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A Teaching Learning Based Optimization for Optimal Design of a Hybrid Energy System

Ahmad Rouhani, Masoud Jabbari, Sima Honarmand

***Abstract*—**This paper introduces a method to optimal design of a hybrid Wind/Photovoltaic/Fuel cell generation system for a typical domestic load that is not located near the electricity grid. In this configuration the combination of a battery, an electrolyser, and a hydrogen storage tank are used as the energy storage system. The aim of this design is minimization of overall cost of generation scheme over 20 years of operation. The Matlab/Simulink is applied for choosing the appropriate structure and the optimization of system sizing. A teaching learning based optimization is used to optimize the cost function. An overall power management strategy is designed for the proposed system to manage power flows among the different energy sources and the storage unit in the system. The results have been analyzed in terms of technical and economic. The simulation results indicate that the proposed hybrid system would be a feasible solution for stand-alone applications at remote locations.

***Keywords*—**Hybrid energy system, optimum sizing, power management, TLBO.

I. Introduction

THE significant increase in energy consumption, non-renewable nature of fossil fuel, high fossil fuel costs, and environmental concerns are major factors in the development of renewable energies [1]. Natural resources in the world have depleted rapidly as mankind venture into the new millennium. The energy consumption is steadily increasing and the deregulation of electricity has caused that the amount of installed production capacity of classical high power stations cannot follow the demand [2]. On the other hand operating small industrial equipment such as measuring instruments, sensors or weather stations, at remote locations require reliable off-grid power supplies. On the other hand, distributed generation (DG) is one new option being promoted for solving distribution system capacity problems [3].

Also, it is known that renewable energy such as wind, hydro, solar, and geothermal are relatively expensive and limited in availability. Anyway, to mitigate the environmental impacts to the planet and the risk of depending only on few sources of energy, there is an increasing interest in renewable energy sources [3].

A method to fill out the gap is to make incentives to invest in alternative energy sources such as wind generator photovoltaic systems and hydropower resources [4]. A common problem is that the wind generators and PV-modules cannot cover the energy demand of the equipment during a period because of the irradiation characteristics of wind and solar. These facts suggest the development of a hybrid system.

A hybrid energy system consists of two or more energy systems, energy storage systems, power conditioning equipment and controllers. It may or may not be connected to the grid. Multiple energy sources including Wind Generator (WG), Photovoltaic panels (PV), Fuel Cells (FC), diesel generators, gas turbines and micro turbines can be combined together to form an hybrid energy system [5]-[12]. The optimal sizing problem is solved for PV-FC hybrid system [13], [14], and for WG-PV-FC hybrid system [15], [16]. Furthermore the optimal sizing of PV-FC hybrid system is performed by means of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) [17]. Modelling of a WG-PV-FC hybrid power system in HOMER software is performing in [18].

The feasibility of the generation structure, the cost of primary energy resources and fuel for the scheme, and the reliability indices of electricity supply, make optimal sizing of the hybrid energy systems a very complicated optimization mathematically. The aim of this study is to identify the most economic and appropriate power supply system for a selected remote area using a Teaching Learning Based Optimization (TLBO).

As shown in Fig. 1, in this paper, a stand-alone hybrid alternative energy system consisting of WG, PV, FC, electrolyser, and battery is proposed for stand-alone applications.

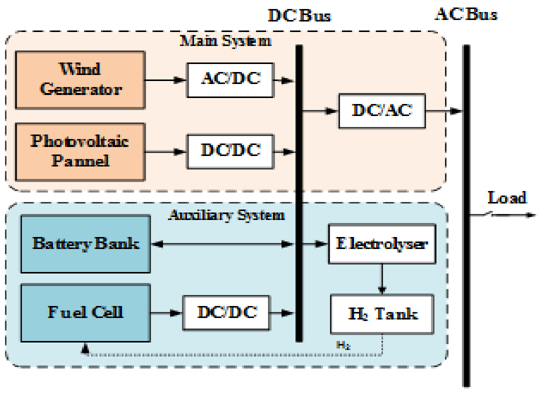

Fig. 1 Proposed system configuration

WG and PV are the primary power source of the system, and the FC-Electrolyser combination is used as a backup and a

Ahmad Rouhani is with the Young Researchers and Elite Club, Beyza Branch, Islamic Azad University, Beyza, Iran (phone: +98 71 36783257; fax: +98 71 36783256; e-mail: rouhani@biau.ac.ir).

