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Optimization and Economic Analysis of Integrated Wind and Pump Storage Power Production and Storage System for Azadi Sport Complex, Tehran, Iran

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Abstract: *In recent years, the uncontrolled growth of the use of fossil fuels and environmental problems created, have caused a lot of attention to optimization of energy consumption and use of renewable energy. One of the potential renewable energies that can be helpful in electricity generation is harness wind and water energy or using of these two kinds of energies simultaneously. In this paper, 2 wind turbines with 12 different scenarios are used to provide electricity for water pumps and the rest of the electricity is sold to the grid. These pumps for the supply of electricity to the three scenarios with three possibilities of per day, pump water into the reservoir with a capacity of 30,000 cubic meters. Considering that in this model power consumption per day is not known, every day water is pumped into the pool. Part of the water used to generate electricity and the rest is sold to the agricultural sector. According to the mentioned issues, software GAMS and Two Stage Optimization are used to optimize this model to consider the risk function of the net daily profit with respect to the amount of water pumped in each scenario.*

Keywords: *Renewable Energy, Wind Energy, Wind Turbine, Hydroelectric Power, GAMS, TWO stage optimization*

INTRODUCTION

One of the most important cases that in the world today has a great effect on the international relations and development of countries is providing the needed energy. At the present time, the most important resources of energy preparation that provides about 90% of the world needed energy is the sources of fossil energy [1]. These resources that are known as irreplaceable resources is running out and their prices that is increasing currently are affected by the world political and economic situations.

According to increasing consumption and environmental problems due to conventional power generation, there will be more attention to the DG. China's vast rural areas installed and operational of renewable energy low voltage such as wind energy, solar energy, hydro power, biomass, etc. have been installed and put into operation in low voltage (LV) power networks, especially in vast rural areas. Normally DG based micro-sources deliver power to the load through hybrid power system (HPS) which can basically solve the problem of energy demand in remote areas. HPS mircrogrids can be connected to the main power network or be operated autonomously [2, 3].

Use of Pumped Hydroelectric Energy Storage (PHES) was started as early as 1890 in Italy and Switzerland. The majority of plants were built from 1960s to the late 1980s. This was due to a rush for nuclear energy after the oil crises in the early 1970s. PHES development in the United States and European countries is closely correlated to the nuclear development. PHES was used as a system tool to supply energy at times of high load demand and to allow base load nuclear units to operate in their base load mode during low load demand period. However, in countries with rich hydro energy and no nuclear, PHES was developed primarily to enhance the operation and efficiency of large scale hydro power plants. In addition, PHES also provided power system management capabilities such as balancing, frequency stability and black starts [4].

The benefits of adding wind power to the power system can be summarized as in the following: 1. Reduction in overall generation cost as less fuel is consumed in conventional power plants and 2. Reduction in carbon emission as less fossil fuel is burned. However, due to the inherent variability of wind, increased wind power integration may create negative impacts on the power system reliability. These negative impacts may demand an increase in the cost of maintaining the same level of power system reliability, also known as wind integration cost. In addition, such negative impacts may offset the benefits of wind power and become significant as more wind power is integrated into the power system [5].

It is important to assess these potential negative impacts to ensure that they offset only a small part of the benefits. There are numbers of studies completed on partnering PHES with wind as a means to mitigate wind variability problem. A few benefits of PHES in regard to wind power integration as a result of these studies are discussed here. PHES is often partnered with wind farms to maximize the profit. At times of low energy price, the wind farms, instead of selling their power to the grid, can be used to pump water from a lower reservoir and store in the upper reservoir. Whenever the energy price increases above a certain threshold level, stored water is released back into the lower reservoir producing electricity which is sold to the grid. Wind power is also sold to the grid during this period of high energy price [6].

Moreover, using of these energy resources due to issues such as lack of security in providing energy and the worthiness of these kinds of fuels including peripheral industries of oil and after all environmental issues caused by use of these fuels have made a lot of problems in the earth ecosystem and as the result, the attention is focused on the other resources [7]. Regarding the population growth and increasing demand for energy, finding the alternative energy resources needed to humans is necessary and the attention centers on energy resources that are renewable and interminable and lack problems caused by fossil resources such as global warming and contamination of the harmful gases and most importantly the different kinds of it to be available free in the most regions of the world and because of this, different usages of renewable energies at global level are grown.

