INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Farshid Mostofi et al., Vol.3, No.4, 2013

Application of ABC Algorithm for Grid-Independent Hybrid Hydro/Photovoltaic/Wind/Fuel Cell Power Generation System Considering Cost and Reliability

Farshid Mostofi*‡, Masoud Safavi**

* Young Researchers and Elite Club, Ardabil Branch, Islamic Azad University, Ardabil, Iran

** Department of Electrical Engineering, Ardabil branch, Islamic Azad University, Ardabil, Iran

(fmos2fi@gmail.com; masoudsafawi@gmail.com)

‡ Corresponding Author; Farshid Mostofi, Young Researchers and Elite Club, Ardabil Branch, Islamic Azad University, Ardabil, Iran, Tel: +98 914 705 0846, fmos2fi@gmail.com

Received: 31.10.2013 Accepted: 14.12.2013

Abstract- This paper is purposed to investigate minimization of overall expenditure of combinatorial self-determining power plant. This preferred complex based on hydrogen storage demanded by electrical capacitors posited in SABALAN dam powerhouse due to local agricultural irrigations include small hydropower units, photovoltaic systems and wind turbines. Systems durability in considerate of reliability computation is estimated approximately 20 years. Genuinely, all intact respective data, such as floodgate outlet water Debi, sunlight and puff intensity from the nearest local weather station and SUNA (Iran naval energy organization), because of utilize in the simulation have been perfectly collected. Therefore, comparison of combinatorial (Hydro, PV, Wind, Fuel Cell) plant with mentioned system without considering the hydropower plant has been studied. Costs of plant fabrication, reliability betterment of entire system and also output-energy expenditure that are economic priorities of affix the hydropower plant to the combinatorial system have been perused. Accordingly, it has been used by a trustable proximate pattern to modify the effect-time of referred system. And also to attain an accurate optimized system capacity, Artificial Bee Colony (ABC) has been preferred. In addition to purpose of confide the validation and accuracy, the obtained results by ABC algorithm has been compared with the results in PSO (particle swarm optimization) which obtained by HOMER software. With good judgment, consequences evaluation testified precision and highly efficiency of ABC to determine the optimum capacity of combinatorial system.

Keywords: Hybrid system; Optimal Design; Hydrogen storage; Reliability; ABC algorithm..

1. Introduction

Necessity of the world to meet the energy demand is a mainspring to studying renewable energy resources. Diversity of energy supply markets, secure long-term sustainable energy supply, and reduce local and global atmospheric emissions can be enhanced by renewable resources [1].from the most promising technologies for supplying load in remote and rural regions, micro hydroelectric, photovoltaic (PV) and Wind Generation (WG) units can be mentioned [3]. Unpredictability of nature of water, solar and wind energy sources is a common disadvantage of these units. Furthermore, the source variations in these sources may not compatible with the demanded time distribution majority of the time [7]. These drawbacks ensue in serious reliability concerns of PV and WG systems in terms of design and operation. Despite of being costly, an approach alternative to overcome reliability problem is over sizing. As another approach, hybrid Hydro/PV/WG systems efficiently combine water, solar and wind sources' complementary characteristics to enhance the system’s reliability and reduce its costs [2]. Fig. 2 shows Block diagram of a hybrid Hydro/PV/WG system. A combination of a Fuel Cell (FC) stack, an electrolyzer, and a hydrogen storage tank is utilized as the Energy Storage System (ESS) and Generating units are connected to a common DC bus. As subject of many recent studies, Hydrogen as a suitable storage medium has been lionized of renewable energy systems [15-17]. This system can perform both long-term and short term storage functions, in very short-term purposes; a super capacitor may enhance system's dynamic response [18].

With a lower investment cost, a diesel generator can perform storage task. Nevertheless, atmospheric emissions and fuel consumption are its main disadvantages. In comparison, in one hand hydrogen-based storage is emission-free and on the other hand they do not need fuel supply. Whereas increasing fuel price and extreme reductions in FC expenditures, it is obvious that hydrogen-based systems will be economic for future applications [2].

Also, in hybrid Hydro/PV/WG/diesel systems, it is not feasible to store extra energy from water, solar and wind in the good seasons period. Oppositely, in proposed hydro-based storage system, electrolyzer converts the surplus energy into chemical formation, in other words, produces hydrogen, and accumulates in the hydrogen tank. When the water flow or wind speed or solar radiation decreases or a peak demand occurs, through the FC, the hydrogen can be shifted to the load [6]. In addition, with attainability of hydrogen sources e.g. when a hydrogen network is available; FC system with a high reliability can independently supply the load [8].due to discontinuous characteristic of water flow ,wind speed and solar radiation, most important challenge in design of this kind of systems is demanded reliable supplement under varying weather conditions, considering operation and invested costs of the components. Therefore, the aim is design of an optimal hybrid system for reliable and economical load supply [18]. In this way, literature offers a variety of methods for optimal designation of hybrid Hydro/PV/WG systems [1–10, 13–16].In [14] Genetic Algorithm (GA) finds the hybrid system components optimal sizes. In some recent works, PSO is prosperously accomplished for optimal sizing of hybrid stand-alone systems, presuming continuous and reliable supply of the load [22]. To demonstrate reliability index of Loss of Power Supply Probability (LPSP), GA and PSO have been utilized in [2] and [8] to find optimal size of a wind/ PV/battery power system. However, the outage probabilities of system components suchlike wind turbines and PV arrays are not considered. Genuinely, proceeding on Hybrid power system's optimal designing, reliability issues is not totally taken in to consideration. For instance, some very given phenomena that may truly effects cost and reliability of system, such as failures and outages of generating units are generally ignored. However, reliability assessment is related to any engineering system [19]. In renewable researches, for either stand-alone or grid-connected application, reliability of different combination of renewable systems with distinct configuration, component characteristics, load profile, and abusive renewable sources, able to be individually evaluated. In this way, [17] investigates the impacts of dubieties in operating parameters and reliability of a Proton Exchange Membrane Fuel Cell (PEMFC) and deduces that, dubiety and reliability in designing stage of any robust and applicable system must be considered. eventually, it affirms that a casual modeling framework should be interfaced with a numerical optimization scheme to provide a robust design tool for casual Optimization under dubiety.

This proposition was a superb motive to consider the impact component reliabilities, on economically designing of stand-alone renewable systems. accordingly, in [2], as the first step toward economical, robust, and reliable hydro/wind/PV hybrid power system designing, the outage probabilities of hydropower units, PV arrays and WGs have been taken into account. But, further studies exposed, the accessibility of DC/AC converter, as the only single cut-set [6] in the hybrid system's reliability diagram, has an extreme influx over the system's reliability. Thus, present study precedes the problem more attentively. In this way, a novel variation of artificial bee colony (ABC) algorithm is explicated to minimize costs over its 20 years of operation, under reliability restriction. All information which include Water flow, wind speed and solar radiation, are gathered from Meshkinshahr city in North West of Iran (latitude: 38_17°, longitude: 48_15°, altitude: 1345 m), and system costs include Annualized Costs (AC) of investment, replacement, and operation and maintenance, as well as costumer's discontent costs [25]. Fig. (1.a) and Fig. (1.a) respectively indicates the taken during head measurement and referred area's geographical layout.

