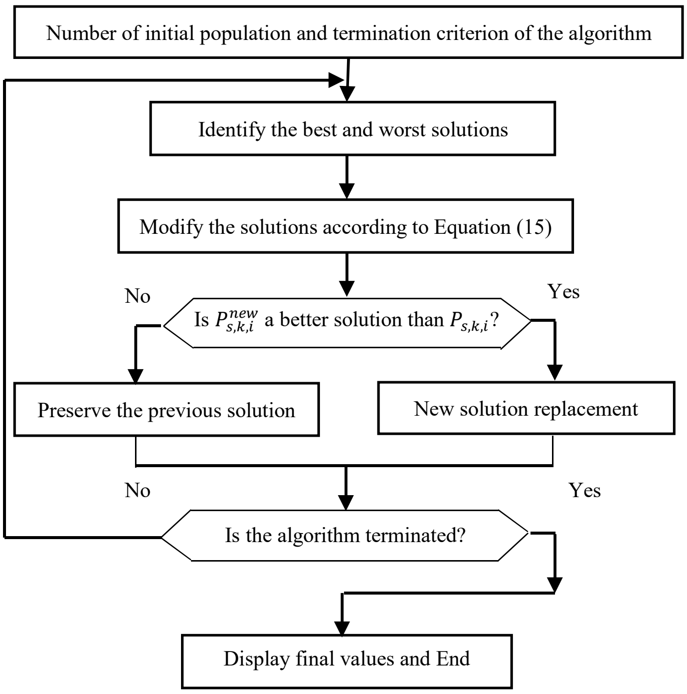

Fig. 3. JAYA Flowchart

$$P_i^{new} = P_i^{min} \quad if \quad P_i^{new} < P_i^{min} \quad or \quad P_i^{new} = P_i^{max} \quad if \quad P_i^{new} > P_i^{max} \quad (17)$$

V. STUDY OF POWER NETWORK IN SOUTHWEST OF IRAN (KHUZESTAN PROVINCE-2019)

Power generation in Iran (2019) was 83 GW. 88% of it is supplied by thermal power plants. The share of steam power plants is 23%, gas power plants 38% and combined cycle power plants 39% and their efficiency is 39%, 31% and 45%, respectively. In Khuzestan province, 48,000 GWh of power has been generated. The share of hydropower plants were 22,500 GWh (47%) and thermal power plants were 25,300 GWh (53%) of total power generation [34]. Also, 45% of the power generated by thermal power plants is generated by the public sector (Ramin and Ofogh) and 55% of it is generated by private sector power plants (Khorramshahr, Gharb Karun, Fajr, Zargan, Abadan and Behbahan). Table (1) gives the specifications of thermal power plants in Khuzestan province.

TABLE I.
NOMINAL POWER, SPECIAL GENERATION AND EFFICIENCY OF KHUZESTAN THERMAL POWER PLANTS

Power Plants	Nominal Power (MW)	Ave. Practical Power (MW)	Generation (MWh)	Operation (%)	Efficiency (%)
Ramin	1903	1703	9416271	66.7	36.6
Ofogh	664	553	2181044	45.1	30.9
Khor.	972	797	4534445	65.4	32.3
G. Karun	340	272	286906	12.1	32.3
Fajr	1483	1284	1441605	12.9	25.3
Zargan	418	292	857942	32.25	34.35
Abadan	814	674	4602184	79.1	48.2
Behbahan	492	414	2709303	75.2	51.1

To explain the method of calculating the cost functions of thermal power plants, Ramin power plant is examined. Ramin power plant is one of the largest thermal power plants in Iran with a generation capacity of 1903 MW, which includes 6 units of 315 MW steam and 2 units of 6.5 MW expansion turbine. The main fuel of this power plant is natural gas and its emergency fuel is fuel oil. This power plant generates more than 36% of Khuzestan province and 5% of Iran and plays an important role in the stability of the national electricity network. Table (2) shows the amount of fuel required for one unit of Ramin power plant and also according to the price per cubic meter of gas (0.13$) the cost of power plant unit.

TABLE II.
THE AMOUNT OF FUEL AND THE PRICE REQUIRED BY ONE OF THE UNITS OF RAMIN POWER PLANT

Power (MW)	50	80	110	160	190
Gas (*1000m3)	18	24	30	36	43
Gas ($/h)	2340	3120	3900	4680	5590
Power (MW)	220	250	280	305	315
Gas (*1000m3)	49	56	62	67	70
Gas ($/h)	6435	7280	8060	8710	9100

From the data in Table (2), the cost function and constraints of Ramin power plant is obtained as Equation (18).

$$C(1) = 1300 + 20P_2 + 0.014P_2^2 \quad \left(\frac{\$}{h}\right) \qquad 680 \le P_1 \le 1725 \ (MW) \quad (18)$$

The cost functions and constraints of other power plants are given in Equation (19).

$$C(2) = 378 + 25.6P_2 + 0.049P_2^2$$
$$110 \leq P_2 \leq 575$$
$$C(3) = 714 + 15.6P_3 + 0.033P_3^2$$
$$220 \leq P_3 \leq 1000$$
$$C(4) = 136 + 43.6P_4 + 0.1P_4^2$$
$$20 \leq P_4 \leq 300$$
$$C(5) = 332 + 30P_5 + 0.061P_5^2$$
$$35 \leq P_5 \leq 1300 \quad (19)$$
$$C(6) = 182 + 33.4P_6 + 0.084P_6^2$$
$$55 \leq P_6 \leq 305$$
$$C(7) = 731 + 22.6P_7 + 0.026P_7^2$$
$$240 \leq P_7 \leq 755$$
$$C(8) = 537 + 27.2P_8 + 0.037P_8^2$$
$$150 \leq P_8 \leq 430$$

VI. Results of ELD by Lambda Iteration and JAYA Technique for Khuzestan thermal power plants.

The results of ELD of eight thermal power plants in southwestern Iran (Khuzestan) by lambda iteration method and JAYA technique have been obtained by considering the demand of 3012 MW as shown in Table (3). In these methods, the runtime are 0.7641 Sec, 15.6910 Sec. And the total cost of generation is calculated at $113550.3276 \ \$/h$, $113548.8761 \ \$/h$ respectively.

TABLE III.
ELD of thermal power plants in Khuzestan by lambda JAYA methods

power plants	P1	P2	P3	P4
Lambda	1084.2660	252.6474	526.6583	33.7972
JAYA	1084.2613	252.6456	526.6571	33.7955
power plants	***P5***	***P6***	***P7***	***P8***
Lambda	166.8807	100.9491	533.8356	312.9655
JAYA	166.8671	100.9449	533.8351	312.9648

The obtained results, in addition to proving the convergence of the JAYA technique, show its proper function. The results show that the two methods used are efficient and increase cost savings. In the lambda iteration method, the fast fuel cost function is converged because the continuous and derivative cost function is considered. As mentioned in the introduction, it is assumed that all generators and loads are connected to one bus, thus eliminating network losses. On the other hand, some nonlinear properties have been removed from the fitness function, which simplifies the fitness function. This matter eliminates the main difference between the two methods, as the main ability of the JAYA technique is to calculate the optimal points in nonlinear functions. Finally, it is suggested that transmission network losses and nonlinear constraints be added to the fitness function for future work.

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