

Load Dispatch for a Power System in terms of Economy and Environment by Using VIKOR Method

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Abstract: Load dispatch considering economy and environment is an important issue at power systems. Economic load dispatch aims to generate demanded energy with minimum cost. It dispatches the load among generators by decreasing fuel cost. Otherwise, thermal plants are used commonly in the world to generate energy and they cause to environmental pollution. Energy generation with the most economic cost is good but protection of environment must be considered. Environmental load dispatch aims to generate demanded energy with minimum emission. It is significant for living in good health and clean environment. In this study, economic and environmental load dispatch problems are applied to a power system that consists of six generators to investigate cost and emission. VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method is used for this study. VIKOR is one of the multi-criteria decision-making methods. It gives the most ideal solution for the problem.

VIKOR Yöntemi ile Güç Sistemi için Ekonomi ve Çevre Yönünden Yük Dağıtımı

Anahtar Kelimeler
Ekonomik
Dağıtım,
Çevresel Dağıtım,
Optimizasyon,
Emisyon,
VIKOR

Özet: Ekonomiyi ve çevreyi göz önünde bulundurarak yapılan yük dağıtımı, güç sistemlerinde önemli bir konudur. Ekonomik yük dağıtımı, talep edilen enerjiyi minimum maliyet ile üretmeyi hedefler. Yükü, jeneratörler arasında yakıt maliyetini azaltacak şekilde dağıtır. Öte yandan, termik santraller enerji üretmek için dünyada yaygın olarak kullanılmaktadır ve çevre kirliliğine nedne olmaktadır. En ekonomik maliyet ile enerji üretmek iyidir fakat çevrenin korunması da dikkate alınmalıdır. Çevresel yük dağıtımı, talep edilen enerjiyi minimum emisyon ile üretmeyi hedefler. Bu durum sağlıklı olarak ve temiz bir çevrede yaşamak için önemlidir. Bu çalışmada, ekonomik ve çevresel yük dağıtım problemleri, maliyet ve emisyonu incelemek için altı jeneratörden oluşan bir güç sistemine uygulanmıştır. Bu çalışma için VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

yöntemi kullanılmıştır. VIKOR, çok kriterli karar verme yöntemlerinden birisidir. Problemler için en ideal çözümü vermektedir.

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1. Introduction

Electric power systems have become complicated due to need of large energy system and privatization of the energy sector. Therefore, it is important to operate power systems economically and generate the energy with the cheapest cost. Operating planning is the important task to find minimum cost. Economic load dispatch problem minimizes the generation cost with meeting demand. It also satisfies the equality and inequality constraints.

The power plants based on fossil fuel are a significant source of power supply in the world. They are chosen due to being abundant on the earth and having ability to generate large amounts of electric power in any one location [1]. However, while energy is generated, environment must be considered because dangerous gases release to the air. Generators that use fossil resources forms particles that contains carbon dioxide, sulfur dioxide, and nitrogen oxide. The excessive increase in the amount of emissions causes to dangerous ecological effects. The resulting pollution affects the animals and plants as well as people. It also causes to global warming. It is significant to consider environment while generating energy for these reasons. Environmental load dispatch aims to reduce emissions.

For these reasons, firstly economic analysis and then environmental analysis are done for power systems. There are a lot of methods that have been used to solve economic and environmental load dispatch problems. Chen et al. provide a nonlinear fractional programming approach to solve the environmental-economic power dispatch problems in

