Economic Load Distribution between Thermal Power Plants and Studying the Changes of Parameters

Mehdi Mahdavian[1], Majid Dehghani[2,3*], Mohammad Reza Yousefi[2,3], Mahdi Sharifi[3,4]

Abstract–The complexity of communication and the size of different areas of power systems are i easing, and the development of the power system requires the optimal allocation of electric power pr ced by a large number of system generators. Electric energy production in power systems is one of most important issues in modern systems, along with minimizing the total production cost of the gen or units in the power system. Economic load distribution is a common optimization problem in pow ystems. In this article, the economic distribution of the load between the production units has been by limiting the minimum and maximum power range between the generator units. To carry out the nomic distribution of the load, the repetition method of the Lagrange coefficient is used. To show th udy data, the simulation results for a power system with two production units and taking into accou osses and a power system with three production units and without losses are presented. Distinct fuel ctions are considered for the units in the study.

Keywords: Economical Load Distribution, Optimization, Lagrange Coefficients, Thermal Plant

1. Introduction

Paying attention to the cycle of electricity production, transmission and distribution has always been in the minds of researchers and researchers, and certainly the expansion of the electricity industry will have a very important impact on the advancement of technology and economy[1,2]. With the expansion of industrial centers along with the increase in demand by energy consumers, the need for energy production and its correct use and distribution has become very important[3,4]. One of the most important parameters in economic exploitation is the set of input-output charact-eristics of thermal units of energy production. Economic load distribution is a process of allocating production between existing production units to minimize the total cost of production and meet the desired equality and inequality constraints [5,6]. Economic dispatch is the process of deciding on the amount of power output of the planned generating units at any point in time [7]. An incorrect load distribution scheme for the power plant will have a negative effect on energy consumption and loss reduction [8,9].

So far, various studies have been presented in the field of economic load distribution, each of which has a different goal, such as reducing fuel costs [10], providing a meta-heuristic method to reduce economic distribution problems [11,12], etc.[13,14].

In [15], the analysis of the problem of economic distribution of load and its mathematical model is presented, and then a system with 6 buses and 3 machines is used to apply the improved algorithm of the Beetle Antenna Search Algorithm (BAS). Also, the improved BAS algorithm is compared with particle swarm optimization (PSO) and other algorithms based on the optimization results of test functions, and it is shown that the improved BAS algorithm has advantages in dealing with economic load distribution problems.

A distributed economic model predictive control strategy for economic load distribution and load frequency control of interconnected power systems is presented in [16], where by using the economic performance of the system without using a hierarchical control structure and by the general economic cost function to calculate The control sequence is optimized and therefore real-time optimization and transient optimization have been achieved.

A multi-objective economic load distribution method for coal power plant based on data mining technology is proposed in [17], in which the optimal decision samples are extracted from the offline database to guide the online economic load distribution according to the load demand of the power grid. Also, the database maintenance strategy is used to optimize and update the offline database, and the

[1]Department of Electrical Engineering, Naein Branch, Islamic Azad University, Naein, Iran
[2*]**Corresponding Author**: Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran Email:dehghani@pel.iaun.ac.ir
[3]Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[4]Department of Computer Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
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proposed method is applied to investigate its effectiveness for an operating coal-fired power plant. The results show that the data mining-based method can achieve optimal load distribution at the plant level while meeting the actual network requirements.

A method to solve economic load distribution problems by limiting the minimum and maximum power limits between generator units is presented in [18], in which the distance between the minimum and maximum power limits of each generator is divided into several parts, and the best part with the minimum total cost Calculated based on the central point of the piece. Also, the repetition process used is one of the artificial methods that works without differential and integral calculus calculations and therefore does not depend on the objective function. The above method has been investigated using two generator units with distinct objective functions.

A meta-heuristic optimization method based on human intelligence, i.e. top-class optimization, is proposed to solve the problems of economic load distribution and economic distribution of combined emissions in[19], where 29 criterion functions are considered for validation.

