

# Capacity planning for fossil fuel and renewable energy resources power plants

S. F. Ghaderi\* ,Reza Tanha\*\* Ahmad Karimi\*\*\*

\*,\*\* Research Institute of Energy Management and Planning and  
Department of Industrial Engineering, Faculty of Engineering, University of Tehran  
P.O. Box 11365 Tehran, IRAN

\*\*\*Department of Mathematics, Tarbiat Modares University, Jalale Ale Ahmad Highway, Tehran, Iran

[Ghaderi@ut.ac.ir](mailto:Ghaderi@ut.ac.ir)

[ie\\_tanha@yahoo.com](mailto:ie_tanha@yahoo.com)

[karimi\\_a@modares.ac.ir](mailto:karimi_a@modares.ac.ir)

## Abstract

Electricity industry is changing by organizational and legislative evolutions dealing with economical and environmental affairs. Besides rapid development in energy generation decreased the related variable costs, considering environmental issues. In this study energy generation technologies are evaluated both from economical and environmental views. Applying Analytical Hierarchy Process (AHP) which is extremely applicable and known as one of the efficient methods to analyze complicated multi criteria problems it is achieved interesting results from evaluation. The main goal of this evaluation which is presented in this essay is to extract total preference weights for generation technology. Total preference weights are determined considering four criteria in fossil fuel power plants and renewable energy resources power plant using this evaluation pattern. For three power plant of gas, steam and combine cycle the total preference weights are calculated by considering seven criteria. For the next eight power plants of wind, small hydro, photovoltaic, solar thermal, micro turbine, biomass, geothermal and fuel cell total preference weights is considered according to seven criteria. Optimum capacity is calculated and determined. Sensitivity analysis is made on two most important criteria of this model named 1- operation and investment cost, and 2-fossil resources scarcity for power plants. 1- Multiple criteria of objective function, 2-possibility of sensitivity analysis on criteria weights and 3-concurrent inspection of qualitative and quantitative criteria in optimization of objective function are three advantages of the proposed model comparing common applying method such as (mono- objective software WASP)

**Key words:** fossil and renewable energy, analytical hierarchy process, linear programming and capacity determination process

## 1. Introduction

Environmental consideration pressure such as global climatic change, weather pollution and forest decadence have encouraged industry to search the methods to decrease the environmental dangers and pollution surface of lateral products. Also in recent years the energy market was extraordinarily unstable in a way that at the beginning of 2002, the energy shortage worrisome in America and high price of oil and natural gas made economical growth slow and assassination attacks of 11 September lowered the prices. Western countries tendency towards dependence decrease on far producers of crude oil and serious support of researches in the field of "pure" and "renewable" energy resources like solar photovoltaic technologies, biomass, wind turbine, geothermal and

fuel cell can lead to new applicable energy. In our country, according to short life of oil and gas resources and increasing demand of energy (will be double during seven years) and increasing of pollution, it is tried the fuel and thermo needs and non-generation consumption like home consumption and possibly industrial consumption and electricity production from other sources of energy specially non-polluted and non-compensatory resources will be determined. According to different technical and economical features of power plants, to determine power plant capacity optimization of each fossil fuel and renewable energy resources power plants to manufacture until 2015 forms a decision making with multiple criteria. At the moment production programmers in Tavanir organization have formed a objective mono-criteria by cost criteria function by changing all qualitative criteria to quantitative and cost material and by running the WASP software which is productive programming software would start optimizing the objective function for different scenarios consists of various design of production. In this article, considering 4 criteria, universal fuel price growth, environmental pollutions and fossil resources scarcity, decision making is involved with multiple criteria and the final weight for fossil fuel and renewable energy resources power plants will be gained. Also considering 7 qualitative and quantitative criteria consist of : setup time, life time, fuel consumption or efficiency, emergency exit rate, internal consumption, capital and operating cost and pollution of environment, decision making by multiple criteria for gas, steam and combined cycle power plants designed and total weight of each gas, steam, compound cycle power plants will be gained and finally for renewable energy resources power plants, considering criteria 7 economical, technological, energy source, technical features, environmental, cultural political social and market, decision making is done by multiple criteria and total weight of each wind, small hydroelectric, photovoltaic, solar thermal, micro turbine, biomass, geothermal and fuel cell power plants is gained. These weights are used for optimal capacity determination of each fossil and renewable energy resources power plants. Those for its solution, the integrated method of analytical hierarchy process (AHP) along with linear programming (LP) are applied. To solve the part of AHP of this article, we have used Expert Choice software and to solve LP part we used Lingo software.

