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Research Article

OPTIMIZATION OF HYBRID PV/WIND/FC SYSTEM CONSIDERING RELIABILITY INDICES USING CUCKOO SEARCH ALGORITHM

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ABSTRACT
In this paper, a hybrid system consisting of wind turbines, solar arrays and fuel cells including electrolyzer and hydrogen storage tank is designed to provide a particular load template. The purpose of designing is to minimize the 20 years costs of energy generation system considering the reliability indices. The system costs consist of capital cost, operation and maintenance cost, replacement cost especially loss of load cost. The considered reliability indices consist of loss of load expected, expected energy not supplied, loss of power supply probability and equivalent loss factor. In this study, the data related to load; solar radiation and definitive wind speed are considered and are related to the North West of Iran. It is assumed that between the system components, the forced outage probability of the main three components i.e. wind turbine, photovoltaic array and inverter is possible. The cuckoo search algorithm is used to optimize the hybrid system and the results were compared with the results presented in some earlier studies.The comparison of results shows that the proposed method in the optimization of the hybrid system has good performance so that the reliability is improved compared to previous studies.

Keywords: *Solar/Wind/Fuel Cell Hybrid System, Reliability/Cost Evaluation, Cuckoo Search Algorithm*

INTRODUCTION
All the attention has been paid to the use of renewable energy sources due to reduction in energy sources from fossil fuels, environmental concerns arising from non-renewable sources of energy, population growth, the process of industrialization and growing demand for energy (Anne-Marie, 2001). Use of renewable energy has grown substantially over the past decade. Many industrialized countries provide much of their required energy from renewable energy sources. The main distributed generation sources are based on the renewable energy i.e. solar array and wind turbines. These types of energy sources in recent years have become increasingly commercial development. Solar arrays and wind turbines convert the solar radiation energy and the wind speed, into electrical energy respectively and their energy levels varies due to weather conditions, including solar radiation and wind speed so that the energy generated by this source is unpredictable. The hybrid system consists of solar arrays and wind turbines are used to be largely appropriate for the load demand or supply network. In a hybrid system, by combining two or more sources,the predictability of generation is increased (Zhan *et al.,* 2012) and in fact, these resources cover their deficiencies to some extent. In the hybrid systems of generation, due to oscillations in solar radiation and wind speed and thereby generated power oscillations, the storage systems should be used to increase reliability and continuous supply of load (Billinton and Allan, 1994). Fuel cells and batteries can be noted as the storage systems that can be combined with solar arrays and wind turbines to compensate the power oscillations generated by solar arrays and wind turbines. The battery can only be a short term solution (Hedstrom *et al.,* 2004). On the other hand, a fuel cell is able to generate the controlled energy at various and long-term time intervals and can being an auxiliary source to increase the reliability of load supply along with solar and wind turbine (Dufo-López, 2008). In optimization of solar-wind hybrid systems the optimal sizing of system component is very important in hybrid system design. If the optimization is done correctly, the required reliability is achieved and power generation costs can be minimized and contestability of renewable energies is increased with other methods of energy generation.So farin previous studies,different systems in a hybrid system is used to generate power.Also several studies have

been done in the field of optimization of hybrid power generation system. In (Monai *et al.*, 2002) a hybrid system consists of solar arrays, fuel cell and SMES is used to supply the load. In (Nelson *et al.*, 2006) the determination of units sizing and analysis of hybrid cost of wind/solar/fuel cell has been done. The performance and sizing of solar array/wind turbine has been studied in (Kim *et al.*, 1997). Sizing of a wind turbine driven diesel generator has been optimized in (Garcia and Weisser, 2006). In (Yang *et al.*, 2008), the method has been proposed to determine the size of the solar-wind system with battery storage.
Optimization is done on the basis of two indicators of reliability and cost. In this study, the genetic algorithm is used to solve the optimization problem. In (Fatih *et al.*, 2009), the aim of study is to determine the optimal sizing of the system component under the minimal cost and desired reliability of load. In this study, a new optimization method is presented to determine the optimal sizing of the component. In (Ángel *et al.*, 2009), the effect of some parameters of size determination such as the sizing factorwhich represents the ratio of the energy generated by system to the energy demand in a solar-wind system with battery storage has been analyzed. In (Askarzadeh, 2013) the optimal design of a solar-wind hybrid system is presented.

The aim of this study was to determine the number of solar panels, wind turbines and batteries with a minimum cost of the system.Discrete optimization technique has been used to solve the optimization problem. In (Subhadarshi and Ajjarapu, 2011) a possible way for a solar-wind hybrid system is used. The wind model is modeled by considering the weather information and wind turbine system has been modeled by considering the wind output. Then a suitable model is presented for optimal use of 2 systems to supply the energy in the most efficient mode.

In (Koutroulis, 2003) a genetic algorithm is used to find the angle of the solar panel installation and to get the maximum energy from the sun.

In (Leva and Zaninelli, 2009), the hybrid diesel/wind/photovoltaic generation systems which supply a power load with high distance is introduced by considering the benefits of renewable energy from an economic standpoint. In (Kashefi *et al.*, 2009), minimizing the power generation cost of solar-wind-fuel cell hybrid system is studied by considering the reliability indices and reliability constraints.

In (Dehghan *et al.*, 2009) the optimization of solar-wind-fuel cell system with the objective of minimizing system cost is presented by considering thereliability constraints using particle swarm algorithm (PSO) and the harmony search algorithm (HS).

In (Abedi *et al.*, 2011), the evolutionary differential algorithm and in (Arabi-Nowdeh *et al.*, 2014), hunting search algorithm is used to optimize the sizing of solar-wind-fuel cell system component considering the cost and reliability indices.

In this paper, in section two, mathematical modeling of solar-wind-fuel cell hybrid system and its components are presented. In section 3, the ratio of reliability to system cost and reliability indices presentation and the formulation of the expectation of the energy generated by system, is evaluated.In section 4, optimization problem is introduced and the objective function of the optimization problem is presented with constraints. Also in this section, the cuckoo optimization algorithm is discussed. In Section 5, the simulation results are given and in section 6, the conclusion is presented.

Modeling of Studied System

In this paper, a hybrid system consisting of solar arrays, wind turbines and fuel cell (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011) is designed to supply a stand-alone load. The fuel cell is used as a storage system due to oscillations of power generated by the solar array and wind turbine and for continuous supply of system load.Fuel cell system includes an electrolyzer and a hydrogen storage tank as the storage of hydrogen. The studied system component is including solar arrays, wind turbines, electrolyzer, hydrogen storage tank, fuel cell and inverter. The hybrid system includes a DC bus bar and an AC bus bar.Hybrid system under study is shown in Figure 1.

