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AHP METHOD FOR UNIT COMMITMENT

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Abstract- Making decision is one of the human characteristics. Every person makes lots of decisions during a day. Some of these decisions raise less important concern but some of them are vitally important. As one takes on more responsibilities, making correct decision will be much more crucial. Due to this fact that making correct and in time decisions can be significant in personal and social life of human beings, the existence of powerful technique which can help humans in this field would be necessary. One of the most efficient and useful methods in this subject is AHP Analytical Hierarchy Process which was primarily introduced in 1980 by Thomas El-Saaty. This technique has been established based on paired comparisons. It makes it possibility to explore different scenarios to managers. Due to its simple and comprehensive nature, this technique has always attracted the attentions of managers as well as different people with different carriers. Furthermore, over the past twenty years it has drawn academic communities' attention to itself. In order to the best vendor in production management, objectives such as price, quality, after sales service and etc should be followed while determining the best layout on such criteria as lower transport costs, greater safety, fewer interruptions (such as noise and traffic ,etc).All people including social and physical scientists, engineers and politicians and even illiterate people would be able to do this without the use of specialists' help. Another point is that the AHP structure of four wooden collaboration and participation in making decisions or solving problems in a group provides for the selection of the best vendor in production management meeting the targets such as price, quality, customer care services are important, whereas in positioning the place of store other parameters such as less transportation cost, more safety, would be considered. This method can be used by all kind of peoples with any job (like Social and physical scientists, engineers and politicians) without any specialists' help. One of the greatest advantages in this method is that it can build a structure for creating partnerships and workshops in order to solve problems.

Keywords: Analytical Hierarchy Process, Normalized Matrix, Relative Weight, Unit Commitment.

I. INTRODUCTION

The UC algorithms can be applied to large-scale power systems and have reasonable storage and computation time requirements. A survey of literature on UC methods reveals that various numerical optimization techniques have been employed to address the UC problems. Specifically, there are priority list methods, integer programming, dynamic programming, mixed-integer programming, branch-and-bound methods, and Lagrangian relaxation methods. Among these methods, the priority list method is simple and fast, but the quality of the final solution is not guaranteed [11].

In every stage of decision making, the decision-making alternative can be discrete or continues. This method is classified in to single criteria and multi-criteria types. Also these criteria can be quantitative, qualitative or be the combination of both. The AHP (Analytical Hierarchy Process) is one of the most comprehensive systems which are designed for multiple criteria decisions, because this type of design can provide the possibility of formulating the issue (as a hierarchical) as well as considering various quantitative and qualitative criteria in the mentioned issue.

This process involves several options in decision making process and has the possibility of sensitivity and analyses on criteria and sub-criteria in issues. In addition to aforementioned advantages, this system is based on paired comparison that not just makes judgments and calculations are more facilitated, but also show the compatibility and incompatibility of the already made decisions.

This is the benefit of this technique in multi-criteria decision makings. This system also has a powerful theoretical basis and it is based on axiom principles. AHP method analyses complex issues simplify them and then solve them. This method has found many applications in social and economical issues.

This method has been used in management matters in the recent years. In this paper, AHP (Analytical Hierarchy Process), a method will be applied for optimizing fuel consumption and costs between the power plants.

This method will be investigated according to calculations, principles and rules that based on AHP. This principle includes: the reverse condition, the principle of homogeneity, dependence on and expectations.

In this paper, research subjects will be five power plants by the names of G_1, G_2, G_3, G_4, G_5 and according to their specific demand and known time, one of them will be chosen. In this research 5 criteria will be considered as fuel costs, reserve spinning capacity, hydro unit and thermal unit. In order to find the power plant, AHP method will be used in 3 steps:

- Making Hierarchy
- Calculating amounts
- Problem description

II. LAGRANGIAN EQUATION

The UC is a difficult optimization problem that has enough potential to save millions of dollars annually in electrical industry and also, unit commitment in power systems refers to the optimization problem for determining the on/off states of generating units that minimize the operating cost for a given time horizon. The objective of problem is that minimize the all operation cost with considering security constraints [12].

This section presents a fast and useful formula to calculate loss sensitivity for any slack bus. The formula is based on the loss sensitivity results from the distributed slacks without computing a new set of sensitivity factors through the traditional power flow calculation. In particular, the loads are selected as the distributed slacks rather than the usual generator slacks. The loss sensitivity values will be unchanged for the same network topology no matter how the status of the AGC units changes.