\*\*Corresponding author. Tel.: +98-09141490515; fax: +98-021-6461680.  
 \*\*E-mail address: [ie\\_tanha@yahoo.com](mailto:ie_tanha@yahoo.com) \*E-mail address: [Ghaderi@ut.ac.ir](mailto:Ghaderi@ut.ac.ir)  
 \*\*\*E-mail address: [karimi\\_a@modares.ac.ir](mailto:karimi_a@modares.ac.ir)

## 2. Mixed method of Analytical Hierarchy Process (AHP) with linear programming (LP)

To inspect the replacement of fossil power plant with renewable energy resources to produce electricity, we use (AHP) Analytical Hierarchy Process and Linear programming.

At first, we apply AHP to gain total preference weights of power plants from net data and generalization (by the use of Expert Choice software). Then we use linear programming for maximization of power plants capacity considering total preference weights got from AHP and as a result the determined power plants will be chosen by their capacities (the use of Lingo software).

### 2.1. Analytical Hierarchy Process (AHP)

AHP is a decision making method which we can make decision related to various criteria or multiple decisions. This method was presented by Professor Saaty and provided great field for decision making.

Main structure of the process consists of objective, criteria and items which are hierarchical to each other.

In this method judgments are done by low quantitative amount 1 to 9 (according to table 1) and by even comparisons (these numbers are presentable by divisions). At first, criteria importance toward objective and then items preference toward each criterion in even comparison matrix will be presented and finally criteria weight will be determined. The advantages of this method are: simplicity, comprehensiveness, judgments incompatibility calculation possibility, structure of Analytical Hierarchy process and qualitative criteria [1]. One of the reasons for selecting this method is provision of group cooperation. To mix different judgments of people, all the even comparisons matrixes were gathered and mixed the judgments by geometrical average and get relative weights of criteria and items [2].

Table1. Saaty spectrum

Numeral Values	1	2	3	4	5	6	7	8	9
Important degree of Pair-Wise Comparison	Equal preference	Equal preference until comparative	comparative preference	comparative preference until strong	strong preference	strong preference until	Very strong preference	Very strong until preference inordinate	preference inordinate

### 2-2 – Total Algorithm of energy production assessment technology (AHP)

- Analytical Hierarchy process drawing of inspected case
- To do even comparison of items in each surface of hierarchy process structure and matrix of even comparison form ( to determine criteria weights )
- Relative preference of criteria toward each other
- Relative preference of each power plant toward each criteria
- Extract of preference weights for criteria and finally gaining the total value of each power

plant and their ranking by the usage of Export Choice software

### 2-3- Even comparison and priorities extraction

In this section, according to AHP algorithm, final weights of items are calculated by Export Choice software. We should form the even comparison matrix of items toward all criteria toward objective. In this case, economical and technical information table (2) and (3) which is collected by Tavanir production planning office organization [3] is used and also considering senior manager and industry experts points of view related to power plant energy, industry and numerous seniority meetings and expertise executive panels and using hierarchical analysis method, special weights are specified according to their importance.

Table 2. Technical and economical information of fossil fuel power plants

Power plants	Time setup (year)	Life time (year)	Emergency exit rate (percent)	Internal consumption (percent)	Efficiency (percent)	Plant factor (percent)	Capital cost		Operating and maintenance cost		
							Euro/KW	Ral/KW	Fixed annual	variable	Euro cent/Kwh
Gas (big)	2	15	6.12	0.5	34.3	41.2	166	1200419	14027	0.0325	0.74
Steam	5	30	7.8	8	41.2	70.4	387	2247117	51336	0.0125	1.58
Combine cycle	4	30	6.74	2	50	70	297	2049000	23758	0.0163	0.85