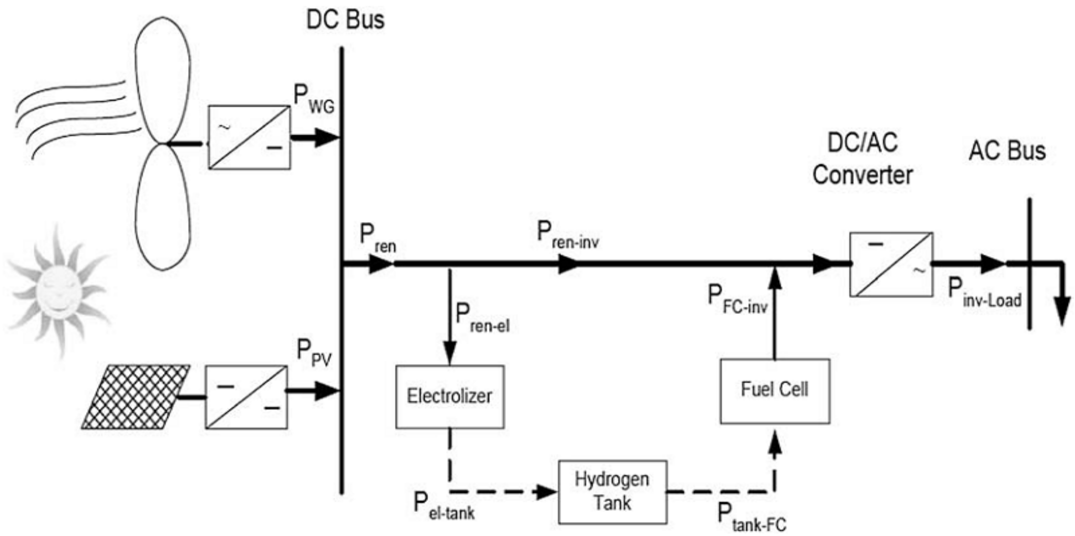

Figure 1: Hybrid solar-wind-fuel cell system (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011)

In the hybrid system of Figure 1, when the total energy generated by renewable sources is equal to the load demand, in this conditions, the total power generated by the solar arrays and wind turbines is delivered through the inverter to the load. In conditions that the total energy generated by renewable sources is larger than the load demand, in these conditions, the excess power generated by solar arrays and wind turbinesis injected intoelectrolyzer to produce the hydrogen. When the total energy generated by renewable sources is less than the load demand, in these conditions, the load power shortage can be compensated by fuel cell.If the fuel cell is not able to compensate the power shortage, In this case, an amount of the load is disconnectedi.e. the fraction of load is lost.

2.1 Solar Array

The power generated by the solar array is obtained by following equation in terms of the intensity of radiation emitted by the array surface(Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011; Arabi-Nowdeh *et al.*, 2013):

$$P_{PV} = \frac{G}{1000} \times P_{PV,rated} \times \eta_{PV,conv} \tag{1}$$

$$G(t,\theta_{PV}) = G_V(t) \times \cos(\theta_{PV}) + G_H(t) \times \sin(\theta_{PV}) \tag{2}$$

In the above equations, P_{PV} represents the output of the solar array, G is radiation power perpendicular to the array surface [volt/m^2] in the t-th time step, $P_{PV,rated}$ is rated power of each array which is obtained for $G = 1000\,W/m^2$, $\eta_{PV,conv}$ is the efficiency of DC/DC converter between each array and DC bus bar. $G_H(t)$ and $G_V(t)$ respectively represent the horizontal and vertical solar radiation intensity.In this study, in order to achieve maximum output power of the solar array,it is assumed that the solar tracking system was used.Output voltage of this system is equal to the 48 V and is connected to the DC bus.

2.2 Wind Turbine

The turbine used in this study is BWC Excel-R / 48 (Khan and Iqbal, 2005). Wind turbine output power curve provided by the manufacturer is shown by Figure 2 which represents the real powertransferred from the turbine to the DC bus bar.Its output voltage is equal to 48 volts DC.

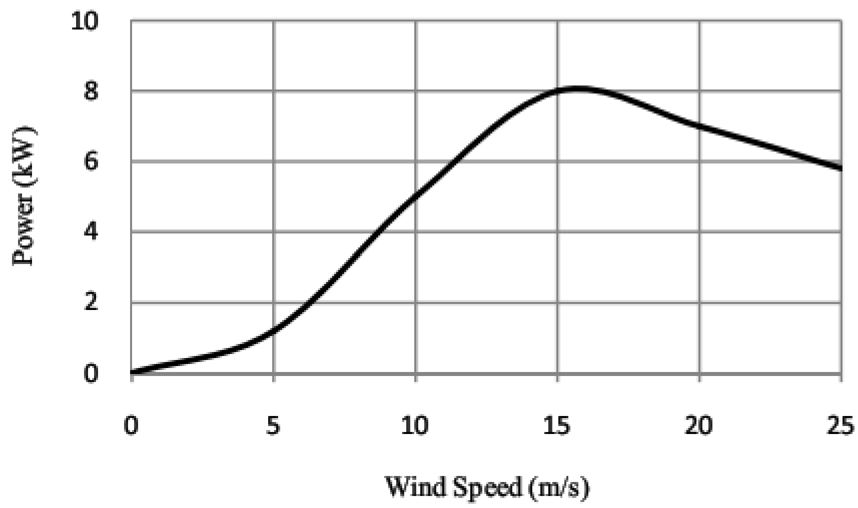

Figure 2: The wind turbine output power of model BWC Excel-R/48in terms of wind speed (Khan and Iqbal, 2005)

Wind turbine output power versus wind speed is expressed as follows (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$P_{WG}=\begin{cases}0 & ;v_W\le v_{cut\,in},v_W\ge v_{cut\,out}\\ P_{WG,\max}\times\left(\dfrac{v_W-v_{cut\,in}}{v_{rated}-v_{cut\,in}}\right)^m & ;v_{cut\,in}\le v_W\le v_{rated}\\ P_{WG,\max}+\\ \dfrac{P_{furl}-P_{WG,\max}}{v_{cut\,out}-v_{rated}}\times\left(v_W-v_{rated}\right) & ;v_{rated}\le v_W\le v_{furl}\end{cases}\tag{3}$$

In the above equation, P_{WG} is output power of wind turbine, v_W is wind speed, $v_{cut\,in}$ is down cut speed, $v_{cut\,out}$ is high cut speed [m/s], $P_{WG,\max}$ is maximum turbine output power [KW] and P_{furl} is output power in high cut speed.