In a steam power plant, the thermal energy of liquid, solid and gas fuels is used to generate steam and use it in steam turbines to generate electricity. Economical load sharing is one of the important issues of power generation centers to supply system loads. Operating costs in power plants depend on various parameters, of which the variable cost of fuel is an important factor. Economic load distribution determines the output power of generators so that the total cost of operation for a specific load is minimal.

In this paper, the economic distribution of the load between the production units are done using the Lagrange coefficient repetition method, where the minimum and maximum power ranges between the generator units are considered. The simulation results are presented for a power system with two production units with losses and a power system with three production units without losses. For the fuel cost of the units, different functions have been considered in the study.

2. Steam Plant

Thermal power plants include boiler, combined cycle and diesel power plants that use fossil fuels to produce electricity.

About 65% of electricity produced in Iran's national electricity network is supplied by Bukhari power plants. In a heating power plant, as a result of the combustion of fuel oil or natural gas, the water in the boiler turns into steam, and then the produced steam turns into dry steam in stages as a result of more heat. (Dry steam means a steam that is completely gaseous and does not have any water drops in it and its temperature is above 500 degrees Celsius.) The steam is directed to the turbine and the generator, which is coaxial and coupled with the turbine, moves along with it. and electric current is produced. The efficiency of heating power plants is around 40%[20,21].

Thermal power plants are mostly used for base load. The main components of a heating power plant are the feed pump, boiler and related equipment, condenser and turbine (in the condenser, the dry steam coming out of the turbine is cooled and turned into a liquid, and the resulting liquid is pumped back to the boiler by pumps. to be).

To provide electrical energy in steam power plants, three types of energy conversion are performed, including chemical energy conversion into thermal energy by a boiler, steam thermal energy conversion into mechanical energy by a turbine, and mechanical energy conversion into electrical energy by a generator. Among the advantages of the boiler power plant compared to the gas power plant, we can mention the high efficiency, greater production range and longer life of this power plant[22,23]. Its disadvantages compared to the gas power plant include the need for water, the lower maneuvering speed, the higher cost of electricity production and the longer construction time of this power plant. Heating power plants are divided into fixed pressure turbines and variable pressure turbines based on the pressure of the steam produced in the boiler and the steam consumed in the turbine. week is used [24,25].

3. Economic Load Distribution

In a thermal power plant, increasing the production capacity of the generators requires an increase in fuel consumption and as a result an increase in cost, but in a hydropower plant, changing the production capacity of the generators does not change the cost of production. The cost function shows the changes in fuel cost according to the output power of a power plant. The total operating cost of a unit is equal to the sum of fuel cost and miscellaneous cost, including the cost of personnel, maintenance, etc., which is expressed as a percentage of the fuel cost. The production of reactive power does not have much effect on the fuel cost because the reactive power is controlled by the current regulation of the excitation circuit. The production reactive power will indirectly affect the cost and operation of the system and is considered as one of the variables of the system. The cost function of each generator is determined empirically and is a function of the production of the same generator. If the energy production cost function of generator k is equal to Ck, the total production cost is equal to:

$$\begin{aligned} C(P_{G1}, P_{G2}, ..., P_{GN}) \\ = C_1(P_{G1}) + C_2(P_{G2}) + ... + C_N(P_{GN}) \\ = \sum_{k=1}^{N} C_k(P_{Gk}) \end{aligned} \quad (1)$$

As can be seen, the total cost function is a separable function. The development of the production cost (increased cost of operation) of the generator in terms of Rials per megawatt hour is equal to:

$$IC_k = \frac{\partial C_k}{\partial P_{Gk}} \quad (2)$$

which is the slope of the cost curve. The Ck cost curve is shown as follows:

$$C_k(P_{Gk}) = \alpha_k + \beta_k P_{Gk} + \gamma_k P_{Gk}^2 \quad (3)$$

where α_k, β_k and γ_k are fixed values that are determined using the least squares estimation algorithm based on the points of the cost curve in terms of power.