Masoud Jabbari is with the Department of Electrical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran

Sima Honarmand is with the Department of Electrical Engineering, Beyza Branch, Islamic Azad University, Beyza, Iran

long-term storage system. A battery bank is also used in the system for short-time backup to supply transient power.

An overall power management strategy is designed for the system to coordinate the power flows among the different energy sources. Simulation studies have been carried out to verify the system performance using practical load profile and real weather data form Shiraz area in south-west Iran. The details of the major system components, system reliability and economical model are also discussed in the paper.

This paper is organized as follows: In Section II, the system sizing and configuration is reviewed with details of the load profile and weather data. The mathematical model of the hybrid WG/PV/FC system is developed in Section III. The power management strategy, the modeling of system reliability and the economic model are explained in section IV to section VI. The optimization method is described in Section VII. The TLBO algorithm is described in Section VIII. Technical and economic analysis of hybrid energy systems are presented in Section IX. Finally, the conclusion of the paper is described in Section X.

II. System Sizing and Configuration

The optimization of the size of a hybrid plant is very important, and leads to a good ratio between cost and performances. Before the system sizing, the load profile and the weather data should be evaluated. Therefore they are presented in the following sections.

A. Load Profile Curve

The load profile curve is needed to size the sources and the other devices. Monthly average of 20 years of Shiraz weather data (Table I), with sample daily load profiles is used to simulation of proposed system. The estimated hourly load profile is shown in Fig. 2. The load average in a day is 1 (KW). This consumption evolution is based on a domestic consumption in a typical remote village.

B. Weather Data

Noticeably, the wind turbine and the solar power is linked to the weather conditions, and hence it is unpredictable, based on a real case near ‘‘Shiraz’’, the wind speed, the solar radiation data and the ambient temperature comes from the average of recent 20 years [19].

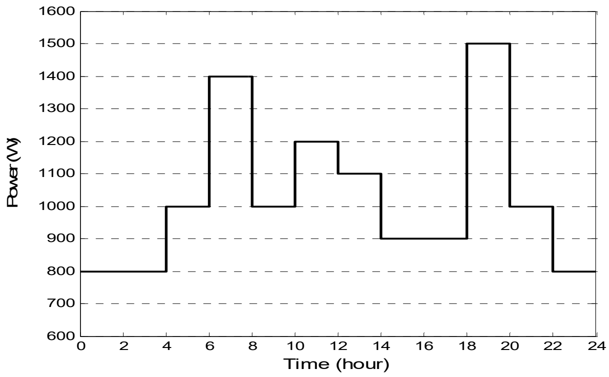

Fig. 2 Load profile on a 24 hours period

TABLE I
Shiraz monthly average of Wind Speed (m/s), Solar irradiation (Wh/m²/day), and Ambient temperature (°C)

Weather Data	**Wind speed (m/s)**	**Solar irradiation (kWh/m^2/d)**	**Ambient temperature (°C)**
January	5.86	3.27	4.39
February	6.28	4.27	6.25
March	6.32	4.94	10.22
April	5.96	6.00	16.94
May	6.54	7.03	22.97
Jun	6.59	7.49	27.14
July	7.07	7.02	28.80
August	6.73	6.72	27.66
September	6.10	6.02	23.57
October	5.40	4.91	18.15
November	5.36	3.64	11.91
December	5.78	3.04	6.67

III. Simulation Model

As shown in Fig. 1 this paper develops the hybrid system consisting of Proton Exchange Membrane (PEM) FC, WG and PV modules that uses battery to store the energy and electrolyser to produce hydrogen. The hydrogen can be produced, during the surplus of energy production, from water by electrolysis and stored in a container for further use. Indeed the electrolyser in this model is used as a dump load.