Table 3. Technical and economical information of renewable energy resources power plants

Power plants	Life time (year)	Capital cost	Efficiency (percent)	Operating and maintenance annual cost \$/KW	Plant factor (percent)	Capacity Factor (percent)	Final price of electricity cent/Kwh
Solar thermal	20	2400	14	52.8	20	30	10
Photovoltaic	20	4000	15	15	30	30	15
Wind	20	1000	30	20	30	30	5
Geothermal	30	3600	36	3.96	93	90	4
Biomass	20	1500	25	75	72	90	6
Fuel cell (natural gas)	10	3000	43	187	83	95	9
Small hydro	50	2500	15	97	29.4	50	5
Micro turbine	30	1500	30	125	30	70	5.4

Even comparisons of this paper are done during three phases and according views of some experts in this field.

**First phase:**

Hierarchical construction for first phase is made. Between fossil and renewable energy resources power plants according to defined criteria there was a Pair-Wise Comparison and the result of this phase was 4 tables of even comparison. Among defined criteria, there `s a pair comparison and their weights are identified.

After entering all even comparisons matrixes in Expert Choice software, the considered model was run and each preference weight of each power plant gained. Total weight of each fossil and renewable energy resources power plants are 0.519, 0.481.

**Second phase:**

In this phase like first phase we run four stages for fossil fuel power plants and finally final weight of each fossil fuel power plant is gained. In this structure, total operation and capital cost criteria will be respectively gained which required investment for establishing 1(KW) of each power plants is calculated and along 30 years (Economical period) we make equivalent these cost. It is essential that if two investment criteria and annual operation cost are individually considered, creating network probability and non-linear dependence among options and criteria are increased, usually AHP process leads to incorrect answers [4]. In this article, applying mixture creativity of these two criteria and equivalence of these two types of investment and annual operation cost prevent this problem.

In this phase, after entering all even comparison matrixes in Export Choice software, model which were mentioned in second phase were performed and final preference weights of each power plants gained. Total weight of each steam, gas and compound cycle power plants are 0.156, 0.550, 0.294.

**Third phase:**

In this phase like first phase, we run four stages for renewable energy resources power plants and at last we gain final weight of each power plant.

In this phase, among defined criteria there `s a pair comparison and weight of each criterion is identified.

Finally for third phase of renewable energy resources power plants final weights are identified according to mentioned criteria. So for wind, small hydroelectric, solar thermal, photovoltaic, biomass, micro turbine, geothermal and fuel cell power plants are 0.174, 0.134, 0.128, 0.117, 0.114, 0.112, and 0.103 are gained.

**3. Capacity determination process of power plants by mathematics linear programming**

After final weight determination of items (in part 2-3) , in this part determination of linear programming of optimized combination of power plant to determine load up to 2015 is planned. The rate of throughout net increasing load up to 2015 will be almost 14520 (MW). Considering 25 to 30 percent as circulatory storage, necessary production rate to fill the load will be between 18150 to 18876 (MW) whose 6000 (MW) will be produced by water electrical power plant. So necessary production rate will be estimated 12150 to 12876 (MW) until that year [5].

To optimize mathematic linear programming, we do definition and symbolism as below:

$P_F$ : Fossil fuel power plants capacity  
 $P_R$ : renewable energy resources power plants capacity

$P_g$ : Capacity of gas power plant  
 $P_s$ : capacity of steam power plant  
 $P_{cc}$ : capacity of combined cycle  
 $P_{Fc}$ : capacity of fuel cell power plant  
 $P_{pv}$ : capacity of photovoltaic power plant  
 $P_{Solar}$ : capacity of solar thermal power plant  
 $P_W$ : capacity of wind power plant  
 $P_{Ge}$ : capacity of geothermal power plant  
 $P_M$ : capacity of micro turbine power plant  
 $P_{Sh}$ : capacity of small hydro power plant  
 $P_B$ : capacity of biomass power plant

$\eta_g, PF_g, W_g$ : Efficiency, plant factor and preference weight of gas power plant

$\eta_s, PF_s, W_s$ : Efficiency, plant factor and preference weight of steam power plant