Fig. 1.a. Sample photos taken during head measurement

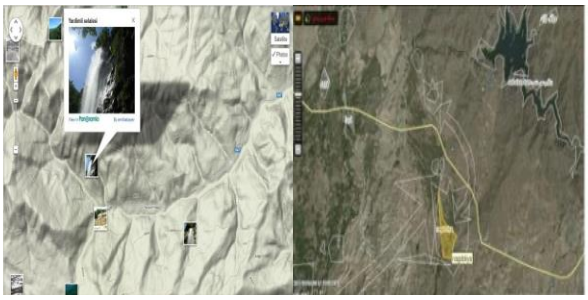

Fig. 1.b. Geographical layout of the project area
(Source: Google Map, 2012).

Eventually, due to achieve an assured consequence from ABC algorithm, it has been compared with the same consequences, which attained by PSO algorithm and HOMER software.

2. Hydro/PV/WG/FC System Modeling

As it shown by Fig. 2, the system consists of 7 major components as well as a DC and an AC Bus bars.

These components involve hydropower unit, wind turbine generators, PV arrays, electrolyzer, hydrogen storage tank, FC and DC/AC converter (inverter). The referred Component models are summarized in the following sections.

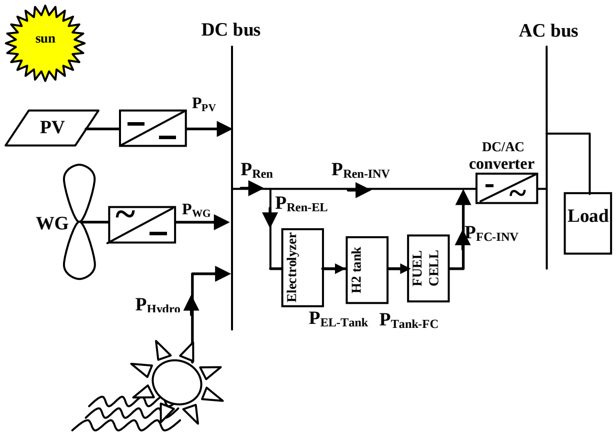

Fig. 2. Block diagram of a hybrid hydro/PV/wind/fuel cell

2.1. Micro Hydroelectric System

The studied hydropower system is runoff the river type which requires the available head and flow rate at the pour points determination. Head can be measured using either of altimeter, clear hose method, pressure gauges, satellite images, sighting meter or level method. According to this study and Fig. 1, the selected sites have steep waterfalls so that their head is measured using rope. The potential calculation of available water sources is shown as follows:

$$P_{total} = P_h \times \eta_t \times \eta_g \tag{1}$$

Where, η_t is the turbine efficiency, η_g is the generator efficiency and P_h is the hydraulic power. The theory output power due to the turbine location is calculated as follows:

$$P_h = C_w \times \rho_e \times g \times h_f \tag{2}$$

Where, C_w is the water density, ρ_e is the electrical discharge co efficiency, g is the gravitational acceleration and h_f is the water head. With considering the hydrologic information and regional topology, Kaplan turbine with its small scale and high speed features, is befitting to utilize. The turbine efficiency, heeded to type of turbine and its technical characteristics is equal to 0.9 [4].

Induction generator because of the variability of the rotor's speed in compare with the synchronic type [3], is appropriate to produce variable speed. The generator efficiency is up to 0.9.

The corresponding characteristics of generator are presented in Table 1.

Table 1. Generator Characteristics [3]

Type	Nominal power	Efficiency	Frequency	Power Factor	Synchronous Speed	Rotor Speed	Rotor Inertia
Induction generator	7 kw	0.9	50Hz	0.8	1500 rmp	1560 rmp	0.02

2.2. Photovoltaic Array

With respect to the solar radiation power, each PV array's output, can be calculated through Eq. (3)

$$P_{PV} = \frac{G}{1000} \times P_{PV,Rated} \times \eta_{MPPT} \tag{3}$$

Where, G is columnar radiation at array's surface (W/m2), $P_{PV,Rated}$ is rated power of each PV array at G= 1000 W/m^2, and η_{MPPT} is the efficiency of PV's DC/DC converter and Maximum Power Tracking System (MPPT). PV systems are generally armed with MPPT systems to attain the maximum output; it is distinct that the PV array working states persist in the maximum power point [2]. Thus, in present study it is granted that PV arrays are equipped with 95% efficient MPPT systems which afford 48 V DC at DC bus side. It should be heeded; effects of temperature are intentionally omitted.

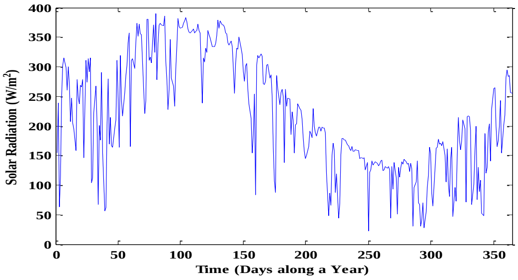

Fig.3. Daily solar radiation during a year.

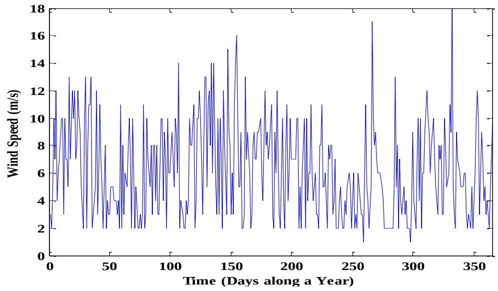

Fig.4. Daily wind speed during a year.

2.3. Wind Turbine Generator

The output power of one another WG unit against wind speed is, always, given by producer and usually describes the real transmissive power from WG to DC bus. In referred study, BWC Excel-R/48 of Bergey Wind Power [16] is investigated that has a rated capacity of 7.5 kW and provides 48 V DC at the output side. Here, the power curve versus wind speed is approximated by the following equation in Fig. 5. The daily average speed at height h_r has been utilized due to calculate the strike speed of the turbine's blade. The turbine's model is shown as follow:

$$V_{(t)} = V_{r(t)} \cdot \left(\frac{h}{h_r} \right)^{r} \tag{4}$$

Where, $V_{(t)}$ is the wind speed in height of h, $V_{r(t)}$ is the wind speed in height of h_r and r is the power-law exponent that is in the range of 0.14 to 0.25 [1]. The out-put power of the turbine $P_{wt(t)}$ resulted by wind speed formula as follows:

$$P_{wt(t)} = \begin{cases} av^3(t) - bP_R & V_{ci} < V < V_r \\ P_R & V_r < V < V_{co} \\ 0 & otherwise \end{cases} \tag{5}$$

Where: $a = \frac{P_r}{(V_r^3 - V_{ci}^3)}$, $b = \frac{V_{ci}^3}{(V_r^3 - V_{ci}^3)}$

And P_r is the rated power of the wind turbine(w) and V_{ci}, V_r , V_{co} are the cut-in wind speed, rated wind speed and cut-out wind speed of the wind turbine, respectively.