A. WG Model

A wind turbine converts the kinetic energy of wind into mechanical energy. Wind generators can be separated according to the type of the axis about which the turbine rotates. Turbines that rotate around a horizontal axis are more commonly used than those that rotate around a vertical axis. The model is based on the characteristics of the power of turbine at steady state. The fitting equation of the output characteristics of wind generator can be expressed as [20]:

$$P_{WG} = \begin{cases} 0 & \mathrm{V} < \mathrm{V_{ci}} \\ aV^3 - bP_r & \mathrm{V_{ci}} < \mathrm{V} < \mathrm{V_r} \\ P_r & \mathrm{V_r} < \mathrm{V} < \mathrm{V_{co}} \\ 0 & \mathrm{V} > \mathrm{V_{co}} \end{cases} \tag{1}$$

where P_{WG} is the output power of wind generator at wind speed V, P_r is the rated power, V is the wind speed at the hub height, V_{ci}, V_r and V_{co} are the cut-in, rated and cut-out wind speeds, respectively. a and b are the polynomial coefficients of the cubic spine interpolation functions which depend on the wind turbine generator type, as shown in:

$$a = \frac{P_r}{V_r^3 - V_{ci}^3} \qquad b = \frac{V_{ci}^3}{V_r^3 - V_{ci}^3} \tag{2}$$

B. PV Model

Insolation data (expressed in W/m^2) is converted into power output from the PV array using (3) [21]:

$$P_{PV} = Ins(t) \times \eta_{PV} \times S_{PV} \tag{3}$$

where *Ins(t)* is the insolation data at time *t* (W/m^2), S_{pv} is PV surface (m^2), and η_{pv} is the overall efficiency of the PV.

C. Battery Model

The battery input power can be positive or negative depending on the charge or discharge mode of operation. The state of charge (SOC) is deduced from the battery power and efficiency (η_{BAT}) [22]:

$$SOC_{BAT} = \int (P_{BAT,Charging} \times \eta_{BAT} - P_{BAT,Discharging})dt \quad (4)$$

The FC is activated when the battery SOC is lower than a minimum threshold value (SOC_{MIN}). On the contrary, FC is stopped and the electrolyser starts up when SOC is higher than a maximum threshold value (SOC_{MAX}).

D. FC Model

This model permits to calculate hydrogen consumption according to the delivered power. It should be noted that the FC auxiliary system needs around 20% of the FC net power (for cooling and air pressurization) [22].

E. Electrolyser Model

An electrolyser is a device that produces hydrogen and oxygen from water. Water electrolysis can be considered a reverse process of a hydrogen-fueled FC. From electrical circuit point of view, an electrolyser can be considered as a voltage-sensitive nonlinear dc load [23]. In this paper electrolyser is considered as a dump load too.

IV. Power Management Strategy

An overall control strategy for power management among different energy sources in a multi-source energy system is needed. Fig. 3 shows the block diagram of the overall control strategy for the proposed hybrid alternative energy system. The power difference between the generation sources and the load demand is calculated as:

$$P_{Net} = P_{WG} + P_{PV} - P_{LOAD} - P_{SC} \quad (5)$$

where, P_{SC} is the self-consumed power for the system operation. The governing control strategy is that, at any time, any excess WG and PV generated power ($P_{Net} > 0$) is supplied to the battery or the electrolyser to generate H_2 that is delivered to the hydrogen storage tanks through a gas compressor. Therefore the power balance equation given in (5) can be written as:

$$P_{WG} + P_{PV} = P_{LOAD} + P_{BAT,Charging} + P_{SC} \quad (SOC \langle SOC_{MAX}) \quad (6)$$

$$P_{WG} + P_{PV} = P_{LOAD} + P_{ELEC} + P_{SC} \quad (SOC = SOC_{MAX}) \quad (7)$$

when there is a defect in power generation ($P_{NET} < 0$), the battery and/or the FC stack begins to produce energy for the load. Therefore, the power balance equation for this situation can be written as:

$$P_{WG} + P_{PV} + P_{BAT,Discharging} = P_{LOAD} + P_{SC} \quad (SOC \rangle SOC_{MIN}) \quad (8)$$

$$P_{WG} + P_{PV} + P_{FC} + (P_{BAT,Discharging}) = P_{LOAD} + P_{SC} \quad (SOC \langle SOC_{MIN}) \quad (9)$$