In the energy market, the formulation of the optimum economic dispatch can be represented as follows [4]:

$$\min F = \sum_j C_j P_j \quad , \quad j \in NG \tag{1}$$

subject to:

$$\sum P_D + P_L = \sum_j P_{Gj} \quad , \quad j \in NG \tag{2}$$

$$\sum_j S_{ij} P_j \le P_{i\max} \quad , \quad j \in NG,\ i \in K_{\max} \tag{3}$$

$$P_{Gj_{\min}} \le P_{Gj} \le P_{Gj_{\max}} \quad , \quad j \in NG \tag{4}$$

The Lagrangian function is obtained from Equations (1) and (2) [4]:

$$F_L = \sum_i f_i(P_{Di}) + \lambda(\sum_i P_{Di} + P_L + \sum_j P_{Gj} \tag{5}$$

Traditionally, generation reference (single or distributed slack) is used in the calculation of loss allocation. This works, but it may be inconvenient or confusing for the users who frequently use the loss factors. The reason is that the AGC status or patterns of units are variable in the real - time EMS or energy markets. The loss sensitivity values based on the distributed unit references will keep changing because of the change of unit AGC status. Thus the distributed load slack or reference is used here [5].

III. PROBLEM DESCRIPTION

A. The Structure of Equations

Due to the eigenvalues, hierarchy can be shown by one number, which can define the relationship between these numbers, importance of criteria and also comparison between them. In associated with this characteristic, a coefficient which it named CI will be defined as follow [4]:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{6}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the mentioned matrix and n is dimension of the matrix and CI will be used in the following formula in order to find RI [4, 7]:

$$CR = \frac{CI}{RI} \tag{7}$$

In this formula RI is a set of data that has an average of random consistency of indexes and CR is rated adjustment. For a matrix with the size of 0 to 9, the value of RI will be acquired as Table 1.

Table 1. *RI* calculated

	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.25	1.32	1.41	1.45

This table shows that in a matrix with size of 1 or 2, mentioning the RI would not be necessary. Generally if CR be less than 0.1 ($CR < 0.1$), the condition is desirable [2]. This is also possible for the eigenvalue to be calculated accurately but it should be considered that this issue also depends on the analysis time and it does not need to be calculated accurately the reason of this extermination is that, this values will be chosen by user's subjective judgments which itself has a wide range of Errors. Therefore in this paper expressing equations in a simple way were attempted.

B. Calculation Method

As the first step in this part, the multiply of the matrix elements need to be obtained as follow [4, 5]:

$$M_i = \prod_i^n X_{i,j} \tag{8}$$

As the second step of this part, the nth root of M_i need to be calculated [4, 5]:

$$W_i^* = \sqrt[n]{M_i} \ , \ i = 1,2,\ldots,n \tag{9}$$

Where W^*can be expressed as a vector:

$$W^* = [W_1^*, W_2^*, \ldots, W_n^*]^T \tag{10}$$

Now W^* need to be normalized as follows:

$$W_i = \frac{W_i^*}{\sum_{i=1}^n W_i^*} \tag{11}$$

and as the next step, maximum eigenvalue need to be obtained as follows :

$$W = [W_1, W_2, ..., W_n] \tag{12}$$

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \tag{13}$$

where $(AW)_i$ is represents as the ith elements in AW vector [4, 5].

It is noteworthy to mention that $\lambda_{\max}$ is useful in power plants unit commitment when matrix is inconsistence, and maximum amount of eigenvalue is known as “Inconsistency rate”. It is assumed that, comparisons made by mentioned method in this paper are consistent so it seemed necessary to maintain this rate.

Dynamic programming methods, which are based on priority lists, are flexible but are computationally expensive. Branch-and-bound adopts a linear function to represent the fuel consumption and time-dependent start cost and obtains the required lower and upper bounds. The disadvantage of the branch-and-bound method is the exponential growth in the execution time with the size of the UC problem.

The integer and mixed-integer methods adopt linear programming technique to solve and check for an integer solution. These methods have only been applied to small UC problems and have required major assumptions that limit the solution space. The Lagrangian relaxation method provides a fast solution, but it may suffer from numerical convergence and solution quality problems [11].