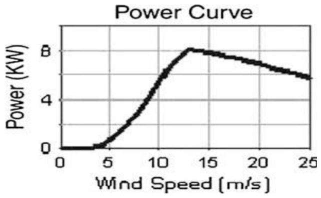

Fig. 5. Power output characteristic of BWC Excel-R/48 versus wind speed [2].

2.4. Generated Power by Renewable Units

By adding the WG and PV powers, infused power from the renewable sources to the DC bus, is calculated as below:

$$P_{ren} = (n_{hydro} \times P_{hydro}) + (n_{WG} \times P_{WG}) + (n_{PV} \times P_{PV}) \tag{6}$$

Where, N_{hydro}, N_{WG} and N_{PV} are numbers of installed hydropower unit, WG turbines and PV arrays, respectively. Reliability of system can be significantly waned by availability and unavailability of system components. Generated power by renewable sources flows through two streams. First stream goes to the inverter to load supplement (P_{ren_inv}), and the second delivers the surplus power to the electrolyzer due to hydrogen production (P_{ren_el}).

2.5. Electrolyzer

Through simple water electrolysis, a direct current has been passed between two submerged electrodes that therewith dialyses into hydrogen and oxygen from the water. Then hydrogen can be accumulated from the anode. Most of electrolysers breed hydrogen under pressure around 30 bar [2]. Besides, the reactant pressures within a Proton Exchange Membrane FC (PEMFC) are approximate 1.2 bar (a little higher than pressure of atmosphere) [17]. Eventually, in the most studies, exhausting side of electrolyser is straightly connected to the hydrogen tank [15, 16 and 21]. Anyhow, in some cases, for increasing the stored energy quantity, a compressor can pressurize emerged hydrogen up to 200 bar [22]. Moreover, in another study, to reducing the energy consumption of compressor, two hydrogen tanks can be used [2].in this configuration, the output side of electrolyser is directly injected to a low pressure capacity. When the tank is bunkering, compressors pomp the hydrogen into second high-pressure tank. So the advantages are, the compressor does not work permanently and it helps to reduce amount of energy consumption.

In this paper, the electrolyzer is directly connected to the hydrogen tank; however, the developed software is flexible enough to handle the compressor model. The definition of the delivered power from the electrolizer to tank is shown as follow:

$$P_{El-Tank} = P_{ren-El} \times \eta_{El} \tag{7}$$

Where, η_{El} is electrolyzer's factor which is assumed to be constant for whole operational range [2].

2.6. Hydrogen Tank

The stored hydrogen's energy in a step of time is attained as following equation:

$$E_{Tank}(t) = E_{Tank}(t-1) + (P_{El-Tank}(t) - \frac{P_{Tank-FC}(t)}{\eta_{storage}}) \times \Delta t \tag{8}$$

Where, $P_{Tank-FC}$ is the hydrogen tank's transferred power to the fuel cell. Storage power factor ($\eta_{storage}$) may give losses from lockage or pumping, and assumed to be 95% for all working states [7].bellow equation shows the mass of stored hydrogen an any time steps:

$$m_{Tank}(t) = \frac{E_{Tank}(t)}{HHV_{H2}} \tag{9}$$

Where, hydrogen's Higher Heating Value (HHV) is equal to 39.7kWh/kg [2]. It is worth to notice that there are lower and upper limitations for the stored hydrogen amount. It is not possible to exceed the rated capacity of the tank by mass of stored hydrogen. On the other hand, because of some problems, e.g. hydrogen pressure drop, a small fraction of the hydrogen (here, 5%) may not be extracted. This fraction is the lower limit of the stored energy. Therefore,

$$E_{Tank,\min} \le E_{Tank}(t) \le E_{Tank,\max} \tag{10}$$

2.7. Fuel cell

Fuel cell is electrochemical device which converts the chemical energy of a reaction directly into electrical energy. PEM fuel cell has reliable performance under intermittent supply and is commercially available at large industrial scale. This type of fuel cell is proportionate to be used in large-scale immovable generation and has fast dynamic response with a power release response time of only 1–3 s [17].it is possible to define the output power of fuel cell as a function of its output and efficiency (η_{FC}),which assumed to be stable (here,50%) [21].

$$P_{FC-Inv} = P_{Tank-FC} \times \eta_{FC} \tag{11}$$

2.8. DC/AC converter (inverter)

It is obvious that an inverter converts electrical power from DC into AC form as the required frequency of the load. The losses of inverter is presented by inverter's efficiency (η_{Inv}) and hastily supposed to be constant for whole working range (here, 90%) [1].

$$P_{Inv-load} = (P_{FC-Inv} + P_{ren-Inv}) \times \eta_{Inv} \tag{12}$$

Table.2. Components specifications [1]

Component	Capital cost ($/unit)	Replacement cost ($/unit)	O & M cost ($/unit-yr)	Life time (yr)	Availability (%)	Efficiency (%)
Hydro	6000	5500	100	20	--	60
PV array	10000	10000	20	20	96	--
WG	75000	75000	750	20	96	--
Electrolyzer	2000	1500	25	20	100	75
Hydrogen tank	1300	1200	15	20	100	95
Fuel cell	3000	2500	175	5	100	50
Inverter	800	750	8	15	99.89	90

2.9. Operation Strategy

Strategy of system operation is correspondent to the following rules.

- ✓ If $P_{ren}(t)=P_{load}(t)/\ \eta_{conv}$, then all of generated power by renewable sources is injected to the load through inverter.
- ✓ If $P_{ren}(t)\geq P_{load}(t)/\eta_{conv}$, then the surplus power is delivered to the electrolzyer. If the injected power exceeds rated power, then the excess energy will revolve in a dump resistor.
- ✓ If $P_{ren}(t)\leq P_{load}(t)/\eta_{conv}$, then the shortage of power is supplied by fuel cell. If the shortage of power exceeds fuel cell's rated power or the stored hydrogen cannot afford that, some fraction of the load must be shed. This fact leads to loss of load.

With considering above conditions, component restrictions are taken into account and Eqs. (1)- (12) govern the system. The prepared algorithm with considering the methodology optimization is shown in fig.6.

3. Reliability assessment

The referred system is accurately simulated in duration of over a year with one-day time steps and also reliability /cost assessment studies are perfectly done. Then, results of economic factor beneficiary are expanded to the 20-year of system's lifetime. Meantime, Load growth and uncertainty in load, solar radiation and wind speed data are neglected.

3.1. Reliability Indices

Several reliability indices are explained in literature [1,2,8 and 18]. Loss of Load Expected (LOLE), Loss of Energy Expected (LOEE) or Expected Energy not Supplied (EENS) and Equivalent Loss Factor (ELF) are some of indices which are used in the reliability evaluation of generating system. From these, LOL is a loss of load index, whereas others belong with category of loss of energy indices. These indices are defined in the following sections.