the thermal power dispatch systems [1]. They use IEEE 30-bus test system to show the effectiveness of their approach. Abdelaziz et al. have discussed an application of Flower Pollination Algorithm to solve Economic Load Dispatch and Combined Economic Emission Dispatch [2]. They have results for small and large scale power systems and consider valve loading effect. Bhattacharjee et al. have presented the solution for a nonlinear constrained multi objective of the economic and emission load dispatch problem with backtracking search optimization technique [3]. Rajan and Malakar solve Optimum Active Power Dispatch problem using Exchange Market Algorithm [4]. They develop the programs in MATLAB and test on standard IEEE 30 bus comprising of six thermal units. Fadıl and Urazel use an iterative solution method based on modified subgradient algorithm operating on feasible values (F-MSG) to solve environmental/economic power dispatch problem [5]. They demonstrate the technique on IEEE 30-bus power system and their method outperforms against the evolutionary methods in terms of solution time values. Rugthaicharoenchep and Thongkeaw solve economic load dispatch in test system of six-generation units with developing particle swarm optimization algorithm [6]. Sen and Mathur present a newly developed hybrid optimization algorithm named ACO-ABC-HS (Ant Colony Optimization-Artificial Bee Colony-Harmonic Search) for solving the problem of Economic Dispatch for a multi-generator system [7]. Dosoglu et al. presents Symbiotic Organisms Search (SOS) algorithm to solve economic emission load dispatch

problem for thermal generators in power systems [8]. Hota and Sahu develop a fuzzy based gravitational search algorithm to solve security constrained economic and environmental load dispatch problems [9].

VIKOR method that is used in this study is a multi-criteria optimization technique and presents compromise solution for the problems. Bansal et al. identifies various sustainability indicators during the construction stage for elevated transportation corridors using fuzzy VIKOR technique [10]. Mohanty and Mahapatra propose VIKOR method to choose ergonomic office chair for improving the comfort level [11]. It is obtained that VIKOR method is not used about power systems. Therefore, it is decided to use VIKOR method in the solution of economic and environmental load dispatch problems. It is determined that which generator, how much energy should generate for economic and environmental dispatch. Thus, both economic and environmental load dispatch can be found in a simpler and better results than the other methods mentioned above.

2. Problem Definition

In this study, two competing functions that are fuel cost and amount of emission are tried to minimize under the conditions of satisfying equality constraint. Fuel cost is minimized for economic load dispatch problem and amount of emission is minimized for environmental load dispatch problem.

Economic load dispatch is formulated by considering the cost function. Each generator in the power system has cost function. The cost curves of the thermal power plants are approximately represented by a quadratic function that is shown in Equation 1.

$$F(\text{total}) = \sum_{i=1}^n a_i + b_i P_i + c_i P_i^2 \quad (1)$$

where $F(\text{total})$ is the total fuel cost (\$/hr), a_i , b_i , and c_i are the fuel cost coefficients of the i -th generator, n is the number of generator in the power system and P_i is the power generated by i -th generator.

Environmental load dispatch problem can be expressed as shown in Equation 2.

$$E(\text{total}) = \sum_{i=1}^n f_i + e_i P_i + d_i P_i^2 \quad (2)$$

where $E(\text{total})$ is the amount of total emission (kg/hr), d_i , e_i , and f_i are the NO_x emission coefficients of the i -th generator, n is the number of generator in the power system and P_i is the power generated by i -th generator.

There are some constraints while solving the power dispatch problems. They are as follows [12]:

Power balance constraint: The total generated power should satisfy the total demand power and the transmission loss (if it is considered in the problem). It is shown in Equation 3.

$$\sum_{i=1}^n P_i - P_{\text{loss}} = P_D \quad (3)$$

where P_{loss} is the transmission loss and P_D is the total demand power.

Generation limits: Each generator should generate power within lower and upper limits as shown in Equation 4.

$$P_i^{\text{min}} \leq P_i \leq P_i^{\text{max}} \quad i \in \{1, 2, 3, \dots, n\} \quad (4)$$

where P_i^{min} is the minimum power that i -th generator can produce and P_i^{max} is the

maximum power that i-th generator can produce.

In this study, one equality constraint of power balance is considered as system constraint. The transmission losses are not considered in the problem. Therefore, total demand power must be equal to the total power generated by the power system.

In the solution of these problems, VIKOR method is suggested instead of many methods that are mentioned above.