Supporting private sector, the government buys the guaranteed electricity with tariff of 18.5 cents in return for each KWh. Last year, 44% of the power plant's consumed fuel has been liquid fuel that worth on average 10 cents in a liter. About 6.3 KWh electricity is produced in power plants that in exchange for a liter fuel and for every KWh costs about 20 cents without considering the expenses for transferring and distributing. These statistics show that using of renewable energies is quite justifiable [8].

In this research to provide electricity, two types of renewable energies including hydroelectric and wind energies have been used. The wind energy is gained by construction of two wind turbines and hydroelectric energy is gained by an artificial pool that is constructed upward of the Azadi sport complex lake. The Couple of these two energies in addition to being renewable, make maximum use of the potentiality with optimization of two stage method in GAMS software of the produced energy. The GAMS software (General Algebraic Modeling System) was originally developed by a group of economists from the World Bank in order to facilitate the resolution of large and complex nonlinear models on personal computer. As a matter of fact, GAMS allows solving simultaneous nonlinear equation system, with or without optimization of some objective function [9].

Nomenclature

SET	S: scenarios for wind turbine K: scenarios for demand

PARAMETER	h(s): Probability of each scenario for wind turbine p(k): Probability of each scenario for demand d(k): Demand under each scenario [KWh] pwd(s): power of wind turbines under each scenario [KWh] pe: Electricity price per KWh in USD /0.18/ pt: Price to wind turbine for pump up water per m^3 in USD /0.13/ pr: Price per m^3 when sold back to locale beverage company /0.03/ C_F: first year unit cost delivered from electricity F: wind turbine energy fraction L: the amount of power consumed by the pumps i: fuel costs are expected to rise d: general market discount rate dm: the amount of interest rate is determined C: flag indicating whether the system is commercial or non-commercial D: down payment M1: ratio of first year miscellaneous costs includes parasitic power, insurance and maintenance. R: ratio of resale value at end of period of analysis to initial investment V1: ratio of assessed valuation of the system in first year to the initial investment in the system t_p: property tax rated base on assessed value t_e: effective income tax rate n: the lifetime of the system n_{min}: years over which mortgage payment contribute to the analysis
VARIABLE	X_1: First stage decision: How much water to pump [m^3] X_2: Second stage decision: How much water to release [m^3] Profit(k,s): Profit under each scenario Exp_profit: Expected Profit of the whole day

Azadi sport complex (ASC)

Artificial Lake Azadi Sport Complex is 220 thousand square meters and has a capacity of 600 thousand one hundred cubic meters regarding north of the stadium as a sports center, and recreational building. The pavement of the road at a high level and low level of wiki in a road car is built on top of the grass around the lake. This site has more than 250 thousand square meters lawn looks. The average depth of the lake is 4 meters (from 50 cm to 8 cm), length of 1200 meters and a width of 180 meters. This is normal and embankments in the lake near the stadium, the place of supply is one hundred thousand. The variety of disciplines boating lake (kayak, Kanaplv, Canadian Canoe, etc.) and water skiing are done [10].

Fig.1. Artificial lake Azadi Sport Complex

2. Wind energy resources evaluation

Like the other renewable energy resources, the wind energy is geographically extensive and at the same time scattered and non-concentrated and almost always available. Naturally, wind energy is fluctuant and intermittent and does not blow permanently. When the sun light reaches the rugged levels of the earth, the temperature and pressure changes and at the result of these changes wind is created and also due to the earth's diurnal movement, the atmosphere transfers the heat from tropical regions to polar regions that it also leads to wind creation. By studding the wind potential energy in any place, the solutions of energy production in vast scale are examined and personal goals in relation to wind energy utilization in future would be determined. In assessing the potentiality, elements such as economic, technical and organizational factors as well as factors related to weather would be considered.

For assessing the potential of the wind energy in Azadi Sport Complex, wind information of the Eshtehard wind measurement station has been used. Eshtehard wind station is located in the eastern part of the area and is the closest station to the proposed location [11]. Wind data are measured in Eshtehard station for a period of annual and months by Renewable Energy Organization of Iran in part of wind resources assessment project in Iran. Inserting wind information of the Eshtehard station in excel wind analysis software [12], the following results are obtained:

3.Wind speed and direction

The wind data is variable and every 3 seconds, the wind's quantity is calculated and every 10 minutes, the average would be obtained and calculated [13]. Monthly average wind data speed and direction are shown in Figure 2 and figure 3. The wind speed during the months of the year is shown in the Figure 2.