3.1.1. Loss of load expected

$$LOLE = \sum_{d=1}^{D} E[LOL(d)] \tag{13}$$

Where, $E[LOL(d)]$ is expected value of loss (mathematical expectation) of load at d_{th} time step defined by:

$$E[LOL] = \sum_{s \in S} T(s) \times f(s) \tag{14}$$

In above equation, $f(s)$ is the probability of encountering states, and $T(s)$ is the loss of load duration (d), given that occurring state s and S is set of all the possible states.

3.1.2. Loss of energy expected (expected energy not supplied)

$$LOEE = EENS = \sum_{d=1}^{D} E[LOE(d)] \tag{15}$$

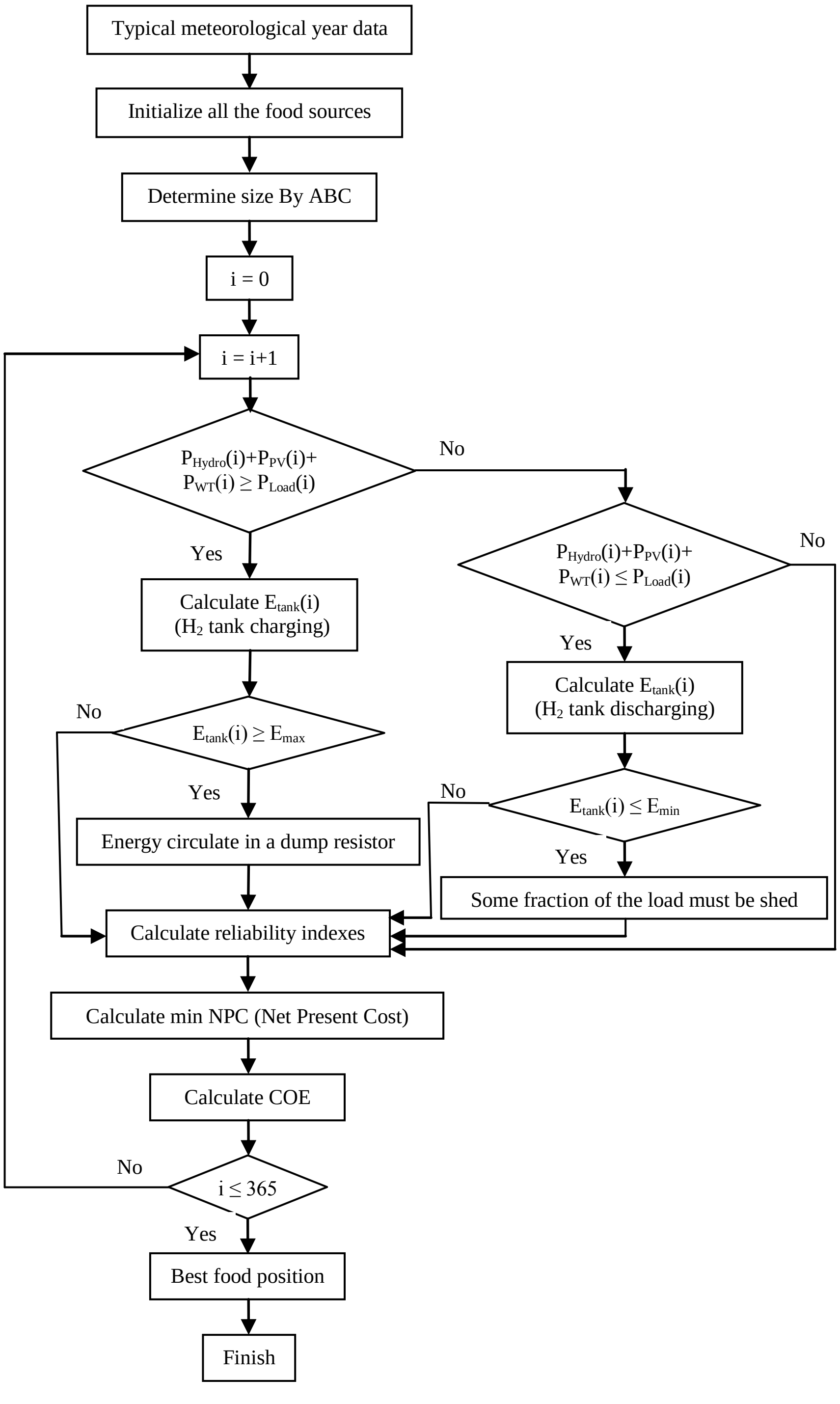

Fig.6. ABC algorithm used for optimization process

Where, $E[LOE(d)]$ is the expected value of energy loss, or energy not supplied, at time step d defined by:

$$E[LOE] = \sum_{s \in S} Q(s) \times f(s) \tag{16}$$

Here, Q(s) is the amount of energy loss (kWh) when system encounters states.

3.1.3. Equivalent loss factor

$$ELF = \frac{1}{D} \sum_{d=1}^{D} \frac{E[Q(d)]}{D(d)} \tag{17}$$

In all above equations, D indicates the number of time steps that system's reliability is evaluated (here, D=365).ELF defines the ratio of the effective forced outage days to the total number of steps. Indeed, it consists of information about both the numbers and outage's magnitudes [1]. Thereupon, as the main reliability index of this study, ELF is chosen.

However, the developed software calculates all above equations. Electricity suppliers of many developed countries aim at ELF < 0.0001.In country sides and stand-alone applications (like this study); it is acceptable to be ELF < 0.01 [2].

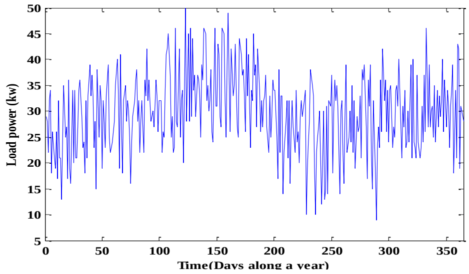

Fig.7. load data profile along a year

4. Problem Statement

The main goal of this study is to achieve an optimized design of a hydrogen-based hydro/WG/PV system. Optimization indignant are wind turbine generators, certain number of hydropower units, and certain number and installation angle of photovoltaic arrays, electrolyzer capacities , hydrogen tank , fuel cell and DC/AC converter. System costs include net present cost of investment, replacement, and operation and maintenance of components, as well as costs of load interruptions during 20 years of operation. The problem is to restrain the maximum allowable ELF reliability index. Besides, system simulation is subject to some other imposes, like components' maximum and minimum power and energy, which are described in previously.