3. Material and Method

In this study VIKOR method is used. It is a multi-criteria method developed by Serafim Opricovic in 1998. It solves a discrete multi-criteria problem with noncommensurable and conflicting area and determines a compromise solution for ranking and selecting considering conflicting criteria [13]. It helps the decision makers to reach a final solution.

The methodology of VIKOR method can be explained in the following steps:

Step 1: The best f_i^* and the worst f_i^- values of all criterion functions are determined.

If the i-th function represents a benefit:

$$f_i^* = \max f_{ij}, f_i^- = \min f_{ij} \quad (5)$$

If the i-th function represents a cost:

$$f_i^* = \min f_{ij}, f_i^- = \max f_{ij} \quad (6)$$

where f_{ij} is the related rating of the i-th criterion.

Step 2: The values of S_j and R_j are calculated. S_j and R_j are used to formulate ranking measure. The solution obtained by $\min S_j$ is with a maximum group utility and the solution obtained by $\min R_j$ is with a minimum individual regret of the opponent [14].

$$S_j = \sum_{i=1}^n w_i \frac{(f_i^* - f_{ij})}{(f_i^* - f_i^-)} \quad (7)$$

$$R_j = \max \left(\sum_{i=1}^n w_i \frac{(f_i^* - f_{ij})}{(f_i^* - f_i^-)} \right) \quad (8)$$

where w_i is the weight of criterion.

Step 3: Q_j index values are calculated according to S_j and R_j :

$$Q_j = v \frac{(S_j - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_j - R^*)}{(R^- - R^*)} \quad (9)$$

where $S^* = \min_j S_j$, $S^- = \max_j S_j$, $R^* = \min_j R_j$, $R^- = \max_j R_j$. v refers to the weight for strategy that ensures maximum group benefit, $(1-v)$ refers to the weight of minimum regret in dissent. The value of v changes between 0 and 1. Generally, the value of v is taken as 0.5.

Step 4: The calculated values of Q_j , S_j , and R_j are ranked in decreasing order. Q_j evaluation unit with the smallest value is expressed as the best option in the alternative group.

Step 5: Two conditions must be satisfied to accept the obtained results as valid. These conditions are:

Condition 1: Acceptable advantage: It states that there is significant difference between the best option and the option that is the closest one to the best option:

$$Q(A^2) - Q(A^1) \geq D(Q) \quad (10)$$

where $Q(A^1)$ is the best option, $Q(A^2)$ is the option that is the closest one to the

best option. $D(Q) = 1 / (j-1)$ where j is the number of evaluation units.

Condition 2: Acceptable stability: A^1 option that has the best Q value must have the best score at least one of the S value and R value.

Whether one of the conditions are not satisfied, the compromise solution is recommended as follows:

- If condition 2 is not satisfied, alternatives A^1 and A^2 are expressed.
- If condition 1 is not satisfied, alternatives A^1, A^2, \dots, A^N for N alternatives are expressed. N is the biggest value that satisfies the inequality $Q(A^N) - Q(A^1) < D(Q)$.

In this study, 6 generators are determined as decision points for both economic and environmental dispatch problems. The fuel cost coefficients of the system (a,b,c) are established as the factors that affect the decision points for economic dispatch problem and the NO_x emission coefficients of the system (d,e,f) are established as the factors that affect the decision points for environmental dispatch problem. The values of f_i in the solution steps are determined by considering cost coefficients (a,b, and c) for economic dispatch problem and emission coefficients (d,e, and f) for environmental dispatch problem.

4. Results

The economic and environmental dispatch problems are solved on the six generators test system. The data of fuel

cost coefficients and NO_x emission coefficients of the system is taken from study of Rughooputh [15]. The structure of the six generators test system is shown in Figure 1.