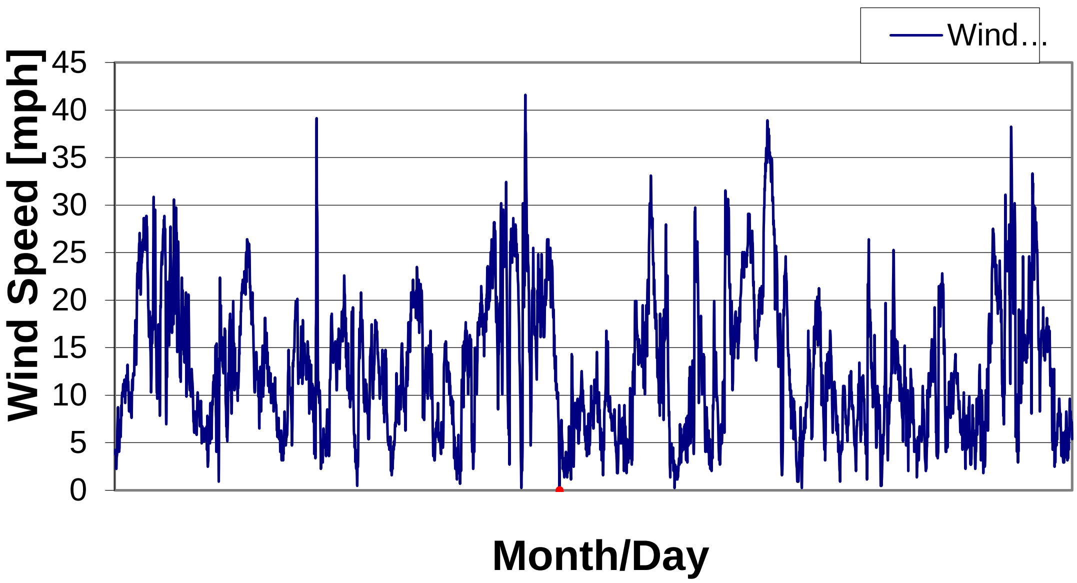

Fig.2. wind speed changes in Eshtehard station in February

One of the most important points in installing wind turbines in the region is the direction of dominant wind. Such a diagnosis causes direction of the first row of turbines to be done well and be in the same direction with the wind blowing in order to get the maximum output. As is clear from Figure 3, the prevailing wind is blowing from the West of Azadi Sport Complex in order to further the efficiency of wind power to be left in the first row of wind turbines.

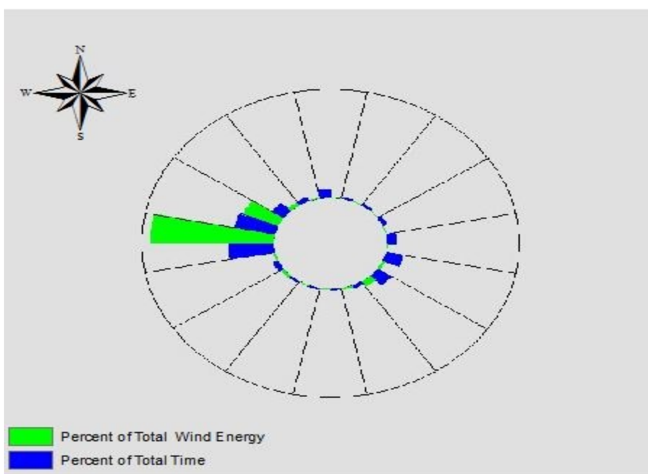

Fig.3. Wind Rose Graph

3.Wind power and its distribution

Weibull distribution is one of the bound probability distributions, which represents the probability of high and low speeds [14]. The curve should not be near the vertical axis, in that case the probable of low speeds ascends and if the curve be far from the vertical axis, the probability of high speeds ascends. But, in very high speeds, the probability decreases sharply. Usually for Weibull function, a numerical definition named K is assigned and usually K=2 is favorable. Distribution of the wind speed data using weibull function is shown in the following equation. To calculate the power output, important parameters such as K and A parameters are calculated and wind share evaluated.