C. Calculations of Relative Amount by the Usage of Least Squares

Generally, a paired comparison matrix is shown as follows where a_{ij} is the amounts of elements of W_i need to be obtained as follows [5]:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{14}$$

It is assumed that mentioned matrix (14) is consistent (It means that if the logical amount of $A \cap B$ and $A \cap C$ be correct then B∩C also has a true logical value) which it means, elements are associated to each other. With this assumption calculation of W_i would be simple and it can be obtained by normalizing elements of each column [1]. In this mode numerical value of a_{ij} will be equal with $\frac{W_i}{W_j}$. The W_i and a_{ij} minimized by the usage of least squares method for W_i with, in this method, attempt, that W_i and W_j be determined in a way that it minimize the difference between $\frac{W_i}{W_j}$ and a_i [3, 4].

In the other word the system becomes closer to compatibility mode, therefore calculation of W_i and W_j need to done by solving following nonlinear program.

$$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij} W_j - W_i)^2 \tag{15}$$

subject to:

$$\sum_{i=1}^{n} W_i = 1 \tag{16}$$

In order to solve the aforementioned problem, Lagrangian equation will be considered as follow:

$$L = \sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij} W_j - W_i)^2 + 2\lambda (\sum_{i=1}^{n} W_i - 1) \tag{17}$$

We have:

$$\sum_{i=1}^{n} (a_{i1} W_1 - W_i) a_{i1} - \sum_{j=1}^{n} (a_{1j} W_j - W_1) + \lambda = 0 \tag{18}$$

$$i = 1, 2, \ldots, n$$

where (n+1) is heterogeneous linear and unknown variable will be obtained. As an example if n be considered as 1 then [3, 4, 5]:

$$\begin{aligned} &(a_{11}^2 - 2a_{21} + a_{21}^2 + 2) - W_1 - (a_{12} + a_{12}) W_2 + \lambda = 0 \\ &-(a_{21} + a_{12}) W_1 + (a_{12}^2 - 2a_{12} + a_{22}^2 + 2) W_2 + \lambda = 0 \\ &W_1 + W_2 = 1 \end{aligned} \tag{19}$$

IV. HIERARCHICAL POWER PLANT BUILDING WITH SPECIFIED

In general view, it can be said that the method of making Analytical Hierarchy Process (AHP) is depending on the type of decision which it need to be made .For an example, if the desired decision be selecting and option, first level will be optioned and be showed in the lowest level, and in the next level criteria for selecting, considered options will be placed and at the highest level the aim of AHP (of an element) will be placed. The first step of AHP is creating a graphical display in with the aim, criteria and options are shown [1].

Figure 1 shows AHP in the selection of best power plant. Highest level in this table shows the aim of purpose which is selection of best power plant and in the second level criteria which are, hydro unit constraint, spinning reserve, must run state, fuel cost and constraint of thermal unit, have been proposed and at the final level, options (G_1, G_2, G_3, G_4, G_5) are shown [3, 4].

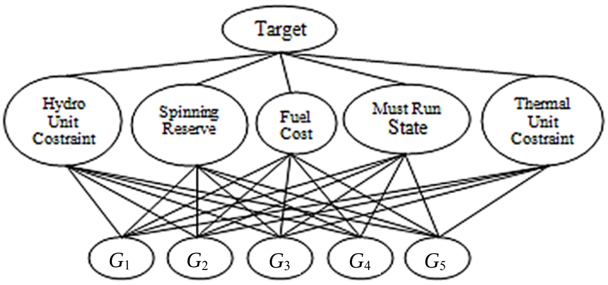

Figure 1. AHP chart in the selection of power plants

If the criteria be shown as P_i then, each criterion will be introduced and compared as follow [1, 3, 4]:

$$p_i = \frac{1}{F(P(t))} \tag{20}$$

where $F(P(t))$ is cost of function.

V. WEIGHT CALCULATION

In this process elements of each rows are pair compare with its corresponding element in the higher level and their weight is calculated we call this weight, relative weight. Then, by combining the relative weight, final weight of each option is specified; we call it the final weight [1].

All the benchmarks in this process of hierarchical analysis are done as a couple [1, 2]. In these comparisons, decision makers will use theoretical judgment, in the way that if the element i with element j be compared the decision makers said importance of i on the j is one of the scenario Table 2.