$\eta_{cc}, PF_{cc}, W_{cc}$ : Efficiency, plant factor and preference weight of combined cycle power plant

$\eta_{pv}, PF_{pv}, W_{pv}$ : Efficiency, plant factor and preference weight of photovoltaic power plant

$\eta_{Solar}, PF_{Solar}, W_{Solar}$ : Efficiency, plant factor and preference weight of solar thermal power plant

$\eta_W, PF_W, W_W$ : Efficiency, plant factor and preference weight of wind power plant

$\eta_{Fc}, PF_{Fc}, W_{Fc}$ : Efficiency, plant factor and preference weight of fuel cell power plant

$\eta_{Ge}, PF_{Ge}, W_{Ge}$ : Efficiency, plant factor and preference weight of geothermal power plant

$\eta_B, PF_B, W_B$ : Efficiency, plant factor and preference weight of biomass power plant

$\eta_M, PF_M, W_M$ : Efficiency, plant factor and preference weight of micro turbine power plant

$\eta_{Sh}, PF_{Sh}, W_{Sh}$ : Efficiency, plant factor and preference weight of small hydro power plant

$W_F$ : fossil fuel power plant final weight of first phase

$W_R$ : renewable energy resources power plant final weight of first phase

$L_{u1}$ : the upper required load equals 12876  
 $L_{L1}$ : lowest required load equals 12150

**Linear programming for first phase is as below:**

$$\text{Max } Z_1 = W_F P_F + W_R P_R$$

S.T.

$$L_{L1} \leq P_F + P_R \leq L_{u1} \quad (1)$$

$$P_F \leq 0.519 * 12876 \quad (2)$$

$$P_R \leq 0.481 * 12876 \quad (3)$$

$$P_R, P_F \geq 0$$

(4)

The objective function represents the fact that total preference weights of projects which total preference weights  $W_i$  are gained by AHP should be maximized.

The first limitation represents total capacity of selected projects should be among required predicted load according to 25 to 30 percent circulatory storage. Restriction (2) and (3) states the highest point of technologies. 4 restriction shows non-negative capacity of power plants.

**Linear programming for second phase is as below:**

$L_{u2}$ : upper required load is 6682/644

$L_{L2}$ : Lowest required load is 6348/512

$$\text{Max } Z_2 = W_g P_g + W_s P_s + W_{cc} P_{cc}$$

s.to

$$L_{L2} \leq P_g + P_s + P_{cc} \leq L_{u2} \quad (1)$$

$$P_g \leq 0.294 * 6682.644$$

(2)

$$P_s \leq 0.156 * 6682.644 \quad (3)$$

$$P_{cc} \leq 0.550 * 6682.644 \quad (4)$$

$$P_s + P_{cc} \geq 0.4 * (P_g + P_s + P_{cc}) \quad (5)$$

(5)

$$\eta_g P_g + \eta_s P_s + \eta_{cc} P_{cc} \geq 0.35 * (P_g + P_s + P_{cc}) \quad (6)$$

(6)

$$0.62 * (P_g + P_s + P_{cc}) \leq PF_g * P_g + PF_s * P_s + PF_{cc} * P_{cc} \quad (7)$$

(7)

$$P_g, P_s, P_{cc} \geq 0$$

(8)

The objective function represents the fact that total preference weights of projects which total preference weights  $W_i$  are gained by AHP should be maximized.

The first limitation represents total capacity of selected projects should be among required predicted load according to 25 to 30 percent circulatory storage. Fifth limitation represents that almost 40 percent of throughout net peak load will be filled by power plants with high output and plant factor (PF). So this programming determination is supposed by steam and combined cycle power plants. To change optimized fuel to electrical energy and minimum decrease of environmental pollution due to electricity production in power plants, the efficiency limitation in this programming is considered 35 percent and applied which is shown limitedly (6). According to plant factor (PF) of power plants which defines the function period of that power plant during this year. It is needed to have enough energy to be produced by gas, steam and combined cycle power plants in circuit should be more than required throughout net. As throughout net load factor (LF) is estimated 62 percent [5] so limitation of produced energy of power plants are shown by limitation (7). Restriction (8) indicates non-negative power plants capacity.