Since the data of wind speed at a height of 40 meters have been sampled,and turbine installation height of 15 m is used in this study, wind speed at this height can be calculated from the following equation (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$v_W^h=v_W^{ref}\times\left(\frac{h}{h_{ref}}\right)^\alpha\tag{4}$$

In above equation, v_W^h is the wind speed in height h, v_W^{ref} is the wind speed in reference height h_{ref} in terms of [m/s] and α is anarrow in the above equationand is a number between0.14-0.25 (Yang *et al.*, 2008).

2.3 Total Generation Power of Renewable Sources

The total generation powers of solar arrays and wind turbinesindicates the amount of power generated by renewable units. Assuming that the number of solar arrays and wind turbines respectively is N_{PV} and N_{WG} , the power generated by all renewable units delivered to the DC busis calculated from the following equation (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$P_{ren} = N_{WG}.P_{WG} + N_{PV}.P_{PV} \quad (5)$$

Planned or emergency exit of renewableunits that may be created for various reasons, such as failure,should be applied in hybrid system design problem to evaluate the system reliability calculations. If the number n_{PV}^{fail} ofsolar array and the number n_{WG}^{fail} of wind turbine are exited from the system,in this case, the total power generated by renewable units can be obtained as follows (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$P_{ren}\left(n_{WG}^{fail}, n_{PV}^{fail}\right) = \left(N_{WG} - n_{WG}^{fail}\right) \times P_{WG} + \left(N_{PV} - n_{PV}^{fail}\right) \times P_{PV} \quad (6)$$

2.4 Electrolyzer

Electrolyzer is a device that produces hydrogen and oxygen from The decomposition of water by electrolysis process.Using electric current passing between two electrodes placed in the water and its degradation,hydrogen and oxygen are derived. Electrolyzer output power can be obtained from the following equation (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$P_{el-tank} = P_{ren-el} \times \eta_{el} \quad (7)$$

In the above equation η_{el} is the electrolyzer efficiency and P_{ren-el} is the power injected by renewable sources into electrolyzer.

2.5 Hydrogen Storage Tank

The task of the tank is the storage of hydrogen received from pressurized electrolyzer.The energy stored in the tank for each time step t is defined as follows:

$$E_{tank}(t) = E_{tank}(t-1) + P_{el-tank}(t) \times \Delta t - P_{tank-FC}(t) \times \Delta t \times \eta_{storage} \quad (8)$$

Δt is length of each time step equal to one hour and $\eta_{storage}$ is storage system efficiency.Mass of hydrogen stored in the tank is calculated from the following equation:

$$m_{storage}(t) = \frac{E_{storage}(t)}{HHV_{H_2}} \quad (9)$$

HHV_{H_2} Indicates a high heating value of hydrogen which its value is equal to 39.7 kWh per Kg (Strunz and Brock, 2006). The minimum and maximum hydrogen tank amount is as follows:

$$E_{\tan k,\min} \le E_{\tan k}(t) \le E_{\tan k,\max} \quad (11)$$

2.6 Fuel Cell

The fuel cell generates the electrical energy with reception of hydrogen. In this study the polymer membrane fuel cell is used because of high reliability.Polymer membrane fuel cell has fast dynamic response about 1 to 3 seconds.Polymer membrane fuel cell output power is obtained as follows(Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$P_{FC-inv} = P_{tank-FC} \times \eta_{FC} \quad (11)$$

In the above equation η_{FC} expresses the fuel cell efficiency.

2.7 Inverter

The inverter in studied system converts the DC power to AC and transfers it to the load. The relation of power transferred to the load is defined as follows:

$$P_{inv-load} = \left(P_{FC-inv} + P_{ren-inv}\right) \times \eta_{inv} \quad (12)$$

In the above equation η_{inv} indicates inverter efficiency.

Evaluation of Reliability/Cost

The studied system is simulated during one year and with time steps of one hour and ratio of reliability to cost evaluation is done.Then with the economic factors, the results is developed for the 20-years useful life of the system. In this study, the load growth, uncertainly of load, solar radiation and wind speed are neglected.

3.1ReliabilityIndices

In this section, a number of different reliability indices which have been used in some studies are presented to evaluate the studied system reliability in load supply of system (Xu *et al.*, 2006; Bagen and Billinton, 2005; Karki and Billinton, 2001). The considered indices include Loss of Load Expected (LOLE), Loss of Energy Expected (LOEE), Expected Energy not Supplied (EENS), Loss of Power Supply Probability (LPSP) and Equivalent Loss Factor (ELF).

$$LOLE = \sum_{t=1}^{N} E\left[LOL(t)\right] \tag{13}$$

In the above equation, $E[LOL(t)]$ indicates the loss of the load expected in time step t and can be calculated from following equation:

$$E\left[LOL\right] = \sum_{s\in S} T_s \times P_s \tag{14}$$

In the above equation, T_s indicates the time of loss of load, P_s is probability of being in state s and S is the all possible states of the system under study.

$$LOEE = EENS = \sum_{t=1}^{N} E\left[LOE(t)\right] \tag{15}$$

In the above equation, $E[LOE(t)]$ is the Expectation of lost load in time t and is obtained as follows:

$$E\left[LOE\right] = \sum_{s\in S} Q_s \times P_s \tag{16}$$

In the above equation, Q_s is the amount of lost load per kilowatt-hour in S state. Loss of Power Supply Probability and probability of load supply inability is obtained as follows:

$$LPSP = \frac{LOEE}{\sum_{t=1}^{N} D(t)} \tag{17}$$

$D(t)$ indicates the required power of load per KWh in time t.