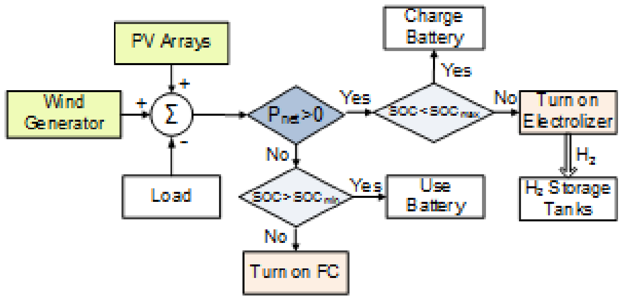

Fig. 3 Block diagram of the overall control scheme for the proposed hybrid WG/PV/FC energy system

V. Modeling of System Reliability

Several approaches are used to achieve the optimal configurations of hybrid systems in terms of technical analysis. In this study, the technical sizing model for the HPFS is developed according to the concept of LPSP to evaluate the reliability of hybrid systems [24]. The methodology used can be summarized in the following steps:

The total power (P_{tot}), generated by the WG, PV generator and FC at hour t is calculated as:

$$P_{tot}(t) = P_{WG}(t) + P_{PV}(t) + P_{FC}(t) \quad (10)$$

Then, the inverter input power ($P_{inv}(t)$), is calculated using the corresponding load power requirements, as:

$$P_{inv}(t) = \frac{P_{LOAD}(t)}{\eta_{inv}} \quad (11)$$

where $P_{LOAD}(t)$ is the power consumed by the load at hour t, η_{inv} is the inverter efficiency (95% in this study). It should be noticed that the electrolyser power is added to P_{LOAD} when it is activated. Three states may be appearing:

a) The total power generated by the WG, PV and FC is greater than the power needed by the load, P_{inv}. In this case, the energy surplus is stored in the batteries and the new storage capacity is calculated using (4) until the full capacity is obtained. The remainder of the available power is dedicated to the electrolyser to produce hydrogen.
b) The total WG, PV and FC power is less than the power needed by the load (P_{inv}), the energy deficit is covered by the storage and a new battery capacity is calculated using (4).

c) In case of inverter input and total power equality, the storage capacity remains unchanged.

In case (a) when the batteries capacity reaches a maximum value ($C_{BAT,max}$), the control system stops the charging process. The wasted energy, defined as the energy produced and not used by the system, for hour t is calculated as:

$$WE(t) = P_{tot}(t)\Delta t - \left(\frac{P_{LOAD}(t)}{\eta_{inv}}\Delta t + \left(\frac{C_{BAT,\max} - C_{BAT}(t-1)}{\eta_{cha}}\right)\right) \quad (12)$$

In case (b), if the batteries capacity decreases to its minimum level ($C_{BAT,min}$), the control system disconnects the load and the energy deficit, loss of power supply for hour t can be expressed as:

$$LPS(t) = P_{LOAD}(t)\Delta t - \left(\begin{matrix}(P_{WG}(t) + P_{PV}(t) + P_{FC}(t))\Delta t \\ + C_{BAT}(t-1) - C_{BAT,\min}\end{matrix}\right)\eta_{inv} \quad (13)$$

where Δt is the step of time used for the calculations (in this study $\Delta t = 1\ h$). During that time, the power produced by the WG, PV and FC is assumed constant. So, the power is numerically equal to the energy within this time step.

The loss of power supply probability, for a considered period T, can be defined as the ratio of all the *LPS(t)* values over the total load required during that period. The LPSP technique is considered as technical implemented criteria for sizing a hybrid WG/PV/FC system employing a battery bank and an electrolyser. The technical model for hybrid system sizing is developed according to the LPSP technique.

$$LPSP = \sum_{t=1}^{T} LPS(t) / \sum_{t=1}^{T} P_{LOAD}(t)\Delta t \quad (14)$$

where T is the operation time (in this study, $T = 1$ year). One more concept can be introduced too. The concept is the energy excess percentage, which is defined as the wasted energy divided by the total energy produced by the WG, PV and FC during the considered period.

$$EXC(t) = \frac{WE(t)}{E_{tot}(t)} \quad (15)$$

For a given LPSP value and a defined period, many configurations can technically meet the required reliability demand of power supply. The optimal configuration can be identified finally from these set of configurations by achieving the lowest LCE. This can be performed by applying an economical model developed in Section VI.