**Linear programming model for third phase is as below:**

$L_{u3}$  : Top required charge is 6193/356  
 $L_{L3}$  : Lowest required charge is 5883/688

$$\text{Max } Z_3 = W_W P_W + W_B P_B + W_{Fc} P_{Fc} + W_{pv} P_{pv} + W_{Solar} P_{Solar} + W_{Ge} P_{Ge} + W_M P_M + W_{Sh} P_{Sh}$$

**s.to**  
 $L_{L3} \leq P_W + P_B + P_{Fc} + P_{pv} + P_{Ge} + P_M + P_{Sh} + P_{Solar} \leq L_{u3}$  (1)

$$\eta_W P_W + \eta_B P_B + \eta_{Fc} P_{Fc} + \eta_{pv} P_{pv} + \eta_{Ge} P_{Ge} + \eta_M P_M + \eta_{Sh} P_{Sh} + \eta_{Solar} P_{Solar} \geq 0.35 * (P_W + P_B + P_{Fc} + P_{pv} + P_{Ge} + P_M + P_{Sh} + P_{Solar})$$
 (2)

$$0.62 * (P_W + P_B + P_{Fc} + P_{pv} + P_{Ge} + P_M + P_{Sh} + P_{Solar}) \leq PF_W * P_W + PF_B * P_B + PF_M * P_M + PF_{Ge} * P_{Ge} + PF_{Sh} * P_{Sh} + PF_{Solar} * P_{Solar} + PF_{pv} * P_{pv} + PF_{Fc} * P_{Fc}$$
 (3)

$$P_W, P_{Ge}, P_M, P_{pv}, P_{Sh}, P_{Solar}, P_B, P_{Fc} \geq 0$$
 (4)

Now, by the gained total preference weights from firsts, second and third phases and tables (2) and (3) data, problems of linear programming are as below and by its solution capacity of power plants foundation will be obtained.

By solving the first phase linear programming model by software Lingo, amount of capacity of each two types of fossil fuel and renewable energy resources power plants and objective function are as below:

$$Z_1 = 6447/296, P_R = 6193/356, P_F = 6682/644$$

By solving the second phase linear programming model by software Lingo, amount of capacity of each three types of fossil fuel power plants and objective function are as below:

$$Z_2 = 2723.514, P_g = 1834/643, P_{cc} = 3675/454.80, P_s = 1042/492$$

Results represent main share of combined cycle power plant to supply the load in 2015 year.

By solving the third phase linear programming model by software Lingo, amount of capacity of each eight renewable energy resources power plants are as below:

$$Z = 853.9538, P_{Fc} = 1520/525, P_W = 2806/171, P_{Ge} = 1866/660, P_M = 0, P_{pv} = 0, P_{Sh} = 0, P_{Solar} = 0, P_B = 0$$

#### 4. Sensitivity Analysis to determine changes limitation optimal solution

In sensitivity analysis by changing weight or significance of a criterion, variation in items ranking will be assessed. Although there is lack of certainty to determine preference rate (weights) of criteria, it is so useful for decision making to select items. Cost and fuel resources scarcity criteria of power plants because of high importance and priority toward other criteria are more influential to select better item and sensitivity analysis are done toward these two criteria. figures (1) and (2) respectively show variation method in ranking of two fossil fuel and renewable energy resources

power plants for the sake of change in resources restriction criteria ranking, and three gas, steam and combined cycle power plants for the sake of change in capital and operation cost of power plants considering between the distance of zero to one. According to figure (1), by increasing the criterion importance resources restriction, choices importances respectively are: renewable energy resources and fossil fuel power plants. According to figure (2), by increasing the criterion importance capital and operation cost, choices importance respectively are: combined cycle, gas and steam power plants.

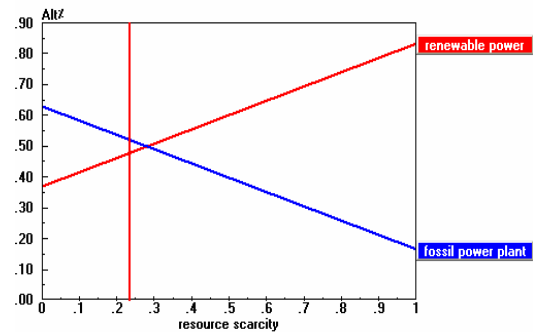


Fig. 1. Renewable energy resources and fossil fuel power plants sensitivity according to resource scarcity.