$$P(V) = \left(\frac{K}{A}\right)\left(\frac{V}{A}\right)^{K-1} \exp\left[-\left(\frac{V}{A}\right)^{K}\right] \tag{1}$$

In the above equation, the coefficients V, K and A, respectively represent the wind speed, shape factor and scale factor. To calculate the shape factor and scale factor experimentally, we use the following equation where U and σ respectively areaverage wind speed and standard deviation [15].

$$K = \left(\frac{\sigma_V}{U}\right)^{-1.086} \qquad \frac{A}{U} = \frac{K^{2.6674}}{0.184 + 0.816K^{2.73855}} \tag{2}$$

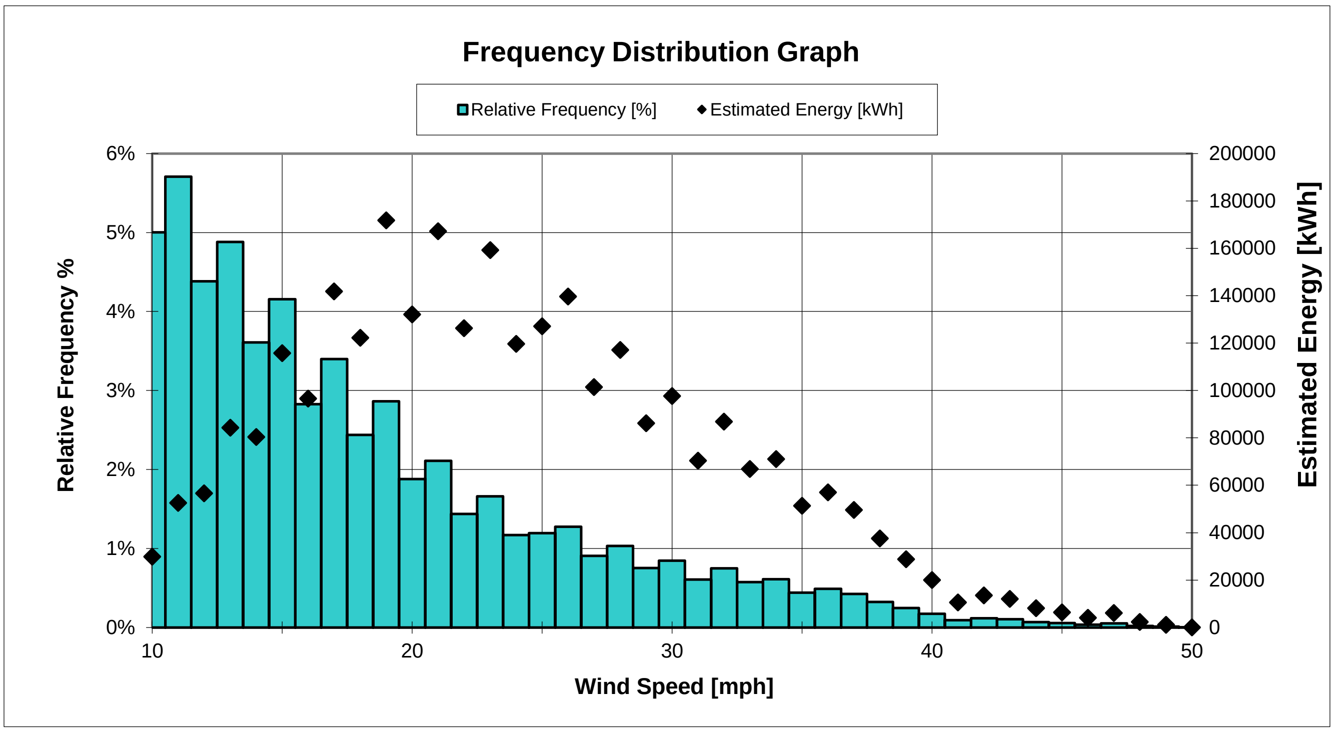

Fig.4. Weibull function of Eshtehard station

3.Wind turbines selection and power production

For utilization of wind energy in the region, turbines of the vertical axis are being used. The key points in choosing wind turbines are turbines starting speed, maximum generation power of turbines and failing speed. Regarding the average speed of the wind and mentioned points, GE 1.5 SL, 77m rotor turbine [16] have been used. Turbine's generation power curve is shown below:

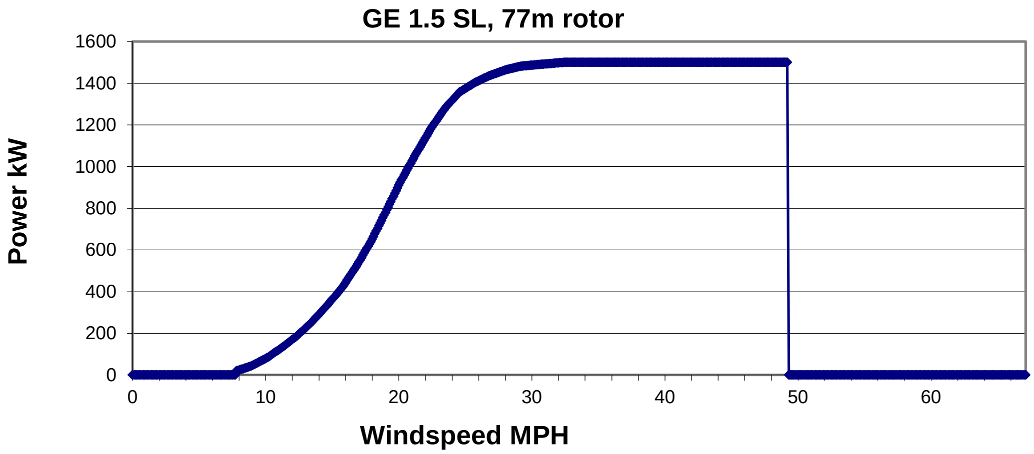

Fig.5. Wind production power turbine, GE 1.5 SL, 77m rotor model

According to the selected wind turbine and wind information calculation show Capacity Factor (cf) in the height of 40 meters is 0.25 and in the height of selected turbine Hub is 0.3 calculation shows that by installing given turbine in the quantity of output power in Azadi sports complex for a turbine in a year would be 3.937.982 KWh. This quantity shows that using wind turbines in the region is justifiable.

According to the ASC map and land availability, the location of the wind turbines Site is defined to install wind turbines as shown in Figure 4.

Fig.6. the location of the wind turbines

Integrated renewable energy Model

The goal of this project is providing part of the Azadi sport complex electricity using hydroelectric and wind renewable energies. Computations done in the previous section about measuring the probability of wind energy show that using wind turbines in this region technically and economically is justifiable. Considering the existence of natural lake in the stadium and with constructing a pool, it is possible to generate electricity using water turbines.

In this model by using some pumps, the lake water would be pumped into a reservoir with the capacity of 30000 cubic meters and height of 20 meters above lake level and a distance of 100 meters of it for 12hours. The reservoir dimensions is 100,50,6. The stored water is used for generating hydroelectric power. In order to provide consumed electricity, two 1.5 MW turbines has been used. The additional amount of produced electricity would be connected to the network and would be sold as renewable electricity.

The amount of water that is pumped and stored every day in the reservoir is a function of the next day consumption and is dependent on it. The remarkable point is that the amount of electricity used on the next day is not completely clear but, it can be considered with 3 scenarios as Low with 40000 KWh, Normal with 50000 KWh and High with 60000 KWh and probabilities that are respectively 0.25, 0.5 and 0.25. Now regarding this point, the amount of pumped water in a day is considered X1 cubic meter. Pumping expenses for water per cubic meter is Pw that is computed in the next section.