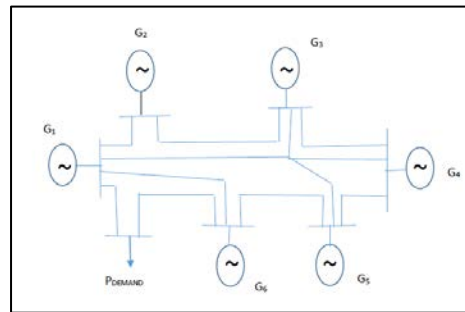


Figure 1. Structure of the test system

In the solution of economic dispatch problem, 6 generators are determined as decision points. The fuel cost coefficients of the system (a,b,c) are established as the factors that affect the decision points. Firstly, values of f_i are determined by considering cost coefficients (a,b, and c). The decision matrix that consists of values of f_i is obtained. While forming the decision matrix, the numbers from 1 to 10 are given as points to the elements of the matrix. The points are determined by considering the values of cost coefficients for each generator. For example, the minimum value of cost coefficient a is for Generator 2. It is benefit to take minimum value due to cost calculation. Therefore, Generator 2 takes the biggest point (10) among other generators for cost coefficient a. The maximum value of cost coefficient a is for Generator 5 so it takes the smallest point (1) among other generators for cost coefficient a. The decision matrix for economic dispatch problem is shown in Table 1.

Table 1. The values of f_i for all criterion in economic dispatch problem

Generators	a	b	c
Generator-1	8	4	1
Generator-2	10	1	2
Generator-3	6	2	6
Generator-4	4	6	4
Generator-5	1	10	8
Generator-6	2	8	10

As seen in Table 1, the maximum value of f_i (f_i^*) is 10 and minimum value of f_i (f_i^-) is 1. These values are taken in the calculations.

The values of S_j , R_j , and Q_j that are mentioned in Step 2 and Step 3 are calculated by using Equation 6, Equation 7, and Equation 8. The weights of criterion are taken from the study [16]. In study [16], the values of criterion for the same power system that is used in this study are obtained by Analytical Hierarchy Process (AHP) method. According to it, the weights of criterion (cost coefficients a, b, c) are 0.08, 0.20 and 0.72, respectively. The values of S_j , R_j , and Q_j and order in economic dispatch problem are shown in Table 2 and Table 3, respectively.

Table 2. The values of S_j , R_j , Q_j in economic dispatch problem

Generators	S_j	R_j	Q_j
Generator-1	0.871	0.72	1
Generator-2	0.84	0.64	0.917
Generator-3	0.532	0.32	0.466
Generator-4	0.622	0.48	0.65
Generator-5	0.24	0.16	0.15
Generator-6	0.115	0.071	0

Table 3. The order of S_j , R_j , Q_j in economic dispatch problem

Generators	Order (S_j)	Order (R_j)	Order (Q_j)
Generator-1	6	6	6
Generator-2	5	5	5
Generator-3	3	3	3
Generator-4	4	4	4
Generator-5	2	2	2
Generator-6	1	1	1

According to the economic dispatch problem result, it is seen that condition 2 is satisfied but condition 1 is not satisfied because difference between the best option and the option that is the closest one to the best option does not satisfy Equation 9. Therefore, Generator 5 that does not satisfy the inequality that is mentioned in condition 1 is taken as the last order in the decision. The value of R_j are taken as a coefficient because Q_j has the zero value that cost can not be calculated. For 500 MW load, approximately 247 MW for Generator 6, 110 MW for Generator 3, 55 MW for Generator 4, 37 MW for Generator 2, 27 MW for Generator 1, and 24 MW for Generator 5 are taken as generated powers. From these results, the fuel cost (FC) is calculated as 27593 \$/hour. When the load is dispatched in terms of economy, the amount of emission (E) is obtained as 382.4821 kg/hour. The economic dispatch results are shown in Table 4.