3.1. Economic exploitation regardless of losses

The consumption load of a network is the average load in the receiving heads of that network and during a certain time interval. Issues related to economic exploitation in power systems largely depend on the nature of the load and the amount of the load. In economic operation, the goal is to minimize the cost of production, provided that the total production of generators covers losses and consumption load, while the production range of each generator (unbalanced constraints) is observed. The objective function in power system optimization methods is the fuel cost of the system. If the losses of the system are ignored, in the conditions of economic operation, m+1, the equation is established as follows:

$$\begin{cases} IC_k = \lambda & k = 1, 2, ..., m \\ \sum_{k=1}^{m} P_{Gk} = P_D \end{cases} \quad (4)$$

where m is the number of generators and λ is the Lagrange coefficient. Lagrange's indeterminate coefficient method is widely used for functions with constraints. One of the limitations of the equation is the production range of generators in terms of rated power and minimum utilization value, which is expressed as follows:

$$P_{Gk,min} \le P_{Gk} \le P_{Gk,max} \qquad k = 1, 2, ..., m \quad (5)$$

The relationship between the Lagrange coefficient and the growth of the production cost of each generator is expressed as follows:

$$\begin{cases} P_{Gk,min} \le P_{Gk} \le P_{Gk,max} & \Rightarrow \ IC_k = \lambda \\ P_{Gk} = P_{Gk,min} & \Rightarrow \ IC_k > \lambda \\ P_{Gk} = P_{Gk,max} & \Rightarrow \ IC_k < \lambda \end{cases} \quad (6)$$

3.2. Economic exploitation considering losses

Transmission line losses in economic distribution between power plants should be considered according to the distance of loads from the power plant. The total loss of the system (PLOSS) is expressed as a square function of the power of the units as follows:

$$P_{LOSS} = P^T B P = \sum_{k=1}^{m} \sum_{j=1}^{m} P_{Gk} B_{kj} P_{Gj} \quad (7)$$

where P is the productive power vector of the generators and B_{kj} are the rows of matrix B, the loss coefficients. The loss coefficients change according to the loading of the generators, but to simplify the calculation, their value is assumed to be constant and they are determined as the base mode for power distribution. If all the load is on a power plant, changing its power does not affect losses. The development of transmission losses and the penalty factor are equal to:

$$ITL_k = \frac{\partial P_{LOSS}}{\partial P_{Gk}} = 2 \sum_{j=1}^{m} B_{kj} P_{Gj} \quad (8)$$

$$L_k = \frac{1}{1 - \frac{\partial P_{LOSS}}{\partial P_{Gk}}} = \frac{1}{1 - ITL_k} \quad (9)$$

In the conditions of economic operation, taking into account system losses, m+1, the equation is established as follows:

$$\begin{cases} IC_k = \lambda (1 - ITL_k) & k = 1, 2, ..., m \\ \sum_{k=1}^{m} P_{Gk} = P_D + P_{LOSS} \end{cases} \quad (10)$$

4. Simulation Results

In this section, different modes are considered for economic load distribution.

4.1. Two production units with losses

The growth equations of the cost of producing electric energy of two generators in a power plant in terms of riyals per megawatt hour (Fig. 1) and system losses in terms of megawatts are:

$$\begin{cases} IC_1 = 781.5 + 0.46\,P_{G1} & 200 \le P_{G1} \le 400 \;\; MW \\ IC_2 = 1195 + 0.55\,P_{G2} & 100 \le P_{G2} \le 300 \;\; MW \end{cases} \quad (11)$$

$$P_L = 0.0005\,P_{G1}^2 + 0.00025\,P_{G2}^2 \quad (12)$$

The load supplied by the power plant is considered equal to 478.75 megawatts. In order to determine the production power of generators in the conditions of economic operation by repetition method, the starting value equal to 1275 and error is considered. According to table 1, the initial value of the Lagrange coefficient is considered equal to 1275.