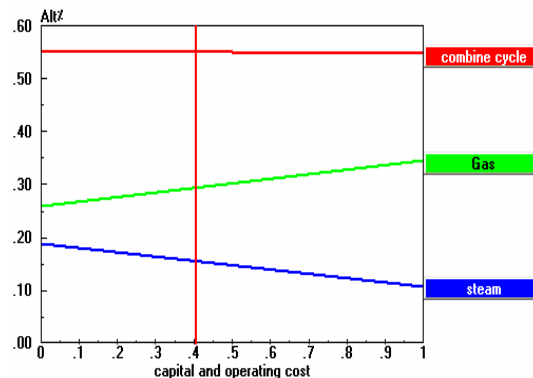


Fig. 2. Projects sensitivity toward total operation cost criteria and power plant capital cost

#### 5. Conclusion

One of the main issues in electrical generation planning is to find optimized combination of power plants to supply secure and sustain load for future. Generally in generation planning, we can optimize the mono criteria objective function by WASP for changing some important criteria to cost criteria apart from no important criteria. On the other hand, this problem follows different qualitative and quantitative factors, so solving a mono criterion function can not be a suitable trend to consider all effective factors and criteria. An appropriate solution is to consider all qualitative and quantitative criteria by using decision making techniques along with multiple criteria. By sensitivity analysis we can observe the variation of response when the importance weight in each criterion is changed as well as optimized combination of power plants. As a result, decision maker is able to inspect effect of all factors on final response under uncertain circumstances. According to sensitivity analysis it is clarified that if fossil fuel resources scarcity criterion of

power plants has important weight, renewable energy resources power plants will be competitive with fossil fuel power plants.

## References

- 1- L. Saaty “*Multicriteria Decision Making the Analytic Hierarchy Process*” University of Pittsburg.(1998)
- 2- H – Jin Son & K. Jomin (1998). “*Capital Budgeting Process for Electric Power Utilities an analytic hierarchy process approach*”. *International Journal of Energy Research* 671-681.
- 3- *Economical and technical information of Iran’s power plants*, production planning office, Tavanir organization 2007.
- 4- R.Ramanathan, L.S.Ganosh, “ Theory and methodology using AHP for resource allocation problem”, *European Journal of Operation Research*, 1993.
- 5- *States simultaneous load estimation report*, macro load observation group, Tavanir organization 2007.
- 6- Ahmaed, K., 1994, “*Renewable Energy Technologies, A Review of the Status and Costs of Selected Technologies*”.
- 7- Bezdek, R.H., et al., 2001, “*National Goals for Solar Energy: Economic and Social Implications*”, *Nat. Resour. J.*, Vol: 22:2.
- 8- Cantor, R., 1991, “*the External Costs of Fuel Cycles: Background Document to the Approach and Issue* ” Prepared for the Energy by resource for the Future, Washington Department, DC.
- 9- Colle, et al., 2004, “*Economic Evaluation and Optimization of Hybrid/Diesel/Photovoltaic Systems Integrated to Utility Grids*”, *Solar Energy*, No. 16, P.P. 295-294
- 10- Federal Ministry for The Environment, Nature Conservation and Nuclear Safety Germany, 2005, “ *Concentrating Solar Power for The Mediterranean Region*”.
- 11- Lesourd, J.B., 2001, “*Solar Photovoltaic System: the Economic of a Renewable Energy Resource*”, *Environmental Modeling and Software*, No.16, P.P. 147-156.
- 12- Saif-ul-Rehamn, M., 2001, “*Economic Competitiveness of Solar Energy With Conventional Fuels and Electricity*”, *Solar Energy*, Vol: 18:6.
- 13- Shababi, SH., Hosseini, M.S., 1997, “*Economic and Technical Evaluations of Solar Photovoltaic Power Plants in Iran*”, *Electricity Magazine*, No. 22, P.P. 43-35.