Equivalent Loss Factor is calculated as follows:

$$ELF = \frac{1}{N}\sum_{t=1}^{N}\frac{Q(t)}{D(t)} \tag{18}$$

3.2 Calculation of Expectation of Energy Generated By Renewable Sources

In this study, according to (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011),the average amount of solar arrays and wind turbines output power instead of considering the exit of each of solar and wind unitsis used as follows to calculate the expectation of reliability indices:

$$E\left[P_{ren}\right] = \sum_{s\in S} P_{ren}(s) \times f_p(s) \tag{19}$$

In the above equation, $f_p(s)$ indicates being in the position S and $P_{ren}(s)$ indicates the power injected into DC bus which is generated by solar and wind renewable units.Since the power is transferred to the load through the inverter, so the probability of its exit should be considered. So the exit probability of solar-wind-inverter units is obtained as follows (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$f_{hybridsystem}(n_{WG}^{fail}, n_{PV}^{fail}, n_{inv}^{fail}) = f_{ren}(n_{WG}^{fail}, n_{PV}^{fail}) \times A_{inv}^{N_{inv}-n_{inv}^{fail}} \times \left(1 - A_{inv}\right)^{n_{inv}^{fail}} \quad (20)$$

In the above equation, A_{inv} is the inverter availability. According to equation (6) and the exit probability of solar-wind units, Expectation of energy generated by renewable units is obtained by following equation (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$E[P_{ren}] = \sum_{n_{WG}^{fail}}^{N_{WG}} \sum_{n_{PV}^{fail}}^{N_{PV}} \left\{ P_{ren}\left(n_{WG}^{fail}, n_{PV}^{fail}\right) \times P_p\left(n_{WG}^{fail}, n_{PV}^{fail}\right) \right\} \quad (21)$$

So the model of energy generated by system from renewable sources is defined as follows considering their availability according to (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$E[P_{ren}] = N_{PV} \times P_{PV} \times A_{PV} + N_{WT} \times P_{WT} \times A_{WT} \quad (22)$$

In the above equation, A_{PV} and A_{WT} indicate the solar and wind availability respectively. Availability of components is defined as follows (Kashefi *et al.*, 2009):

$$A_{com} = \frac{\mu_{com}}{\mu_{com} + \lambda_{com}} \quad (23)$$

In the above equation, μ_{com} and λ_{com} are the rates of the maintenance and component failure.

Optimization Problem

The objective of this paper is the optimal sizing of system component including the number of wind turbines, solar arrays, angle of installation of solar arrays, electrolyzer capacitance, hydrogen tank, fuel cell and inverter with minimizing the system energy generation costs.

Objective Function

Net present cost of component of i hybrid system can be obtained as follows (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011):

$$NPC_i = N_i \times \left(CC_i + RC_i \times K + O\&MC_i \times PWA\right) \quad (24)$$

In the above equation, N represents the number of unit or size of component per kWh or kg, *CC* represents the initial investment cost in dollars per unit, RC indicates the cost of each replacement in terms of dollars per unit, *O& MC* annual maintenance cost in dollars per unit per yearand R is the 20 year project life. *Ir* is real interest based on the nominal interest $ir_{nominal}$ and the annual inflation rate (*f*) is obtained as follows:

$$ir = \frac{ir_{nominal} - f}{1 + f} \quad (26)$$

In the above equation, *PWA*represents the present value factor of annual paymentsand K is a constant.Their relation is as follows:

$$PWA(ir, R) = \frac{(1+ir)^R - 1}{ir(1+ir)^R} \quad (26)$$

$$K_i = \sum_{n=1}^{y_i} \frac{1}{(1+ir)^{n.L_i}} \quad (27)$$

In the above equations y represents the number of replacementsand *L* is the length of the life time of the components.Net present value of the loss of load is calculated as follows:

$$NPC_{loss} = LOEE \times C_{loss} \times PWA \tag{28}$$

In the above equation C_{loss} represents the cost of loss of load for each KWh load in terms of dollar per KWh.Theobjective function optimization problem is expressed as follows:

$$J = \min_X \left\{ \sum_i NPC_i + NPC_{loss} \right\} \tag{29}$$

In the above equation, *i*indicates the component (the studied system component) and X is a vector with seven variables of optimization problem including a number of wind turbine, solar arrays, and angle of installation of solar array, electrolyzer capacitance, hydrogen tank, fuel cell and inverter.

Problem Constraints

In solving the optimization problem with the objective function of (29) the following constraints should be considered:

$$E\left[ELF\right] \le ELF_{\max} \tag{30}$$

$$0 \le N_i \tag{31}$$

$$0 \le \theta_{PV} \le \pi/2 \tag{32}$$

$$E_{tank}(0) \le E_{tank}(8760) \tag{33}$$

In the above constraints, θ_{PV} represents the angle of installation of solar arrays.Constraint of equation (31) shows that the number of solar arrays must be a positive integer.Constraint of equation (32) indicates thatthe angle of the solar arrays toward the sunmust be between zero and 90 degrees.Constraint of equation (33) shows that at the start of the program its energy should be higher than the initial energy of tank.

Cuckoo Optimization Algorithm

Cuckoo optimization algorithm is one of the newest and most powerful evolutionary optimization methods which have been introduced.This algorithm is inspired by the life of a bird called cuckoo which by (Rajabioun, 2011; Yang and Deb, 2009), has been developed.Cuckoo algorithm is based on the life of one type of cuckoo.This algorithm has been developed by flying levy instead of isotropic random walk.Later in the year 2011 by Rajbiyoun cuckoo algorithm (Rajabioun, 2011) is fully examined in more detail. All kinds of 9000 birds in the world have the same way to be a mother. They all lay eggs. No birds do not wastetheirinfant.But they laid eggs and their chicks grows up outside of the body. In between, some of the birds are free from any other trouble nesting and parental responsibilities and resorted to a smartly to feed their chicks.

These birds are called "child parasites "That do not build their own nests and lay their eggs in the nests of other birds and wait until they take care of the eggs of these birds along with their eggs. The cuckoo is the most famous of child parasite that is an expert in cruel deception. Like other evolutionary algorithms Cuckoo's work begins with an initial population. Population of cuckoos have a number of eggs that put eggs in the nests of host birds.Some of the eggs that are more similar to the host bird's eggs have more chance to grow and become an adult cuckoo. Other eggs were identified and destroyed by the host bird. The amount of grown eggs demonstrate the suitability of nests of those area.If the eggs are more capable to live in an area and be saved more profit is equally allocated to that region. So the situation in which the highest number of eggs to be saved will be a parameter which COA plans to optimize it. It is necessary to solve an optimization problem that the values of the problem variables are formed as an array form. In the Cuckoo Optimization Algorithm the name of this array is habitat (Rajabioun, 2011; Yang and Deb, 2009).

$$Habitat = \left[X_1, X_2, ..., X_{N\text{var}}\right] \tag{34}$$

In an optimization problem of N_{var} dimensions, a habitat will be an $1\times N_{\text{var}}$ array which indicates the current position of cuckoos.This array is defined as follows:
The amount of ratio of being (or profit amount) in current habitat is obtained by evaluating the profit function of f_p in habitat (Rajabioun, 2011; Yang and Deb, 2009). So

$$\text{Pr}ofit = f_p(habitat) = f_p(X_1, X_2, ..., X_{N\text{var}}) \quad (35)$$