The total consumed load changes between 277.5 and 597.5 megawatts according to the presence of losses. In this part, the results are shown using the computer program considered based on the λ repetition method. With an error of 0.1 MW, the results of Fig. 2 show the production of generators and system losses as a function of the total consumed load.

As it can be seen, up to the consumption load of about 300 megawatts, the output of the generator is at a minimum. Fig. 3 shows the value of the Lagrange coefficient in terms of the total load. In fig. 4, the changes of the error of the total consumed load with production are considered, and in fig. 5 the number of repetitions to determine the response λ is shown in terms of the total consumed load.

Table 1. Lagrange coefficient repetition method

λ (R/MWh)	P_{G1} (MW)	P_{G2} (MW)	P_{LOSS} (MW)	P_D (MW)
1275	284.44	67.37	41.59	310.22
1325	304.48	107.22	49.23	362.47
1375	323.43	145.45	57.59	411.29
1425	341.38	182.18	66.57	456.99
1475	358.40	217.48	76.05	499.83
1450	350.00	200.00	71.25	478.75

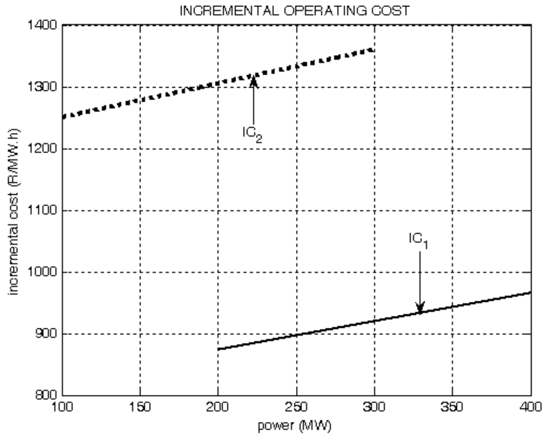

Fig. 1: Equations of development cost of energy production of two generators

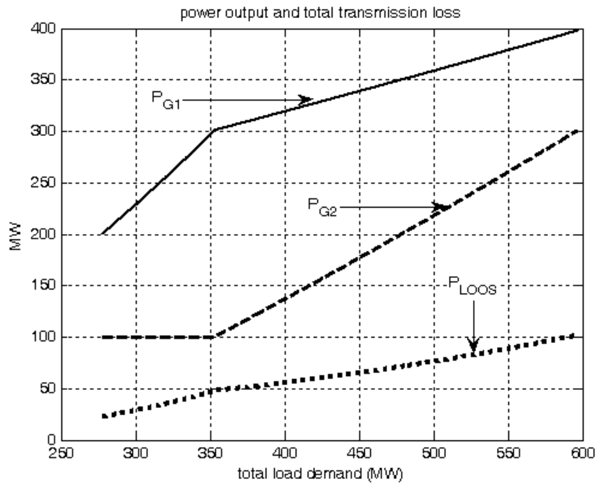

Fig. 2: Production of generators and system losses

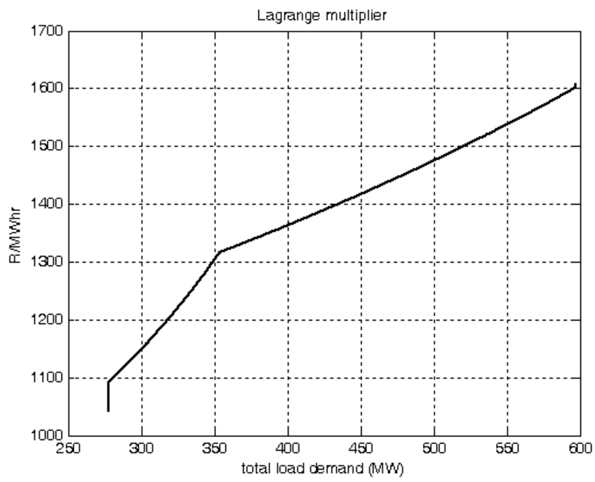

Fig. 3. Lagrange coefficient

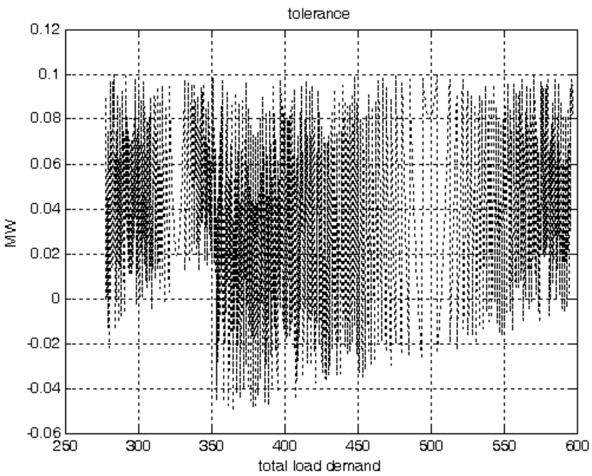

Fig. 4. Variations in total load error