The Net Present Cost (NPC) of component i is defined in [7]:

$$NPC_i = N_i \times \left\{ \begin{array}{l} \left[CC_i + RC_i \times K_i(ir, L_i, y_i) \right] \times \\ \times CRF(ir, R) + O\,\&\,M\,C_i \end{array} \right\} \tag{18}$$

Where, N can be number (unit) or capacity (kg or kW), CC indicates capital cost (US$/unit), RC is replacement cost (US$/unit), O and MC are respectively component annual operation and maintenance cost (US$/unit-yr) and *R* is the project's useful lifetime (here,20years). The real interest rate *ir*, which is here a nominal function ($ir_{Nominal}$) and annual inflation rate (*fr*), defined by [7]:

$$ir = \frac{ir_{Nominal} - fr}{1 + fr} \tag{19}$$

For the main goal of this study, to achieve a better comparison instead of NPC (Net Present Cost), COE (Cost of Energy) is considered. Eqs. (20) and (21) calculate COE. For calculate the present value of the components, capital recovery factor (CRF) is a ratio that consider the interest rate. the lowest COE will be yield by the optimization algorithm and hence, the initial value of the rated PV, hydropower and wind capacities will be altered to meet these criteria.

$$COE(\$/KWh) = \frac{(Capital\ Cost + O\,\&\,M\ Cost + Replacement\ Cost) \times CRF}{P_{Load}} \tag{20}$$

$$CRF(ir, R) = \frac{ir \times (1 + ir)^R}{(1 + ir)^R - 1} \tag{21}$$

Eventually, the objective function of this study is defined as in below equation.

$$C = \min \left\{ \sum_i^X NPC_i \right\} \tag{22}$$

In above mentioned equation, *i* is component indicator, and *X* is a seven dimensional vector consisting of optimization variables. The optimization problem is undergone with the following constraints.

$$E[ELF] \le ELF_{\max} \tag{23}$$

$$N_i \ge 0 \tag{24}$$

$$E_{tank,\min} \le E_{tank}(t) \le E_{tank,\max} \tag{25}$$

$$E_{Tank}(0) \le E_{Tank}(365) \tag{26}$$

Where, constraint (26) certifies that the stored energy amount in the hydrogen tank at the end of first year is more than its initial amount. Thus, reliability evaluations are accomplished for worst condition.

5. Artificial Bee Colony Algorithm (ABC)

The artificial bee colony (ABC) algorithm is One of the most recent meta-heuristic algorithms which is a population-based method that has shown agreeable performance in investigation with different types of optimization problems [11]. The foraging behavior was aspirator of bees the artificial bee colony algorithm. The ABC includes three groups of bees: onlookers, scouts and employed bees that is the procurer of possible solution of optimization problem as a food source, and the suitable value of the solution as the nectar amount of the associated food source.

In the ABC algorithm, the food sources number is supposed to be same with the number of employed bees. Initially, the employed bees find the food sources and present them on the dance area. At first, the food sources is found by the employed bees and delivered to the dance aria. After employed bees' operation, data is shifted to the onlooker bees, which select sources for search based on their nectar amounts (fitness values). looking for new food sources when a food source has been unoccupied ,is the duty of The third group of bees .it means that the employed and onlooker bees could not find an alternative at that solution area. As the algorithm struggles to find non-dominated solutions, an updating procedure is required to survey the newly discovered solutions. to preserve the best diversity of the Pareto front, a crowding distance operator is used to determine the best spread-out of solutions. Exploration and exploitation in the population based optimization methods are essential to be well-balanced. Exploration of optimization method recourses to the ability of search form to verify the unknown regions of the solution space, while the exploitation refers to the algorithm ability in utilizing data of the best-so-far solutions in the search process. The ABC algorithm search equation uses the data of the previous solutions in the colony to afford a new entrant solution which is good at the exploration but feeble at exploitation. Such conditions lead the algorithm to get trapped in positional optima because of a negligible balance between exploration and exploitation [12]. In presented study, to dominate this deficiency, the search process of employed and onlooker bees is considered to use the data from both the best-so-far solutions and the current colony members, because of make a good balance between exploration and exploitation of the algorithm. Since the optimization methods pertain to find the non-dominated solutions, the record of the Pareto solutions is the best-so-far solutions in the search process. General overview of the proposed ABC algorithm is presented in fig.8.

5.1. Initialization of food sources

At the first step, initial population of SN food positions would be generated by ABC algorithm. SN indicates the size of the employed and onlookers bee colony. Each member of the population is represented by $X_i (i = 1,...,SN)$ which is a problem solution. Every solution in the population is generated according to:

$$X_i^j = X_{\min}^j + rand() \times (X_{\max}^j - X_{\min}^j) \qquad (27)$$

Where, $X_{\min}^j$ and $X_{\max}^j$ are respectively the minimum and maximum possible value for j_{th} variable of the solution. *rand ()* is an identical random number between 0 and 1.

5.2. Employed Bee Phase

At the stage of employed bees, an employed bee coordinates the related solution to find a new one in the local area of the solution. After new solution producing, fitness value of new solution is catch and set to be a candidate solution. As the problem, if the candidate solution is able to dominate the previous one, the new position is memorized and forgets the previous one by employed bee. Otherwise, the employed bee discards the new solution and keeps the previous position in its memory. The process of modification to find a new position in the proposed ABC has a little difference from that of an objective problem. As the record of non-dominated solutions keeps the best solution so far, the algorithm uses data of the archive through use of:

$$V_i^j = X_{K_a}^j + rand() \times (X_{K_a}^j - X_i^j) \qquad (28)$$

Where, V_i^j is the new value of the j_{th} position of the state variable. $X_{K_a}^j$ is the j_{th} variable of a randomly selected solution in the record (indexed by K_a). X_i^j is the j_{th} value of the j_{th} solution in the population. In addition, to prevent the algorithm trap in local optima, the algorithm is modified by applying Eq. (29) that information of the current population is used with a probability. After repeatedly simulations, the distinguished value of this probability has been selected to be 0.25. it means that a probability of 0.75 the algorithm uses Eq. (28) with a stress on exploitation around the supreme solutions so far, and with a probability of 0.25 it uses Eq. (29) with the purpose of more exploration.