COA is an algorithm that provides the maximum benefit. To use the COA to solve the problem of minimization, it is sufficient to multiply a negative sign in the cost function. To start the optimization algorithm, a habitat matrix is produced. A random number of egg is allocated for each habitat. Each cuckoo lays eggs in nature between 5 and 20.These numbers as upper and lower limits allocated to each cuckoo eggs are used in different iterations. Another habit of a real cuckoo is that they lay their eggs in a specific domain that the Egg Laying Radius can be defined using these limits.ELR is proportional to the total number of eggs, the current eggs of the cuckoo and upper and lower limits of problem variables. The ELR is defined as follows (Rajabioun, 2011; Yang and Deb, 2009):

$$ELR = \alpha \times \frac{number \quad ofcurrent \quad cuckoo's \quad eggs}{total \quad number \quad of \quad eggs} \times (Var_{hi} - Var_{low}) \quad (36)$$

α is a variable that the maximum value of ELA is set by it. The cuckoo puts its eggs in the nests of host birds that are in their ELR (see Figure 3-14). When cuckoos put all their eggs, some of the eggs that are less like to host bird's eggs, are identified and Kicked out of the nest.So after each laying, P% of all eggs (Usually 10%) that their profit function is less, are destroyed. Other chickens are fed and grow in host nests. When the cuckoo chicks grew and matured while they live in their environments and groups but when it is near the time of egg laying, migrate to better habitat where there is greater chance to survive the eggs. After forming Cuckoo groups in different areas of biology (The problem search space), Group with the best position is selected as the target point for other cuckoos to migrate. Although it is difficult each Cuckoo belongs to which group. To solve this problem, Cuckoos Grouping is done by k-means classification method. A k is between 3 to 5 normally is sufficient. However, the Cuckoo groups were formed, average profit of group is calculated to obtain the relative optimality of the habitat of that group can be obtained. Then the group with the highest average amount of profit (optimality) is selected as the target group and other groups migrate towards it.

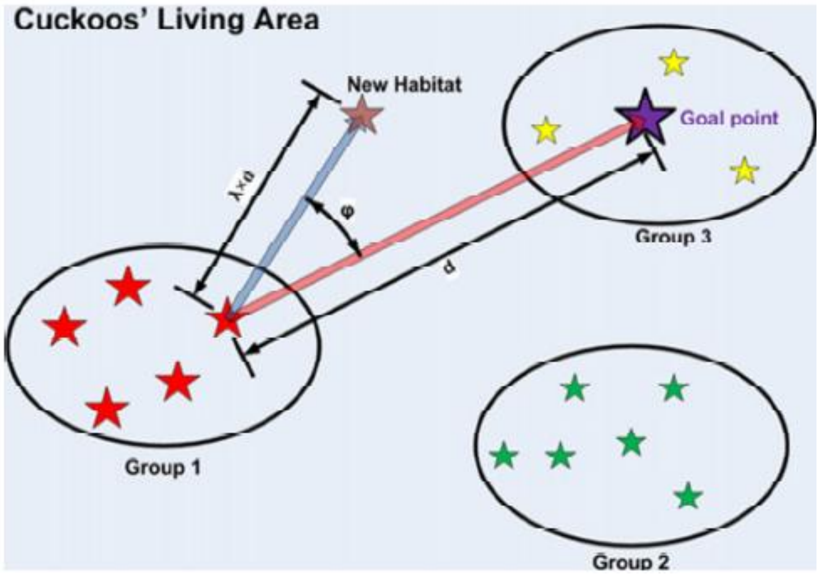

Figure 3: Cuckoo migrate towards the target habitat

When cuckoos migrate to the target point, they don't travel all the way to the target site. During a part of route, they have a deviation from path. This type of movement can be seen in Figure 3 clearly. As is clear from the figure, each cuckoo has one path to current ideal targetand there is a deviation of φ radians.These two parameters helps cuckoos to search more environment.Random number between 0 and 1, and φ is a number between π /6 and-π /6 respectively. When all the cuckoos migrated to the target point, and new residential areas of each cuckoo were identified, each cuckoo has a number of eggs. According to the number of eggs of each cuckoo, an ELR is determined for it and then egg laying begins. Migration operator formulation of the Cuckoo optimization algorithm is as following equation:

$$X_{NextHabitat} = X_{currenttHabitat} + F(X_{Goalpoint} - X_{currentHabitatt}) \quad (37)$$

After a few iterations, all of cuckoos arrive to an optimum point with maximal similarity to the host bird's eggs and also arrive to point with highest food sources. This site will have the greatest overall benefit and the minimum number of eggs will be destroyed. The main steps of COA can be expressed as follows:

Step 1: determine randomly the cuckoo's current habitat.
Step 2: Assign a number of eggs to each cuckoo.
Step 3: determine egg laying Radius of each cuckoo.
Step 4: cuckoos lay eggs within nest of hosts which are in their egg laying radius.
Step 5: a number of eggs which are identified by the host, are destroyed.
Step 6: Cuckoo eggs that have not been identified are grown
Step 7: evaluate the new cuckoo's habitat
Step 8: determine the maximum number of cuckoos which have any place to live and eliminate those that are in the wrong habitats.
Step 9:Cluster the cuckoos using the K-means method and specify best group of cuckoos as the objective habitat.
Step 10:New Cuckoo's population is moving toward the target habitat.
Step 11: If the stopping conditionis satisfied, stop, otherwise go to step 2.

Simulation Results

System Data

The system data consists of annual radiation and wind information related to one of the areas of the North West of Iran which is extracted with accuracy of one sample per hour (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011). Annual wind speed curves at a height of 15 meters and horizontal and vertical radiation curves, respectively are shown in Figures 4 to 7.The annual load curve which is the same curve of IEEE standard load with a peak 50kW (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011), is presented by figure 7. In Table 1, the amounts of parameters of various system components are provided.Conditions assumed for the studied system includes loss of load cost, load peak, load template, ELF, Real interest rate and system life that are presented by Table 2. According to the Table 2, the loss of load cost in studied system is considered 5.6 US*$/kWh* (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011).