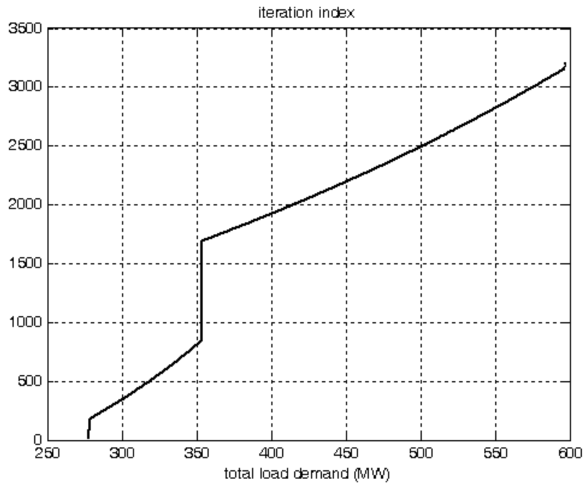

Fig. 5. The number of iterations to determine the Lagrange coefficient

4.2. Three production units without casualties

The growth equations of the cost of producing electric energy of three generators in a power plant in terms of riyals per megawatt hour are considered as follows:

$$\begin{cases} IC_1 = 10 + 0.016 P_{G1} & 100 \le P_{G1} \le 500 \text{ MW} \\ IC_2 = 8 + 0.020 P_{G2} & 300 \le P_{G2} \le 1000 \text{ MW} \\ IC_3 = 9 + 0.025 P_{G3} & 200 \le P_{G3} \le 700 \text{ MW} \end{cases} \quad (13)$$

The losses of the system are ignored and the consumption load of the whole power plant varies from 600 to 2200 MW. The curve shows the cost of three generators in terms of production power changes. As can be seen, IC1 changes between 11.6 and 18, IC2 changes between 14 and 28, and IC3 changes between 14 and 26.5 rials/MWh. In light loads, generator one works at its minimum value of 100 MW, and in heavy loads, generator two works at its maximum value of 1000 MW. IC1 cost growth in 250 MW power is equal to 14.0. IC2 cost growth in 500 MW power and IC3 cost growth in 360 MW power is 18.0 and IC2 cost growth in 925 MW power is 26.5.

Fig. 6 shows the production changes of each generator according to the total load. Fig. 7 shows the changes of the Lagrange coefficient according to the changes of the total load. As can be seen, the Lagrange coefficient changes between 11.6 and 28.0.