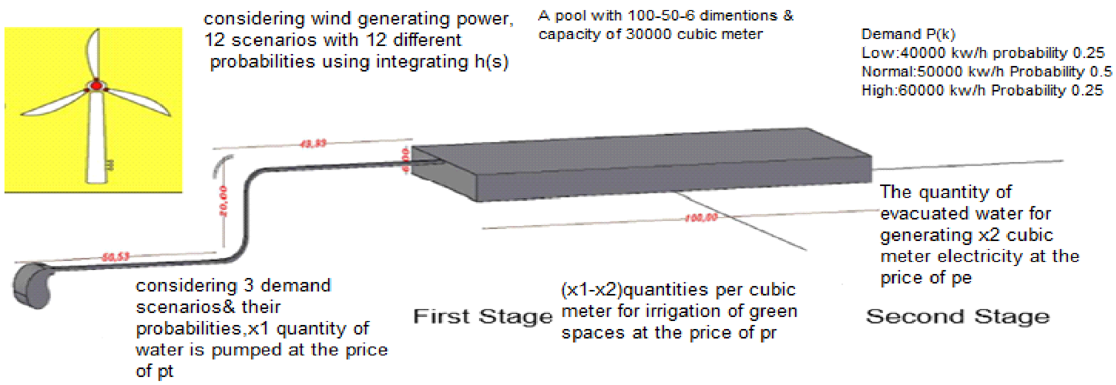

Fig.5. Overview of water storing mode

Of the X1 quantity of pumped water, X2 cubic meters of it with regard to the different demand scenarios for generating hydroelectric power is used and the price of each kw/h generated power is Pe. The other point in this model is that, it is not necessary to generate the whole amount of consumed electricity. At the end of every night for repairmen and inspection of different parts of the power plant, extra amount of water that is the result of difference between quantities X1 and X2 is evacuated and would be sold at the price of Pr for agricultural affairs and irrigation of green spaces.

Another point in this model is related to electricity generated by wind turbines. Regarding turbines generated power, 3areas with 12 different scenarios and probabilities that are resulted by integrating of zero speed to Vin of one scenario, in to Vr of 10 scenarios and Vr to Vout of one scenario are obtained.

If (K) equals the number of demand scenarios, amount of demand in each scenario is shown as d (k), S is the number of wind generation scenario, h(s) is the occurrence probability of each scenario and pw(s) is the amount of generated wind in each scenario. According to the points mentioned above, the required conditions are as follow:

$$X2(k) \leq X1 \qquad\qquad X2(k)*e \leq d(k)$$

Considering wind probabilities and generating power of GE, 1.5 SL turbine, results will be as follow:

TABLE 1. Parameters h(s) probability of each scenario for wind turbine

S_1	**0.07843**	**S_2**	**0.02500**	**S_3**	**0.03265**	**S_4**	**0.04509**
S_5	**0.05011**	**S_6**	**0.07728**	**S_7**	**0.09121**	**S_8**	**0.11222**
S_9	**0.10365**	**S_{10}**	**0.11233**	**S_{11}**	**0.06610**	**S_{12}**	**0. 20594**

Regarding the occurrence probability of each scenario, generating power of wind turbines that is dependent on the percent of generation power of each scenario is calculated according to the table below [17]:

TABLE2. Wind power generation scenarios

scenario	**wp_s**	π_s
S_1	100.00	0.07843
S_2	94.97	0.02500
S_3	84.97	0.03265
S_4	74.98	0.4509
S_5	64.98	0.05011
S_6	54.98	0.07728
S_7	44.99	0.09121
S_8	34.99	0.11222
S_9	19.99	0.10365
S_{10}	15.00	0.11233
S_{11}	5.00	0.06610
S_{12}	00	0.20594

In this project, 2similar wind turbines for utilizing wind energy have been used. For this reason and considering the probability of each scenario, the output power of wind turbines is calculated in the following table:

TABLE 3. Power of wind turbine under each scenario [KWh]

S_1	**1000**	**S_2**	**949.7**	**S_3**	**849.7**	**S_4**	**749.8**
S_5	**649.8**	**S_6**	**549.8**	**S_7**	**449.9**	**S_8**	**349.9**
S_9	**199.9**	**S_{10}**	**150**	**S_{11}**	**50**	**S_{12}**	**0**

Economic Analysis

According to the mentioned points and assigned parameters, profit that is the result of difference between selling wind and hydroelectric power and expenses of pumping and power plant is as follow:

$$profit = x_2(k)*e*pe + (x_2 - x_1)*pr + \left[pw(s) - \frac{9.81*x_1*25}{0.8*43200}\right] - x_1*pt \qquad (3)$$

e: coefficient of converting cubic meter to kw/h that its quantity is considered 2.5[18].

Net profit is the sum of the product of the probability of wind generating power in each scenario and demand probability in each scenario and the net profit in each scenario [19].

$$Exp_{profit} = \sum_{s=1}^{S}\sum_{k=1}^{K} h(s)*p(k)*profit \qquad (4)$$

In this model, for more correct conclusion and more reliable computation, it's better to use risk function. For this reason, risk function is defined as:

$$Risk = \sum_{s=1}^{S}\sum_{k=1}^{K} h(s) * p(k) * (profit - Exp_{profit})^2 \quad (5)$$

$$Objective = (1-\beta) * Exp_{profit} - \beta * Risk \quad (6)$$

In the above equation, β is the gap between final profit and the profit with considering the risk function. As it is clear of the above equation, β can be quantities between 0 to 1[20].