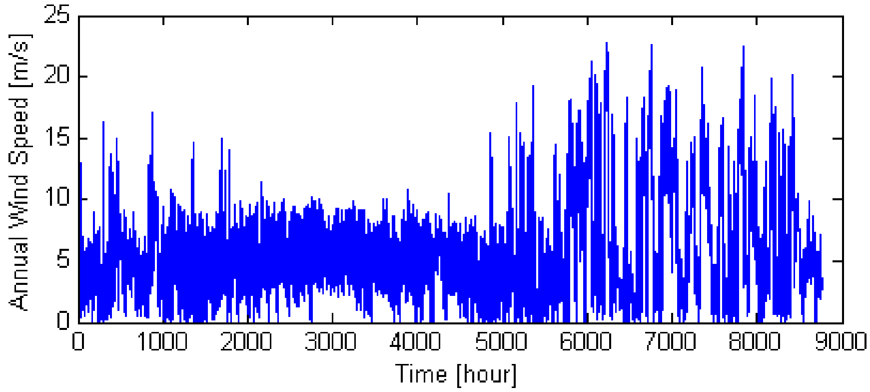

Figure 4: The annual wind speed at the height of 15 meters ina year

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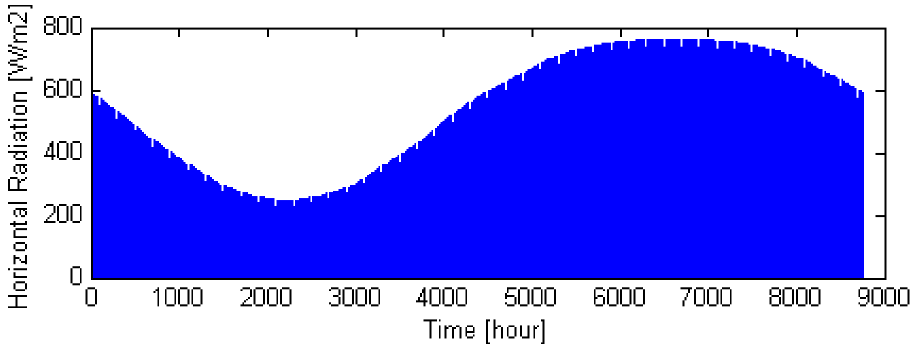

Figure 5: Horizontal solar radiation intensity on the array surface in a year

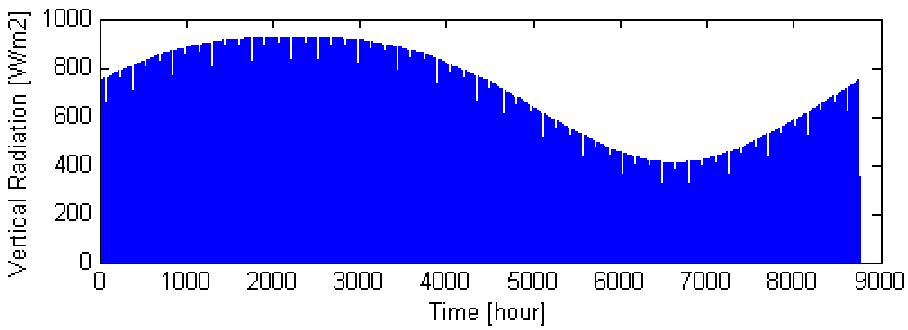

Figure 6: Vertical solar radiation intensity on the array surface in a year

Table 1: The Rated Parameters of the Studied System Component (Kashefi *et al*., 2009; Dehghan *et al*., 2009; Abedi *et al*., 2011)

Device	Investment Cost (US$/unit)	Replacement Cost (US$/unit)	Maintenance and Repair Cost (US$/unit-yr)	Efficiency (%)	Lifetime (Year)
Wind Turbine	19400	15000	75	-	20
PV Array	7000	6000	20	-	20
Electrolyzer	2000	1500	25	75	20
Hydrogen Tank	1300	1200	15	95	20
Fuel Cell	3000	2500	175	50	5
ConverterDC/AC	800	750	8	90	15

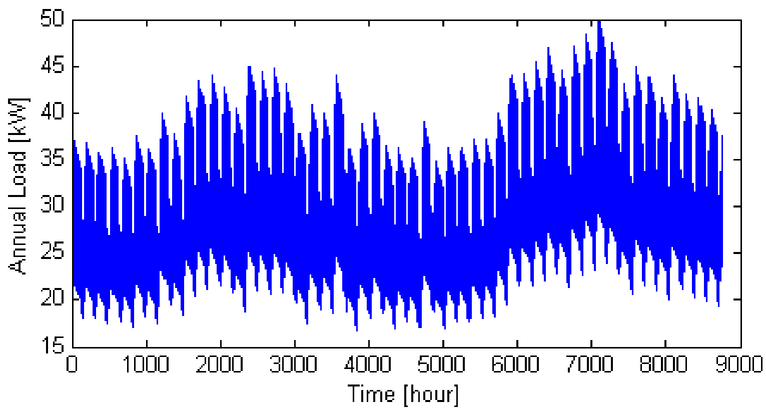

Figure 7: The IEEE annual load curve with a peak of 50 kW

Table 2: The Assumed Conditions for Studied System (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011)

System Lifetime	Real Interest Rate	ELF_{max}	Load Pattern	Peak Load	Load Curtailment Cost
20 Years	6%	0.01	IEEE RTS	kW50	5.6 US$/kWh

The Simulation Results

In this section the results of the optimization of the hybrid system are presented by Table 1 using cuckoo optimization algorithms and for the nominal parameters of the system component. The simulation is done by the computer with Pentium IV, CPU with 3.2 GHz, 512 MB RAM.Number of algorithm iterations, has been considered 200 iterations.Decision variables in the proposed optimization method consists of the number of solar arrays, the number of wind turbines, electrolyzer power, mass of tank hydrogen, fuel cell power, inverter power and The angle of the solar arrays toward the sun.Cuckoo algorithm parameters are presented in Table 3.The convergence curve of the algorithm to solvethe optimization problem is shown in Figure 8.The results obtained in this paper are compared with optimization results of the system studied in (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011). The results comparison consists of optimal combination or optimal sizing of the studied hybrid system component which is presented by Table 4. Comparison between the results indicates that the cuckoo optimization methods has presented the proper results such as references (Kashefi *et al.*, 2009; Dehghan *et al.*, 2009; Abedi *et al.*, 2011) which have used respectively the PSO, the HS method and the evolutionary differential algorithm. The power generated by renewable sources including total powers generated by wind turbines and solar arrays is shown by Figure 9 during a year. Expectation of the energy stored in the hydrogen tank in a year is shown by Figure 10.