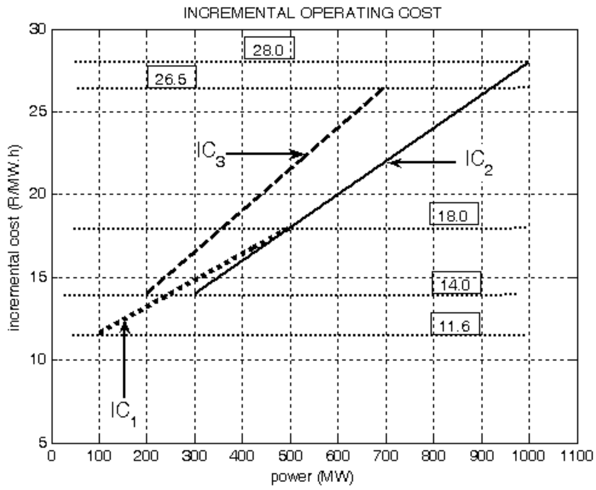

Fig. 6. Cost curve of three generators according to production power

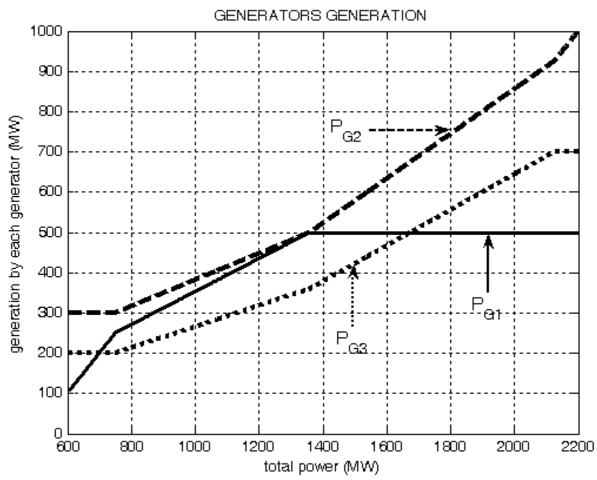

Fig. 7. Production power of each generator

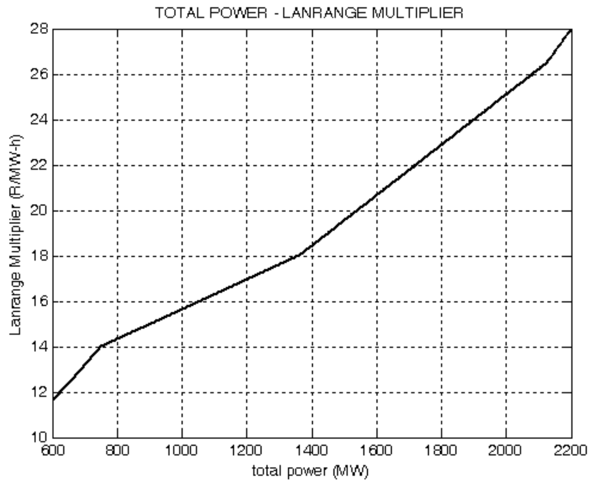

Fig. 8. Lagrange coefficient changes according to total load changes

5. Conclusion

The complexity of communication and the size of different areas of power systems are increasing, and the development of the power system requires the optimal allocation of electric power produced by a large number of system generators. The participation of a generator in load sharing in a certain period of time is a commitment and must be done. After solving the commitment of the production unit, the problem of optimal allocation of existing generators is raised to meet the expected load demand in the time frame. In economic load distribution, the power of active generators is determined in such a way that the cost of production in the system is minimized. In continuous industrial centers, the production capacity of generators is usually much higher than the load demand and there are different situations for allocating loads in the generator. But reducing the cost of energy production is important and sharing the economic burden is important. The biggest production cost is fuel cost. The economic distribution of the load between the generating units between the generator units is presented using the Lagrange coefficient iteration method. The simulation results are presented for a power system with two production units and considering losses and a power system with three production units without losses.

As shown, economic exploitation considering losses requires solving the nonlinear problem, which is done using the Lagrange method.

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