At the end for obtaining the maximum profit, TOW STAGE OPTIMIZATION in GAMS software has been used.

Obtaining the cost of wind turbines and pumping stations per cubic meter of water

To get the costs and economic analysis, methods P_1, P_2 are used. The price of pumping water per cubic meter includes constructive and pumping expenses [21]. This quantity involves expenses such as purchasing wind and water pumps, excavation, putting, plumbing, laying pipes, down payment, mortgage principal and interest, Income tax deductions of the interest, Maintenance, insurance and parasitic energy costs and lagging.

In this method, P_1 and P_2 are calculated life cycle savings (LCS) each individually in the following equation.

$$LCS = P_1 C_{F1} FL - P_2 C_S \quad (7)$$

P1 in the above equation is equal to ratio of life cycle fuel cost savings to first-year fuel savings with use of the wind turbine energy. Also P2 in the above equation is equal to ratio of life cycle expenditure incurred from the additional investment to the initial investment. F is wind turbine energy fraction to equal 1 because produced electricity by wind turbine can provide total energy. And C_{F1} is equal to first year unit cost delivered from electricity. L is the amount of power consumed by the pumps which is calculated by the following equation:

$$P = \frac{\gamma QH}{\eta} \quad (8)$$

According to the height of 20 meters and pumping time of 6 hours and flow amount of 30000 cubic meter of water, kWh electricity consumption is obtained.

$$P_1 = (1 - Ct_e) PWF(n_e, i_F, d) \quad (9)$$

In above equation, respectively amount of C and t_e is defined flag indicating whether the system is commercial or non-commercial and effective income tax rate. Present worth factor (PWF) is obtained in the following equation.

$$PWF(n, i, d) = \frac{1}{d-i}\left[1 - \left(\frac{1+i}{1+d}\right)^n\right] \quad (10)$$

In the above equation n is the lifetime of the system which is considered to be 20 years and i is fuel costs which is expected to rise at 9% per year and d is general market discount rate considered 14%.

P_2 is attached to the seven main parameters which is shown by the following equation.

$$P_2 = P_{2,1} + P_{2,2} - P_{2,3} + P_{2,4} + P_{2,5} - P_{2,6} - P_{2,7} \quad (11)$$

$P_{2,1}$ is equal to down payment (D) which is considered to be 20% in this model, P2, 2 is equal to Life cycle cost of the mortgage principal and interest to obtain below equation.

$$P_{2,2} = (1-D)\frac{PWF(n_{\min},0,d)}{PWF(n_L,0,d_m)} \quad (12)$$

In the above equation, parameter n_{min} is the characteristic years over which mortgage payment contributes to the analysis. Usually the minimum is n_e or n_L. The amount of interest rate is determined with the parameter d_m.

Income tax deductions of the interest is obtained the following equation:

$$P_{2,3} = (1-D)t_e\left\{PWF(n_{\min},d_m,d)\left[d_m - \frac{1}{PWF(n_L,0,d_m)}\right] + \frac{PWF(n_{\min},0,d)}{PWF(n_L,0,d_m)}\right\} \quad (13)$$

The amount of effective tax rating (t_e) in this model is equal to 30%.

$P_{2,4}$ parameters to gain Maintenance, insurance and parasitic energy costs is obtained in the equation 14.

$$P_{2,4} = (1-Ct_e)M_1 PWF(n_e,i,d) \quad (14)$$

M_1 parameter represents ratio of first year miscellaneous costs including parasitic power, insurance and maintenance. To specify Net property tax costs ($P_{2,5}$), t_p and V_1 parameters must be known. In this model, property tax rated base on assessed value (t_p) and ratio of assessed valuation of the system in first year to the initial investment in the system (V_1) respectively to be considered 300$ and 1.

$$P_{2,5} = t_p(1-t_e)V_1 PWF(n_e,i,d) \quad (15)$$

Year over which depreciation contributes to the analysis (n'_{min}) and depreciation lifetime in year parameters are used to determine the straight line depreciation tax deduction ($P_{2,6}$).

$$P_{2,6} = \frac{Ct_e}{n_d} PWF(n'_{\min},0,d) \quad (16)$$

The amount of present worth of resale value ($P_{2,7}$) can be obtained by blow equation.

$$P_{2,7} = \frac{R}{(1+d)^{n_e}} \quad (17)$$

In the above equation, R parameter represents ratio the resale value at end of period of analysis to initial investment. Amount of R parameter in Iran is 30%.