VI. Economic Model

There are different financial analysis models based on "discounted cash flow analysis" such as, net present value, required revenues analysis, profitability index, internal rate of return and levelized cost [25]. These analysis models are termed as financial indicators and are used for comparison of different projects. The choice of model would depend on the sector for which the analysis is being performed. As the project is related to electricity generation, it was categorized as a private utility sector project. In this section, an economic sizing model is developed for the HPFS according to the levelized cost of energy concept. The LCE is defined as:

$$LCE = \frac{TPV \times CRF}{E_{LOAD}} \quad (16)$$

where E_{LOAD} is the yearly output in (KWh), *TPV* and *CRF* are the total present value of actual cost of all system components and the capital recovery factor, respectively, which can be expressed as:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (17)$$

$$TPV = C_{WG} + C_{PV} + C_{FC} + C_{ELEC} + C_{BAT} \quad (18)$$

where i is the annual discount rate, n is the system lifetime in years, C_{WG} the sum of present value of capital and maintenance costs of the WG in system life, C_{PV} the sum of present value of capital and maintenance costs of the PV generator in system life, C_{FC} the sum of present value of capital and maintenance costs of the FC in system life, C_{ELEC} the sum of present value of capital and maintenance costs of the electrolyser in system life and C_{BAT} is the sum of present value of capital and replacement costs of battery bank in system life. The configuration with the lowest LCE is taken as the optimal one from the set of configurations, which guarantee the required LPSP. The annual discount rate is considered as 10%, system lifetime is 20 years and the details of proposed system components can be found in Table II.

VII. System Optimization

Different approaches have been reported for optimization cost of generation units such as linear and nonlinear programming, probabilistic approach, dynamic programming, and iterative techniques [26].

A. Problem Formulation

The aim of this study is to achieve a stand-alone hybrid generation system, which should be appropriately designed in terms of economic, reliability, and environmental measures subject to physical and operational constraints/strategies.

1) Objective Function

The function that must be optimized is the system cost. This function is defined as a sum of WG cost (C_{WG}), PV cost (C_{PV}), battery cost (C_{BAT}), electrolyser cost (C_{ELEC}), and FC cost (C_{FC}).

$$C_{system} = C_{WG} + C_{PV} + C_{FC} + C_{ELEC} + C_{BAT} + PF \quad (19)$$

The cost for each element should be deducted:

$$C_i = N_i \times [CCost_i + RCost_i \times K_i + OMCost_i] \quad i = WG, PV, Battery, FC, Electrolyser \tag{20}$$

where N_i is the number/size of the system component, $CCost_i$ is the capital cost, $RCost_i$ is the replacement cost, K_i is the number of replacement, and $OMCost_i$ is operation and maintenance cost through the system operation. *PF* is penalty factor that will added to objective function when one or more constrains dose not satisfy. The cost of the system elements can be seen in Table II.

2) System constraints

a) Power Balance Constraint

For any period t, the total power supply from the hybrid generation system must supply the total demand P_{LOAD} with a certain reliability criterion. This relation can be represented by (21):

$$P_{WG} + P_{PV} + P_{BAT} + P_{FC} \geq P_{LOAD} + P_{ELEC} + P_{SC} \tag{21}$$

b) Bounds of Design Variables

The proposed hybrid system optimization parameters including the battery capacity (Cap_{BAT} *(KWh))*, number of PV panels (N_{PV}), and FC power level ($P_{FC}(W)$) should be within a certain range:

$$Cap_{BAT,Min} \prec Cap_{BAT} \prec Cap_{BAT,Max} \tag{22}$$

$$N_{PV,Min} \prec N_{PV} \prec N_{PV,Max} \tag{23}$$

$$N_{WG,Min} \prec N_{WG} \prec N_{WG,Max} \tag{24}$$

$$P_{FC,Min} \prec P_{FC} \prec P_{FC,Max} \tag{25}$$

Also, as the battery needs certain energy to supply the load in the beginning hours of the next day, battery energy at the end of the day (in normal condition) should be equal or greater than the battery energy at the beginning of the day.

$$E_{BAT,End} \geq E_{BAT,Start} \tag{26}$$

As discussed before, the objective of optimum design of this renewable hybrid generation system is to simultaneously minimize C_{SYSTEM}, as well as maximize system reliability. The design parameters that should be derived include number of wind turbines, PV panels, battery capacity and FC power level.