Table 2. Preference values for paired comparisons

Preferred	Value
Extremely Preferred	9
Very Strongly Preferred	7
Strongly Preferred	5
Moderately Preferred	3
Equally Preferred	1
Preferences between the above Intervals	2, 4, 6, 8

Table 2 preferences the values for paired comparisons. For example in comparison of G_1 and G_2 in terms of power plant fuel costs, the decision maker believes that the G_1 power plant is preferred on the G_2. Then he will be asked by using Table 2 expressed his preference. If believe that G_1 power plant is strongly preferred than G_2, we use value of 5. Now power plant cost pair fuel has been compared, and the weight (relative weight), will be calculated by this benchmark. Then other comparisons will be done and plants relative weight than other criteria and standards into the goal will be calculated and finally, the absolute weight of the options will be calculated.

It should be noted that in the paired comparisons, preference of each element on its own, is equivalent to one thus, all elements are on the diameter of the paired compares on matrix are equal to one, also, it is acceptable. If G_1 (power plant) over G_2 has the preference value of 3, prefer of G_2 over G_1 would be 1 to 3, in this case fuel paired comparison matrix can be completed as Table 3.

Table 3. Paired comparison matrix for 5 power plants toward reverse spinning

	G_1	G_2	G_3	G_4	G_5
G_1	1	4	8	6	2
G_2	1/4	1	4	2	1/2
G_3	1/8	1/4	1	1/2	1/6
G_4	1/6	1/2	2	1	1/4
G_5	1/2	2	6	4	1

When the paired comparison matrix established, the weight of each power plants can be calculated, in the order word, by the usage of paired comparisons (which it mentioned in paired comparison matrix). The weight of each power plant can be easily calculated. In order to calculate the weight of each item of paired comparison matrix (relative weight), and for reviewing and clear realization of the case, one of the approximated methods (which is simple and conceptual) will be introduced.

This method has the following 3 steps:

- Step 1: Total amounts in each column, after accounting for $G_1 = \frac{49}{24}$, $G_2 = \frac{31}{4}$, $G_3 = 21$, $G_4 = \frac{27}{2}$, $G_5 = \frac{47}{12}$ is obtained (numbers are expressed as a fraction).
- Step 2: The division of each element of matrix in to the sum of total column of the same element (Note: The sum of the column values in a normalized matrix, is equivalent to one). This step is known as normalization matrix each in shown in Table 4.

Table 4. Result of the second step (columns normalization)

	G_1	G_2	G_3	G_4	G_5
G_1	24.49	16.31	8.21	12.27	24.47
G_2	6.49	4.31	4.21	4.27	6.47
G_3	3.49	1.31	1.21	1.27	2.47
G_4	4.49	2.31	2.21	2.27	3.47
G_5	12.48	8.31	6.21	8.27	12.47

- Step 3: Average (mean) elements in each row of the normalized matrix, are calculated. This average value is an estimate of weight desired. Calculation of the average of elements in each row is shown in the Table 5.

Thus, it can be concluded that with regard to spinning reserve power plant G_1 (with preference 0.4683) is the best plants and then power plant G_5 (with preference 0.2680), G_2 (with preference 0.1435), G_4 (with preference 0.0758) and the final rating, power plants G_3 (with preference 0.0441) are placed in the last row.

Table 5. Results from the third step (to obtain the average of rows)

	G_1	G_2	G_3	G_4	G_5	Average of Rows
G_1	0.4897	0.161	0.3809	0.4444	0.5106	0.4683
G_2	0.1224	0.1290	0.1904	0.1481	0.1276	0.1435
G_3	0.0612	0.0322	0.0476	0.0370	0.0425	0.0441
G_4	0.0816	0.0645	0.0952	0.0740	0.0638	0.0758
G_5	0.2448	0.2580	0.2857	0.2962	0.2553	0.2680
Total	1.00	1.00	1.00	1.00	1.00	1.00

VI. OTHER CALCULATED RELATIVE WEIGHT

In the previous section, the weight of each plant to measure the fuel cost was calculated. Now, the power plants, compared to other criteria (water unit constraints, spinning reserve, state, labor, fuel costs and constraints of thermal units) has also been calculated and also measured weight relative to the target. It is also clear that the final results in Table 6 can be conducted (similar to what was calculated in the previous section).

After calculating the weight ratio of plants to all criteria, you can specify the weight standards; in other words, the contribution of each of the criteria in determining the best plants to be identified. Since it is necessary to compare the criteria pair, we asked the decision maker about preferred pair of these criteria, and we formed the paired comparison on a matrix shown in Table 7. The calculation result is shown in Table 8.