$$V_i^j = X_k^j + rand() \times (X_k^j - X_i^j) \qquad (29)$$

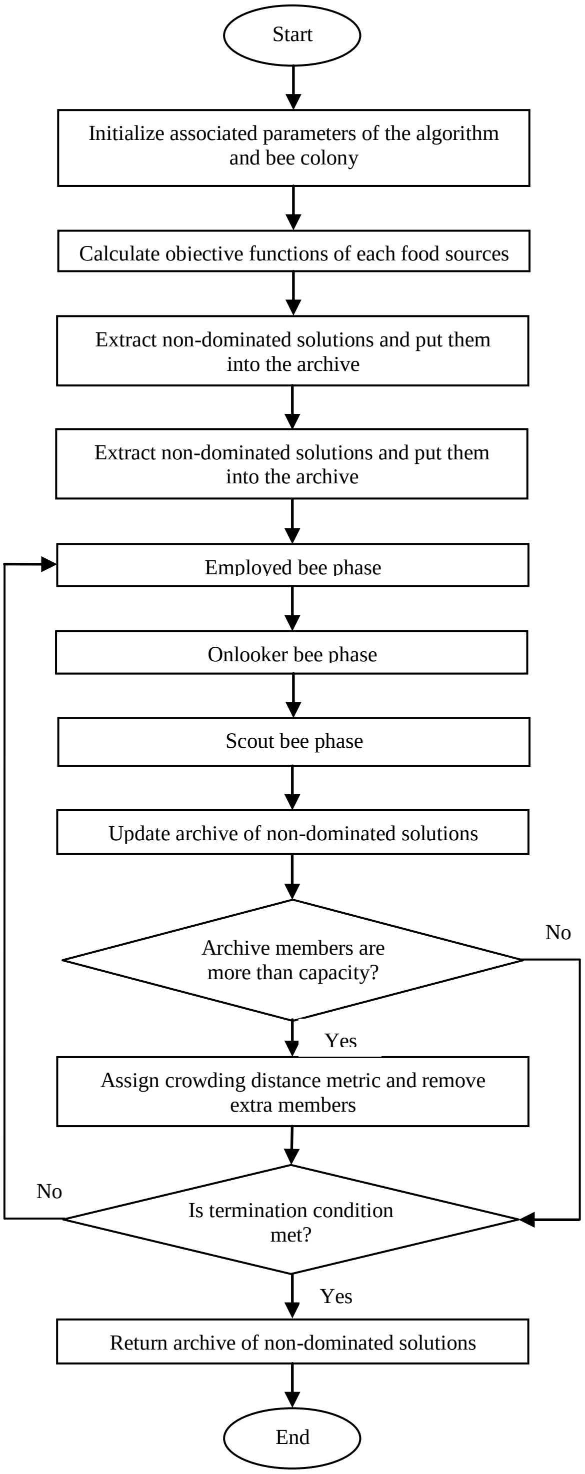

Fig.8. Schematic of the proposed ABC algorithm

As Eq. (29) represents, *j* is j_{th} variable's index that is selected by chance and k is the index of random solution in the population, and X_k^j is a random solution selected from the current population where $k=1 \ldots SN$.

5.3. Onlooker Bee Phase

When the search process has been completely done by all the employed bees, information about the nectar content of each food source will be shared with the onlookers in the hive. In this step of the algorithm, every onlooker bee evaluates the nectar amount of all the food quarries, and then with a probability p_i, depending on the quality of the foods, onlooker bee selects one of them. As the ABC set on problem, the calculation of the probability is completely different. As explained in the work of [12], Eq. (30) is utilized in the proposed ABC algorithm attain the selection probability of each solution as follows:

$$p_i = \frac{a_i}{\sum_{j=1}^{SN} a_j} \tag{30}$$

Where, a_i is the fitness value of the i_{th} solution in the population and is calculated by the following formula:

$$a_i = \frac{dom_i}{SN} \tag{31}$$

The *i* solution dominates dom_i which is the number of solutions in the current population. It is obvious from Eqs. (30) and (31) that solutions in the population with a higher fitness value have greater odds of being selected for modification and to acquire a solution. Through the onlooker bees in the algorithm utilization, the convergence rate of the algorithm is intensified.

5.4. Scout Bee Phase

The duty of the scout bees in the algorithm is to explore of new positions in the search space by using Eq. (27). A bee converts to a scout bee when after a number of modifications around a food source has no improvement and this food source is then supposed to be left. When food source abandonment is more than a predefined parameter called Limit, the related food source is replaced by a new randomly made solution in the search space.

5.5. Updating the Archive of Non-Dominated Solutions

With considering all the explorations and the exploitation of the bees, the non-dominated solutions of the current population are able to be extracted. There are four possible conditions for encountering a candidate solution in the current colony of bees' evaluation: bees: (1) if the attain of non-dominated solutions is vacant, then the candidate solution is added to the archive; (2) if the candidate solution is not dominated by any of the archived solutions, and also it does not dominate any solutions in the archive, then the new solution is added to the archive; (3) if the candidate solution dominates at least one solution in the archive, then all the dominated solutions are removed from the archive and new one is added; (4) if the candidate solution is dominated by any solution in the archive, then it is discarded. As the capacity of the archive of non-dominated solutions is finite, then if the archive is full of non-dominated solutions it is necessary to retain the best non-dominated solution. Thereupon, in the proposed verge, similar to the Non-dominated Sorting Genetic Algorithm (NSGA-II), a crowding distance operator determines the best spread-out non-dominated solutions of the archive [11]. A crowding distance operator calculates an estimate of the solution's density surrounding a particular solution in the archive. For this purpose, the average distance of two solutions on either side of this solution, along with each of the objective is calculated. This value is an estimate of the perimeter of the cuboid shaped by using the nearest neighbors as the vertices, which is called the crowding distance of that solution. Accordingly, the non-dominated solutions in a less crowded area are more interesting than non-dominated solutions with a bigger value of crowding distance, and are preserved in the archive. The proposed algorithm is terminated after a number of predefined cycles.

6. Implementation of the ABC Algorithm to Hybrid System Design Problem

In the aforesaid section, the fundamentals of the ABC were explained. This section brings forward the details of the referred ABC algorithm for solving the hybrid system design. Hereon, to apply the proposed algorithm in this problem, pursuing steps have to be taken:

Step 1: Input data definition.

Input data comprises the hybrid system unit's specifications, the number of solutions in the populations (SN), objective function, the maximum number of cycles (Maxcycle), the maximum size of archive (MaxArchive), and the maximum number of abandonment for a solution (Limit).

Step 2: Constraint relaxation of the hybrid system sizing problem.

This step of ABC algorithm struggles to determine if the chosen system configuration (find a food position) passes the functional evaluation provides service to the load within the bounds set forth by the loss of load energy expectancy. If the evaluation sufficient food has a lower Net Present Cost of system (NPC) than the lowest NPC value attained at the previous repeat, this system configuration (best food position) is presumed to be the optimal solution for the minimization problem in this repetition. This optimal solution will be replaced by better solutions, if any, produced in subsequent ABC algorithm during the program evolution. After the selection process, the optimal solution will be subject to the Updating the archive of non-dominated solutions and compute the crowding distance operations due to produce the next generation population until a prespecified number of generations have been reached or when a criterion that determines the convergence is satisfied.

Step 3: Generate the initial population.

The incipience population of the algorithm is generated as follows:

$$X = \begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ . \\ X_{SN} \end{bmatrix}_{SN \times N_v} \tag{32}$$

N_v is the length of each solution in the population .it is defined by below equation:

$$N_v = 3 \times N_{hyb} + BL \tag{33}$$

Step 4: Extract the non-dominated solutions of the initial population.

In this step of the algorithm, for each member of the population, the objective function is computed based on sizing of hybrid system. Hereafter, the non-dominated solutions of the incipient population are inserted into the Archive.

Step 5: cycle = 1.

Step 6: Employed bee phase.

An employed bee explores a new solution for each solution of the population by having the Eqs. (28) and (29). If the new solution overcomes the old one, the new one is held, otherwise is discarded.

Step 7: Calculate the selection probability of the Solutions

When all employed bees fulfill the scan process, a probability is specified to each solution which has a straight correspondence with the quality of the solution. It is obvious that the solutions with better objective values have higher probability values.

Step 8: Onlooker bee phase.

With considering the attained probability values related to each solution, onlooker bees conduct the search process for detecting new solutions and updating the population by using the roulette wheel selection rules.