Based on those element costs, the system total cost is defined. The simulation model is run for any combinations of WG, PV surface, battery capacity and FC power level that are created by TLBO. The FC and electrolyser working rate is obtained. After that, these results are used to calculate the total cost of the system, assuming that the system lifetime is 20 years (equal to the PV lifetime).

TABLE II
DETAILS OF COMPONENTS

Wind Generator	
Technology	WHISPER 200
Rated Power	1 KW
Cut-in Speed	3.1 m/s
Rated Speed	11.6 m/s
Cut-out Speed	25 m/s
Capital cost	3200 US$
Operation & Maintenance cost	100 US$/year
Lifetime	15 year
PV array	
Technology	Polycrystalline
Maximum Power	120 W
Efficiency	12 %
Module unit	1.07 m^2
Short circuit current	7.74 A
Open circuit voltage	21 V
Capital cost	4.84 US$/$W_{peak}$
Lifetime	20 year
Fuel cell array	
Technology	PEMFC
PEMFC stack	100 W
Efficiency	50 %
Operating Temperature	80 ^{oC}
Capital cost	8 US$/W
Replacement cost	6 US$/W
Lifetime	5000 hour
Electrolyser	
Technology	Alkaline
Efficiency	74 %
Capital cost	20 US$/W
Lifetime	20 year
Battery	
Technology	Lead-acid
Capital cost	20 US$/KWh
Lifetime	5 year
Charging efficiency	80 %

VIII. TEACHING–LEARNING-BASED OPTIMIZATION

This optimization method is based on the effect of the influence of a teacher on the output of learners in a class. It is a population based method and like other population based methods it uses a population of solutions to proceed to the global solution [27]. A group of learners constitute the population in TLBO. In any optimization algorithms there are numbers of different design variables. The different design variables in TLBO are analogous to different subjects offered to learners and the learners' result is analogous to the 'fitness', as in other population-based optimization techniques. As the teacher is considered the most learned person in the society, the best solution so far is analogous to Teacher in TLBO. The process of TLBO is divided into two parts. The first part consists of the "Teacher phase" and the second part consists of the "Learner phase". The "Teacher phase" means learning from the teacher and the "Learner phase" means learning through the interaction between learners. In the sub-sections below we briefly discuss the implementation of TLBO [28], [29]. More detail of proposed TLBO is shown in Fig. 4.

A. Initialization

Following are the notations used for describing the TLBO

- *N*: number of learners in class i.e. "class size"
- *D*: number of courses offered to the learners
- *MAXIT*: maximum number of allowable iterations

The population *X* is randomly initialized by a search space bounded by matrix of *N* rows and *D* columns.

The *jth* parameter of the *ith* learner is assigned values randomly using (27)

$$x_{(i,j)}^{0} = x_{j}^{min} + rand \times (x_{j}^{max} - x_{j}^{min}) \quad (27)$$

where *rand* represents a uniformly distributed random variable within the range (0,1), x^{min}_j and x^{max}_j represent the minimum and maximum value for *jth* parameter. The parameters of *ith* learner for the generation *g* are given by

$$x_{(i)}^{g} = \left[x_{(i,1)}^{g}, x_{(i,2)}^{g}, x_{(i,3)}^{g}, \ldots, x_{(i,j)}^{g}, \ldots, x_{(i,D)}^{g}\right] \quad (28)$$

B. Teacher Phase

The mean parameter *Mg* of each subject of the learners in the class at generation *g* is given as

$$M^{g} = \left[m_{1}^{g}, m_{2}^{g}, m_{3}^{g}, \ldots, m_{j}^{g}, \ldots, m_{D}^{g}\right] \quad (29)$$

The learner with the minimum objective function value is considered as the teacher $X_g^{Teacher}$ for respective iteration. The Teacher phase makes the algorithm proceed by shifting the mean of the learners towards its teacher. To obtain a new set of improved learners a random weighted differential vector is formed from the current mean and the desired mean parameters and added to the existing population of learners.

$$Xnew_{(i)}^{g} = x_{(i)}^{g} + rand \times (x_{Teacher}^{g} - T_F \times M^{g}) \quad (30)$$

T_F is the teaching factor which decides the value of mean to be changed. Value of T_F can be either 1 or 2. The value of T_F is decided randomly with equal probability as,

$$T_F = round\left[1 + rand(0,1)\right] \quad (31)$$

where T_F is not a parameter of the TLBO algorithm. The value of T_F is not given as an input to the algorithm and its value is randomly decided by the algorithm using (31). After conducting a number of experiments on many benchmark functions it is concluded that the algorithm performs better if the value of T_F is between 1 and 2. However, the algorithm is found to perform much better if the value of T_F is either 1 or 2 and hence to simplify the algorithm, the teaching factor is suggested to take either 1 or 2 depending on the rounding up criteria given by (31).