Table 6. The water unit constraints, spinning reserve, labor conditions, and constraints of thermal units

	Hydro Unit Constraint	Fuel Cost	Must Run State	Thermal Unit Constraint
G_1	0.0433	0.4683	0.4611	0.0364
G_2	0.1731	0.2680	0.0505	0.0812
G_3	0.4502	0.0758	0.0926	0.2686
G_4	0.1223	0.0441	0.1485	0.1463
G_5	0.2111	0.1435	0.2014	0.4672

Table 7. Paired comparison criteria matrix

	Hydro Unit Constraint	Spinning Reserve	Must Run State	Fuel Cost	Thermal Unit Constraint
Hydro Unit Constraint	1	1/6	1/4	1/9	1/2
Spinning Reserve	6	1	2	1/2	4
Must Run State	4	1/2	1	1/4	3
Fuel Cost	9	2	4	1	6
Thermal Unit Constraint	2	4	2	6	1

Table 8. The final comparison, both the criteria weights

Criterion	Value
Hydro Unit Constraint	0.0424
Spinning Reserve	0.2657
Must Run State	0.1419
Fuel Cost	0.4746
Thermal Unit Constraint	0.0751

VII. CALCULATE THE FINAL WEIGHT OF POWER PLANTS

Since the weight criteria reflects their importance in determining the purpose and weight of each option relative to the criteria and also the share option is the relevant criterion, it can be easily said that the final weight of each option is obtained by multiplying the total weight of each criterion in the choice of the bench mark weight [1, 2].

Then according to the calculated relative weight, final weight of each option is obtained as follows:

The final weight of the G_1 power plant:

$$0.424\times 0.0433+0.4746\times 0.4887+0.1419\times 0.4611+$$
$$+0.0751\times 0.0364+0.02657\times 0.4683=0.4263$$

The final weight of the G_2 power plant:

$$0.0424\times 0.1731+0.4746\times 0.0990+0.1419\times 0.0505+$$
$$+0.0751\times 0.0812+0.2657\times 0.1435=0.1057$$

The final weight of the G_3 power plant:

$$0.0424\times 0.4502+0.4746\times 0.1656+0.1419\times 0.0926+$$
$$+0.0751\times 0.2686+0.2657\times 0.0441=0.1427$$

The final weight of the G_4 power plant:

$$0.0424\times 0.1223+0.4746\times 0.0359+0.1419\times 0.1485+$$
$$+0.0751\times 0.1463+0.2657\times 0.0758=0.0744$$

The final weight of the G_5 power plant:

$$0.0424\times 0.2111+0.4746\times 0.2105+0.1419\times 0.2014+$$
$$+0.0751\times 0.4672+0.2657\times 0.2680=0.2437$$

As it can be noticed, power plant G_1 is the best choice between all the power plants and bench marks, as compared to the paired one mentioned before.

VIII. CONCLUSIONS

In this paper, an attempt was made to describe one of the decision-making methods used frequently in industrial engineering and in other words is rooted in this field. Moreover, by using this new method, appropriate plants from the standpoint of cost and other parameters can be selected. In other words, the decision making and optimization can be done by comparing the effective standard generators and power plants using a hierarchical approach. Afterwards, the best option considering all the bench marks can be selected and compared.

One of the noticeable advantages of this type of method is that this method is a very simple way to choose and decide in a way that there is no need for any special expertise and experience to investigate. However, it should be noted that, following this method another hierarchical way, in recent years, known as nonlinear systems or networks was introduced which was the expansion of AHP method. In this method the dependencies between the criteria and options were mutual, so this should also be taken into consideration in all the calculations which should be done according to a series of equations and methods called large matrix. The Hierarchical approach is simple and at the same time so efficient and fast that it lets us achieve our desired goals as fast as possible.

As mentioned in the paper it should be noted that when we compare the same criteria together and to the options, sufficient accuracy and attention to details are necessary because any false comparisons with the standards and criteria options will end up ruining favorable response.

NOMENCLATURES

P_D : The real power load

$P_{i_{\max}}$: The maximum requirement of power supply at the active constraint *i*

P_{Gj} : The real power output at generator bus *j*

$P_{Gj_{\min}}$: The minimal real power output at generator *j*

$P_{Gj_{\max}}$: The maximal real power output at generator *j*

P_L : The network losses

S_{ij} : The sensitivity (shift factor) for resource or unit *j* & active constraint *i* with respect to market based reference

C_j : The real - time price for the resource (or unit) *j*

$K_{\max}$: The maximum number of active constraints

NG : The number of units

λ : The Lagrangian multiplier

n : investigated matrix size

X_{ij} : An element of investigated matrix

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