Step 9: Updating the archive of non-dominated solutions.

In this step, the archive of Pareto solutions is updated. If the size of archive is bigger than Max Archive, then proceed the step 10; otherwise go to the step 11.

Step 10: Calculate the crowding distance.

In this level, the crowding space of each solution is computed and then the best archive's solutions are kept and the rest of them are discarded.

Step 11: Check the termination criterion.

The maximum number of cycles (Maxcycle) is the termination criterion. If the cycle is lower than the Maxcycle, then cycle = cycle + 1 and leap to the step 6; otherwise the algorithm has been terminated and the so far found non dominated solutions have been extracted. To obtain the best values of the parameters, a series of experiments has been implemented. The values of the applied parameters in the referred algorithm, which have been utilized in all of the experiments, are clearly illustrated by table.3.

Table 3. Parameters of the proposed ABC algorithm.

SN (Population Size)	MaxCycle (Iteration)	MaxArchive	Limit
60	200	50	50

7. Results

To find an optimum confection of proposed hybrid system, MATLAB simulation software has been used. Comprehensive performance studies were implemented with demand of 60 Primary populations and repetition for proposed algorithm was considered 200. Below figure depicts ABC isotropic diagram due to optimize the combinatorial (PV, Wind and Fuel Cell) system.

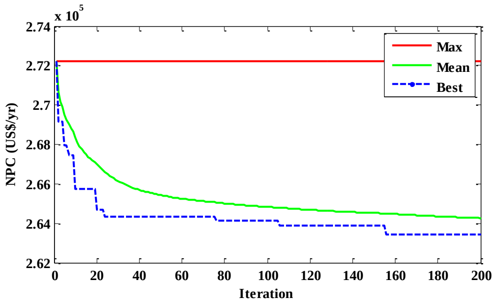

Fig.9. Convergence of the ABC algorithm for hybrid PV/Wind/FC system

Likewise, Proficiency of chosen algorithm diagnosis as optimized point from the dimensioned standard deviation index has been computed and shown in table (2). Furthermore, reliability indexes and also cost of energy (COE) for both of systems (PV, Wind and Fuel Cell) and (hydro, PV, Wind and Fuel Cell) are illustrated in below diagrams.

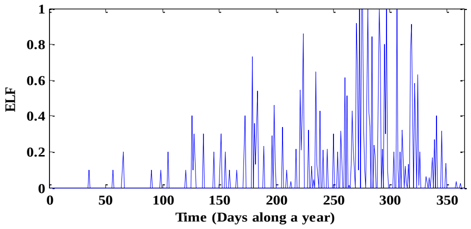

Fig.10. ELF index for hybrid PV/Wind/FC system

According to attained diagram for ELF index by proposed confection, loss of system as shown in fig.10 occurs 7 days per year, simultaneously when load has maximum amount 50 (KW). In fact proposed system aimed to supply in this situation. Specified measure of ELF is 0.007451 (KWh) and proportionate to be used in mentioned area.

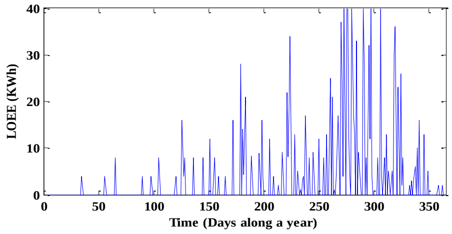

Fig.11. LOEE index for hybrid PV/Wind/FC system

Accordingly, resulted measure for one year period with LOEE index has been calculated by ABC algorithm 2.29451 (MWh/yr). As shown, system in most of days of year has definite amount of losses whereas system had quiescence for 7 days namely not able to feed consumer. Attained numeric measure of losses shows that loss of load energy (LOLE) for (PV, Wind, FC) hybrid system was 2.29451 (MWh/yr). Fig.12 shows LOLE index.

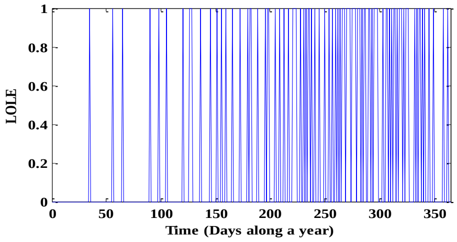

Fig.12. LOLE index for hybrid PV/Wind/FC system

Above diagram illustrates LOLE in one year duration is measured 312.32 (h/yr). Thusly, according to fluctuations caused by wind force through winding and also deficiency of sunshine invariability, LOLE is measured 312.32 (h/yr).affiliate to diagram, loss of system occurs in 85 days for a year and leads to distinguish an efficiency reduction in power system. Besides, a definite dimension of (COE) for the system has been calculated and measured 0.134 ($/KWh). Fig.13 shows the quantity of stored hydrogen in a year.

According to diagram, in combinatorial system (PV, Wind and Fuel Cell) quantity of stored hydrogen in 6 days for a year reduced to minimum amount accordingly clearly states quiescence.

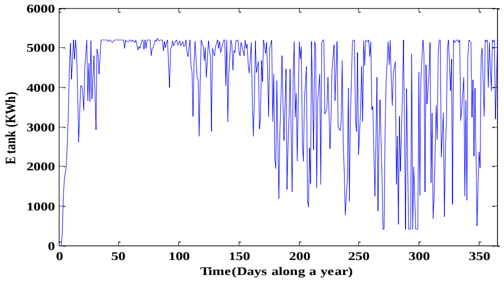

Fig.13. Daily expected amount of stored energy in the hydrogen tank in PV/Wind/FC hybrid system

Affixture of a small Hydropower plant to the combinatorial (PV, Wind and fuel cell) system not only helps to enhance reliability ELF, but also reduces NPC about 39451 ($) lower than system without hydropower plant. Below figure depicts ABC isotropic diagram purposed to (Hydro, PV, Wind and Fuel Cell) system optimization.

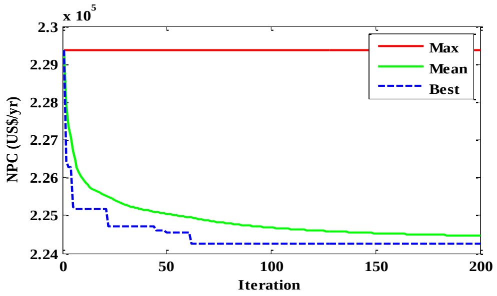

Fig.14. Convergence of the ABC algorithm for hybrid Hydro/PV/Wind/FC system

According to the consequences, it is obvious that reduction of NPC and COE beside the reliability enhancement after hydropower plant affixture, are one of the fundamental utilities of optimization. Measure of reliability indexes in proposed system is calculated and also shown in figures (15), (16) and (17).