If $Xnew^g_{(i)}$ is found to be a superior learner than $X^g_{(i)}$ in generation *g*, than it replaces inferior learner $X^g_{(i)}$ in the matrix.

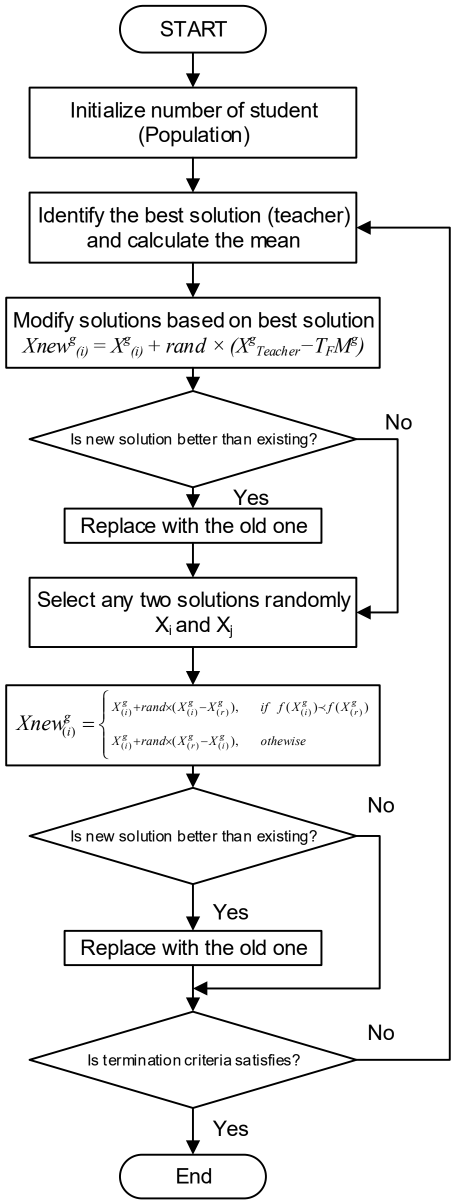

Fig. 4 TLBO flow chart

C. Learner Phase

In this phase the interaction of learners with one another takes place. The process of mutual interaction tends to increase the knowledge of the learner. The random interaction among learners improves his or her knowledge. For a given learner $X^g_{(i)}$, another learner $X^g_{(r)}$ is randomly selected ($i \neq r$). The *ith* parameter of the matrix *Xnew* in the learner phase is given as

$$Xnew_{(i)}^{g} = \begin{cases} X_{(i)}^{g} + rand \times (X_{(i)}^{g} - X_{(r)}^{g}), & if \ f(X_{(i)}^{g}) \prec f(X_{(r)}^{g}) \\ X_{(i)}^{g} + rand \times (X_{(r)}^{g} - X_{(i)}^{g}), & othewise \end{cases} \quad (32)$$

IX. Simulation Results and Validation

In this section, several simulations have been made by considering different combinations taking into account, the power of WG, PV and FC and the capacity storage. Technical and economic evaluation of hybrid systems with the proposed method has been studied with Shiraz weather data that are given in Table I. Considering the different structure; the system simulation has been done. Then the simulation results are used to optimize the size of the system by TLBO. The convergence of the algorithms to obtain the optimum size of the system is shown in Fig. 5. The convergence of the TLBO algorithm is compared to the GA and PSO applied to the proposed system in [16]. The parameters are optimum values that are given in Table III.

In order to inspect the operation of system according to power management strategy, Fig. 6 is presented. In Fig. 6 operation of system in a typical day and normal weather condition on 24 hours term is shown. For a start, the FC does not work because the battery SOC is high enough and the wind and solar power is weak, thus the load is supplied by the battery (see Fig. 6). When the battery SOC is lower than the threshold value, the FC is activated and the load is supplied. But the FC is unable to supply the load more than 500 W, thus in spite of low SOC, battery supplies surplus of the load.