Table 3: The Cuckoo Search Algorithm Parameters to Solve the Optimization Problem

COA Parameters	Value
Cuckoo Numbers	7
Min number of per cuckoo eggs	2
Max number of per cuckoo eggs	4
Max iteration	200
Motion coefficient	9
Cluster numbers	1
Convergence radius	5

Table 4: The Optimal Combination or Optimal Sizing of the Studied Hybrid System Component

Parameter	θ_{PV}	P_{inv}	P_{FC}	M_{tank}	P_{el}	N_{PV}	N_{WG}
COA	**33.14**	**47.59**	**42.03**	**174.178**	**118.93**	**215**	**11**
PSO (Kashefi *et al.*, 2009)	34.129	46.725	43.431	144.19	119.44	224	8
PSO/HS (Dehghan *et al.*, 2009)	33.12	45.72	43.42	143.24	119.44	223	8
DE (Abedi *et al.*, 2011)	34.1	46.7	43.4	144.2	119.4	224	8

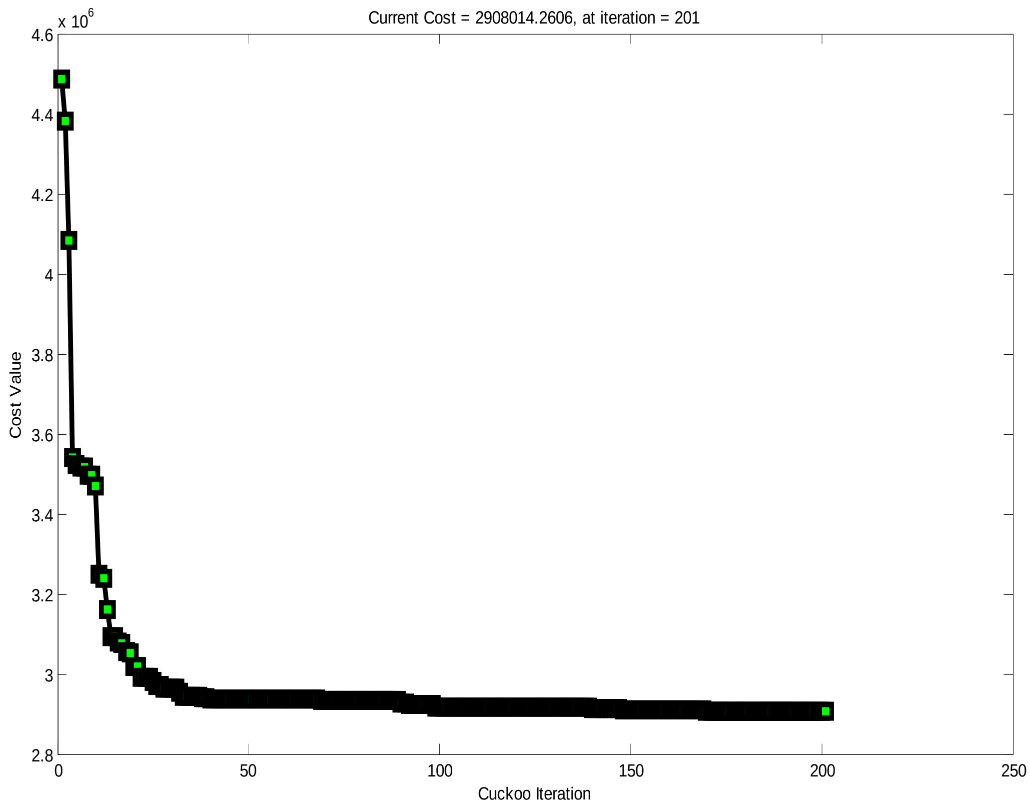

Figure 8: Convergence curve of Cuckoo search algorithm based on its iterations in solving the optimization problem