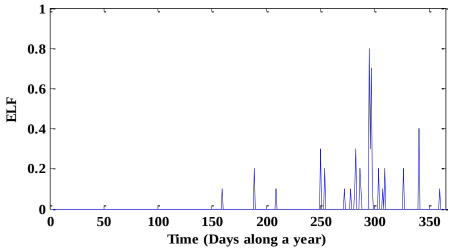

Fig.15. ELF index for hybrid Hydro/PV/Wind/FC system

To notice ELF on proposed confection, quiescence rate is only one day per year and this day exactly corresponded to the peak time with the maximum load 50 (KW). In this time proposed system is tasked to cover the peak load. ELF index was measured 0.004293 (KWh) that is certainly proportionate to use in commented area. Figure (16) shows the LOEE index.

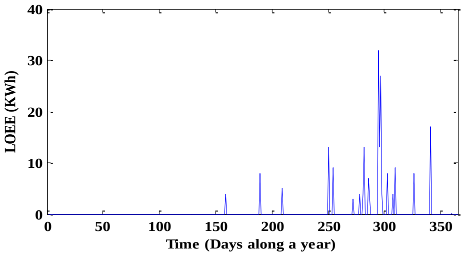

Fig.16. LOEE index for hybrid Hydro/PV/Wind/FC system

As for above diagram, LOEE index was measured by ABC algorithm for a year duration 1.43257 (MWh/yr). This amount indicates the entire loss power was made by hybrid hydro, PV, Wind and fuel cell system. According to above graph, whilst proposed plant is able to supply the load through year, and only one day of year is not able to supply the load. Figure (17) shows the LOLE index.

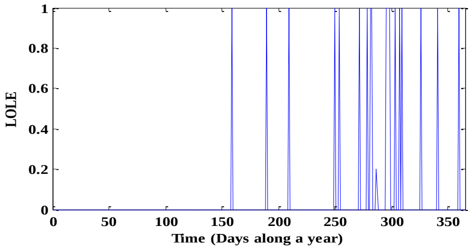

Fig.17. LOLE index for hybrid Hydro/PV/Wind/FC system

Above diagram shows the rate of losses in case of fluctuations through winding and deficiency of sunshine invariability occurs 126.61 (h/yr) in 17 days through year which caused to reduce the efficiency of system. Moreover, measure of COE has also been calculated 0.097 ($/KWh). Fig.18 illustrates stored hydrogen quantity of combinatorial (Hydro, PV, Wind and fuel cell) system.

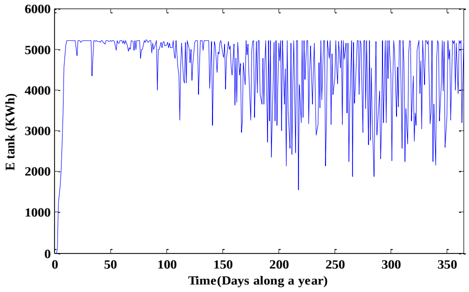

Fig.18. Daily expected amount of stored energy in the hydrogen tank in Hydro/PV/Wind/FC hybrid system

To consider the amount of stored hydrogen through a year that never be minimized even in sunshine and wind intensity lockage, proposed system is able to tackle the consumer. Below table contains optimization data for proposed system and the system without watery plant.

Table.4. Optimal combination in the hybrid systems.

Parameters			**N hydro**	**N_{PV}**	**N_{WG}**	**P_{FC}(kw)**	**P_{EL}(kw)**	**M_{Tank}(kg)**	**P_{INV}(kw)**
Optimal result	**PV, Wind, Fuel Cell system**	**ABC**	**-**	**214**	**9**	**43.195**	**118.52**	**101.24**	**47.63**
		PSO	-	219	8	43.54	119.17	103.92	48.14
		HOMER	-	217	9	42.16	119.48	102.54	47.92
	Hydro, PV, Wind, Fuel Cell system	**ABC**	**1**	**196**	**8**	**43.814**	**119.72**	**121.3**	**47.523**
		PSO	1	201	9	43.119	117.49	120.4	47.629
		HOMER	1	219	11	42.4	118.52	118.6	46.45

Table 5. Optimal costs and reliability indices in the hybrid systems.

Parameters		**NPC(1000×US$/yr)**			**COE ($/KWh)**	**ELF**	**LOEE(MWh/yr)**	**LOLE(h/yr)**
		Mean	**Best**	**S.D.**				
PV, Wind, Fuel cell system	**ABC**	**264.546**	**263.729**	**0.0042548**	**0.134**	**0.007451**	**2.29451**	**312.32**
	PSO	266.517	265.442	0.0076313	0.149	0.007456	2.31729	314.16
	HOMER	-	266.109	-	0.231	-	-	-
Hydro, PV, Wind, Fuel cell system	**ABC**	**224.513**	**224.278**	**0.0026649**	**0.097**	**0.004293**	**1.43257**	**126.61**
	PSO	224.457	224.991	0.0031491	0.129	0.004307	1.44036	127.92
	HOMER	-	225.612	-	0.214	-	-	-

According to the table.5, construction of the combinatorial (hydro, PV, Wind and fuel cell) system costs 224278 ($). In comparison, construction of the system without hydropower plant costs 263729 ($). Cost difference dissension from lower cost of the hydropower plants affaires in comparison with cost of photovoltaic panels and wind turbines. It is obvious that solar energy only available through the day and generated power utilizes to hydrogen reservation which is abusive in hydropower plant in combinatorial (watery, windy, hydro) system when peak load and lack of electricity are occurred. Proposed system has been assembled in order to supply in peak load (50kw) and enhance an optimize combination and also achieve to economic establishment. Beside of aforementioned reasons, reliability of proposed system is surely suitable in commented area.

As regard to measured expenditure for NPC and COE in optimized system, cost lowness of system, in compare with attained results in ABC, PSO algorithms and HOMER software is visible. Additionally, demand of standard deviation from average in ABC algorithm is lower than in PSO algorithm, hence accuracy of real optimized point calculation in referred algorithm should be taken into account.

8. Conclusion

The main investigations and studies on combination of (hydro, PV, Wind and fuel cell) system with a small hydropower plant is to provide the demanded power from waterworks facilities and also reducing the cost of installation and utilization .all summarized information have been gathered from 20 years duration to achieve a precisely survey of the expenditures. Also this study has been assisted by information from one of outlying places of Ardabil province bested on northwest of Iran. To optimize the referred combination, Artificial Bee Colony (ABC) has been utilized and attained results accomplished by PSO algorithm and HOMER software. According to reliability indexes of referred system, it is obvious that, comparison reliability improvement percentage between (hydro, PV, Wind and fuel cell) system and referred system without hydropower plant in ELF index is 43.49%, LOEE is 37.56% and LOLE is 59.47%. In spite of notable reliability of referred system through optimization, cost of building a combinatorial (hydro, PV, Wind, Fuel Cell) system is about 39451($) lower than its cost without hydro plant affixture. Therefore, price and installation of hydropower plant facility is more economic than photovoltaic and wind turbines. Proposed system is not only economic and reliable, but also causes to reduce the cost of energy. One of the significant goals through the study is covering load of hydro suctions and system reliability modification through a year. Indubitably, proposed optimized results prove the suitability of the referred system to actualize on studied area. Genuinely, execution of combinatorial (hydro, PV, Wind and fuel cell) power plant replaces reproducible energy sources instead of fossil fuels to reduce pollution.

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