According to points raised and Iranian economy conditions and taking into account the useful life of 20 years, price to wind turbine for pump up water per cubic meter is equal to 0.13$.

2 Without considering Risk function

If the risk functions is not used, software results would be as follow:

TABLE 4. Results with Risk function

Consumed electricity scenario	Pumped water (x1)	Evacuated water for generating electricity(x2)	Evacuated water for agriculture & green spaces
LOW	24000m^3	16000m^3	8000m^3
NORMAL	24000m^3	20000m^3	4000m^3
HIGH	24000m^3	24000m^3	0m^3

With regard to the amount of pumped water in each demand scenario and produced electricity by water turbine and selling the surplus water of the pool for agriculture and irrigation of green spaces, profit will be according to the following.

TABLE 5. Profit under each scenario for wind turbine

Demand scenario	Wind generating power scenario											
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
LOW	4829	4802	4748	4694	4640	4586	4532	4478	4397	4370	4316	4289
NORMAL	6509	6482	6428	6374	6320	6266	6212	6158	6077	6050	5996	5969
HIGH	8189	8162	8108	8054	8000	7946	7892	7838	7757	7730	7676	7649

Considering total probabilities of the wind and electricity consumption and its product in each scenario, net profit in a day will be 6163$.

5.3 Considering Risk function

Now if risk function to be considered in this model and be included in the software, conclusion and profit computation would be more logical. Results of this model are as follow:

TABLE 6. Results with Risk function

Consumed electricity scenario	Pumped water(x1)	Evacuated water for generating electricity	Evacuated water for agriculture &green spaces(x1-x2)
LOW	16000m^3	16000m^3	0m^3
NORMAL	16000m^3	16000m^3	0m^3
HIGH	16000m^3	16000m^3	0m^3

As it is clear from the above table, when risk function is being considered, the amount of pumped water in each scenario equals with each other and with the amount of water that is evacuated for generating hydroelectric power. In this model, the whole amount of pumped water for generating hydroelectric power evacuates and there is not any water for selling to farmers and for irrigation of green spaces.

Regarding various β in this model, net profit is different. The more β, the more risk probability and consequently the less profit. Determining the exact quantity of β is dependent on the employer and the extent of risk in the model. With regard to this point, for different β net profit will be specified according to the following table:

TABLE 7. Daily net profit for different β

Row	1	2	3	4	5	6	7	8	9	10	11
β	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Net profit	6163	5979	5582	5429	5340	5278	5234	5198	5162	5131	5096

Regarding the fact that net profit is being calculated in the worst conditions e.i β=1 in the software, it is concluded that daily net profit in this method will be 5096$.

Conclusion

Today, in the modern industrial societies energy consumption in addition to having the risk of fossil resources ending has faced the world with irrevocable and threatening environmental changes. As the result of international programs and policies for the world sustainable development pay a particular attention to renewable resources. For example, EU has defined 12 percent of its needed electrical energy by new energies in its energy producing programs as a goal. In our country "Iran New Energies Organization" following the ministry of electricity policy making in energy affairs, has been responsible for dealing with this important issue since 1995. For the purpose of achieving the world's newest information and technology using of renewable energy resources, measuring capacity, implementation of various solar plans, wind and earth heat as well as hydrogen and bio copper have been included in the agenda.

Now considering this important issue in the country, models and projects should be presented that in addition to be profitable and refundable in a logical time can allocate an important part of generating renewable energies to itself. One of these projects is the model that has been described in details. In this model for providing renewable water and wind electricity jointly, in addition to two wind turbines, a pool for storing and generating water electricity has been used.

Regarding the presented model, it is clear that without considering the risk net daily profit causes investment refunds more quickly in about 4 years. In the second method when considering the risk function, investment will be refundable in less than 5 years. It should be noted that in the second method determination of β can be changeable dependent on the employer diagnosis and the type of project.

Observing the fact that the government supports investing in the field of generating renewable energy, in addition to the gained profit in this model because of high efficiency, promotes private sector to invest in this industry.

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