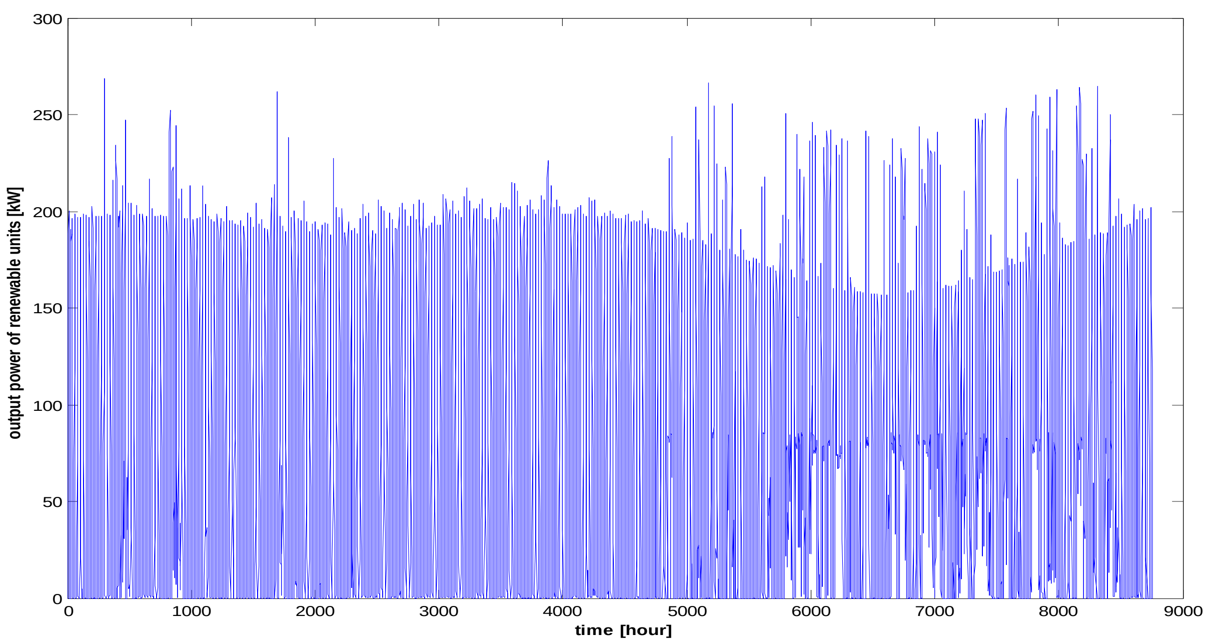

Figure 9: The power generated by renewable sources in a year

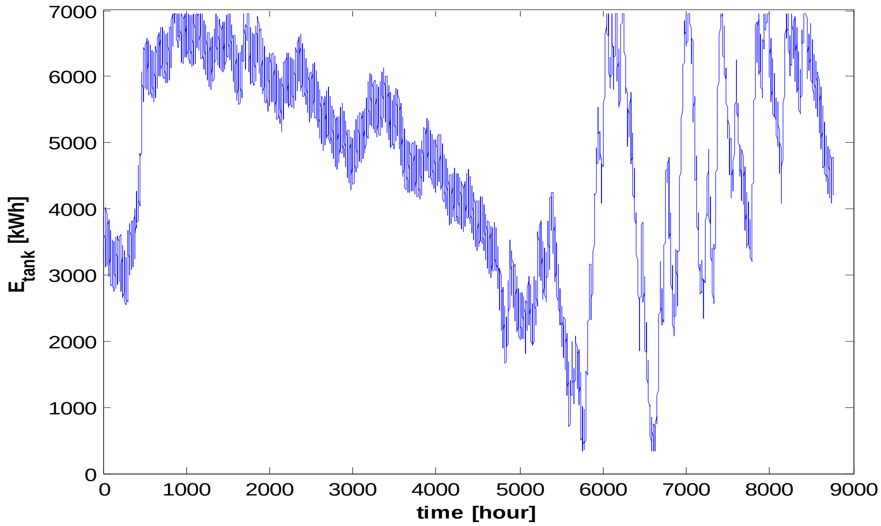

Figure 10: Expectation of the energy stored in the hydrogen tank in a year

The mean of net present cost of energy generation, is the present value of costs done over the 20 year life of the system, for the construction, replacement and maintenance of generator units, the storage system and inverter and the loss of load cost is equal tothe present value of the costs of loss of customers load.To expressly, thenet present cost of generation is the same $\sum_i NPC_i$ and the net present cost of loss of load is the same NPC_{loss}.The results of the optimization including the system costs and reliability indices are presented in Table 5. By observing the results and compare them to other authorities it is clear thatthe results of the proposed optimization method is suitable results.Expected Energy not Supplied, the ELF and LOLEin a year are shown by Figure 11.

Table 5: The Amounts of Cost and Reliability Indices of Hybrid System

Parameter	*LOLE* (**hr/yr**)	*LPSP*	*LOEE*)**MWh/yr**(	*ELF*	(**MUS$**) NPC_{loss}	**Investment Cost** (**MUS$**)	$\sum_i NPC_i$ (**MUS$**)
COA	**333.24**	**0.0078**	**2.1**	**0.0068**	**0.135**	**2.65**	**2.9**
PSO (Kashefi *et al.*, 2009)	333.27	0.0087	2.35	0.0082	0.137	2.321	2.5
PSO/HS (Dehghan *et al.*, 2009)	335.85	0.0092	2.34	0.0067	0.143	2.312	2.634
DE (Abedi *et al.*, 2011)	336	0.009	2.4	0.008	0.15	2.3	2.7

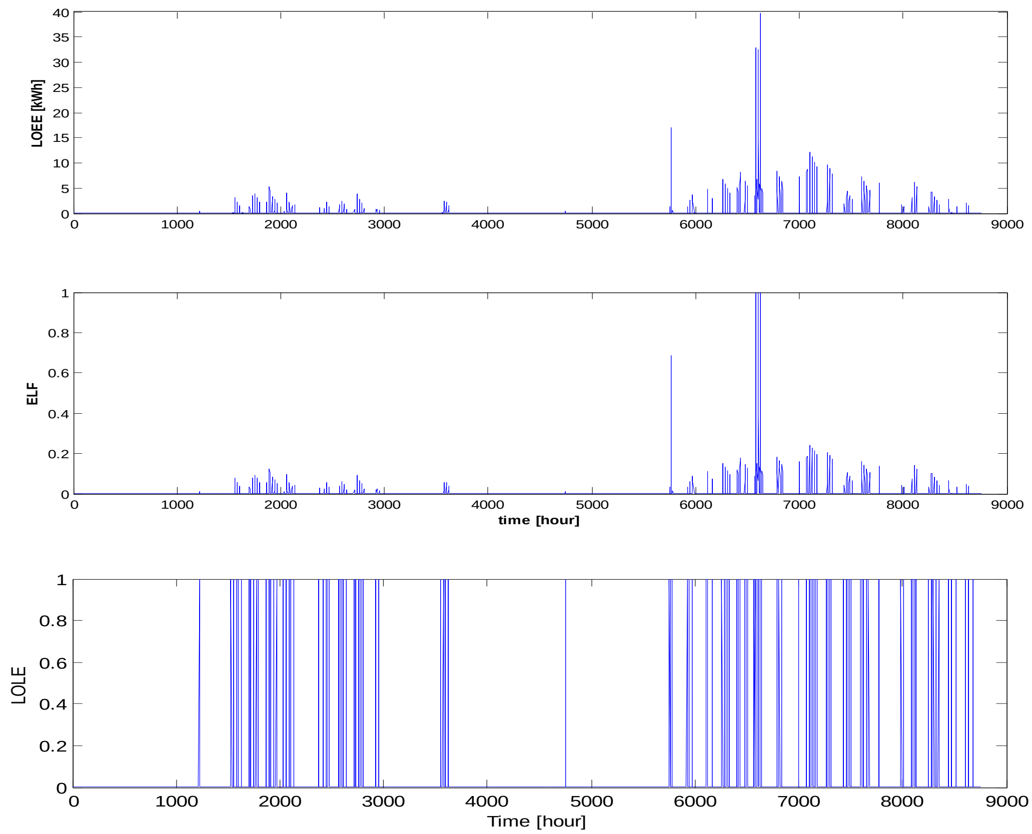

Figure 11: Expected Energy not Supplied, the ELF and LOLE in a year

CONCLUSION

In this paper a method is presented to determine the optimal sizing of wind-solar-fuel cell hybrid system considering the reliability indices. The wind-solar-fuel cell hybrid system is designed and optimized by the cuckoo search algorithm with the aim of minimizing the system energy generation costs including the costs of net present value of the investment,maintenance and replacement of component and also the costs of load not supplied during the 20 years of system useful life.Software is developed in Matlab environment. The evaluation of hybrid system reliability/cost is done in one year with time steps of one hour. In the system optimization process with the proposed algorithm, the number of wind turbines, the number and angle of installation of solar arrays, electrolyzer capacitance, hydrogen storage tank, fuel cell and inverter and as a result, the amounts of costs and reliability are obtained. According to the results, it was observed that the amount of obtained ELF is as the reliability constraint at optimal point and is obtained less than its maximum value and this is a proof of the better optimization of system. By comparing the results, it was determined that performance of the proposed method is desirable compared to performed optimization methods. Thus, the system costs are slightly increased but reliability indices are improved. The proposed system with a higher reliability than the other performed methods is able to sell its generated energy in the power market with higher costs.

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