Table 4. The economic dispatch results

Symbol	Value	Unit
P1	27	MW
P2	37	MW
P3	110	MW
P4	55	MW
P5	24	MW
P6	247	MW
FC	27593	\$/hour
E	382.4821	kg/hour

In the solution of environmental dispatch problem, 6 generators are determined as decision points. The NO_x emission coefficients of the system (d, e, f) are established as the factors that affect the decision points. Firstly, values of f_i are determined by considering emission coefficients. The decision matrix that consists of values of f_i is obtained. While forming the decision matrix, the numbers from 1 to 10 are given as points to the elements of the matrix. The points are

determined by considering the values of emission coefficients for each generator. For example, the minimum value of emission coefficient d is for Generator 1 and Generator 2. It is benefit to take minimum value due to reduction of emission. Therefore, Generator 1 and Generator 2 take the biggest point (10) among other generators for emission coefficient d . The maximum value of cost coefficient d is for Generator 5 and Generator 6 so they take the smallest point (2) among other generators for emission coefficient d . The decision matrix for environmental dispatch problem is shown in Table 5.

Table 5. The values of f_i for all criterion in environmental dispatch problem

Generators	a	b	c
Generator-1	10	2	10
Generator-2	10	2	10
Generator-3	2	10	5
Generator-4	2	10	5
Generator-5	5	5	2
Generator-6	5	5	2

As seen in Table 4, the maximum value of f_i (f_i^*) is 10 and minimum value of f_i (f_i^-) is 2. These values are taken in the calculations.

The values of S_j , R_j , and Q_j that are mentioned in Step 2 and Step 3 are calculated by using Equation 6, Equation 7, and Equation 8. The weights of criterion are taken from the study [16]. In study [16], the values of criterion for the same power system that is used in this study are obtained by Analytical Hierarchy Process (AHP) method. According to it, the weights of criterion (cost coefficients d, e, f) are 0.08, 0.20 and 0.72, respectively. The values of S_j , R_j , and Q_j and order in environmental dispatch problem are shown in Table 6 and Table 7, respectively.

Table 6. The values of S_j , R_j , Q_j in environmental dispatch problem

Generators	S_j	R_j	Q_j
Generator-1	0.2	0.125	0
Generator-2	0.2	0.125	0
Generator-3	0.53	0.45	0.47
Generator-4	0.53	0.45	0.47
Generator-5	0.895	0.18	1
Generator-6	0.895	0.18	1

Table 7. The order of S_j , R_j , Q_j in environmental dispatch problem

Generators	Order (S_j)	Order (R_j)	Order (Q_j)
Generator-1	1	1	1
Generator-2	1	1	1
Generator-3	2	3	2
Generator-4	2	3	2
Generator-5	3	2	3
Generator-6	3	2	3

According to the environmental dispatch problem result, it is seen that condition 1 and condition 2 are satisfied. The value of R_j are taken as a coefficient because Q_j has the zero value that cost can not be calculated. For 500 MW load, approximately 127 MW for Generator 1 and Generator 2, 88 MW for Generator 5 and Generator 6, 35 MW for Generator 3 and Generator 4 are found as generated powers. From these results, the amount of emission (E) is calculated as 397.7193 kg/hour. When the load is dispatched in terms of environment, the fuel cost (FC) is obtained as 31517 \$/hour. The emission dispatch results are shown in Table 6.

Table 6. The emission dispatch results

Symbol	Value	Unit
P1	127	MW
P2	127	MW
P3	88	MW
P4	88	MW
P5	35	MW
P6	35	MW
FC	31517	\$/hour
E	397.7193	kg/hour

5. Discussion and Conclusion

In this study, VIKOR method is used to solve economic and environmental dispatch problems. It is obtained that VIKOR method is not used about power systems. Therefore, VIKOR method is chosen in the solution of economic and environmental load dispatch problems. These problems are solved in 6 generators test system. In economic dispatch problem, generation cost is calculated as 27593 \$/hour and the amount of emission is calculated as 382.4821 kg/hour. In environmental dispatch problem, the amount of emission is calculated as 372.416 kg/hour and generation cost is calculated as 31517 \$/hour. When the results of economic and environmental dispatch problems are compared, it is obtained that economic dispatch has lower generation cost of 3924 \$/hour than environmental dispatch. However, emission levels of environmental dispatch are better than economic dispatch by 10.0661 kg/hour.

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