As long as the solar power rises during the day, load is mainly supplied by WG and PV and battery is in charging mode.

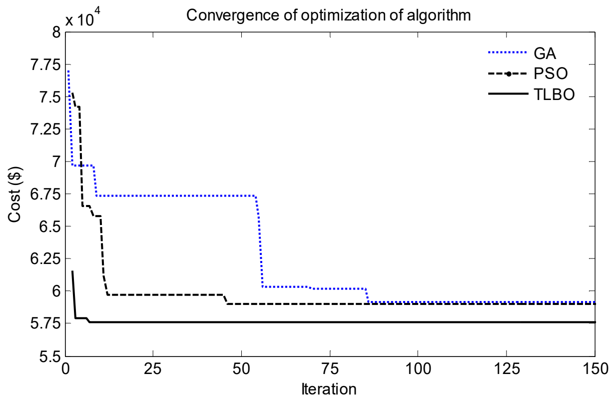

Fig. 5 Convergence of optimization of algorithms

When the battery SOC reaches its nominal value, the battery charging is stopped and the electrolyser is activated. On condition that the FC is working, it supplies the load up to 500W. Over this value, both WG and PV supplies the additional load or the battery supplies it at the time of the wind speed and solar radiation does not exist. During the day, WG and PV charges battery and when battery reaches its nominal SOC, FC is stopped. The battery SOC in different modes of battery operation is shown in Fig. 7.

TABLE III
OPTIMIZED VALUES OF WG/PV/FC HYBRID SYSTEM

	Number of WG	Number of PV panels	FC power	Batteries Capacity
Optimum values	3	32	500 w	22 KWh
	LPSP	**LCE**	**EXC**	**Total cost**
	0	0.732 $/KW	20 %	57571 US$

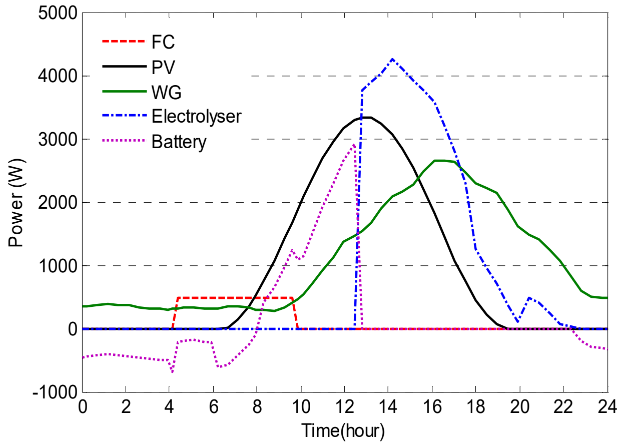

Fig. 6 Powers evolutions during 24 hours

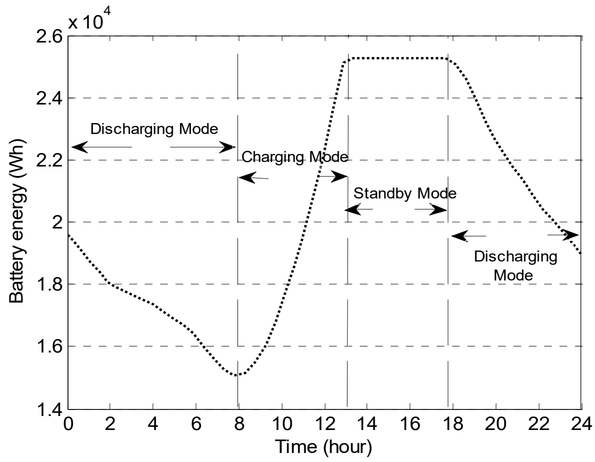

Fig. 7 Energy of battery during 24 hours

X. CONCLUSION

If the hybrid plants with renewable resources are constructed based on technical and economic studies, they can bring a significant economic benefits. In this paper the optimization of hybrid WG/PV/FC systems with TLBO algorithms was performed. Thus the specified system has been simulated and the results were discussed. The results of simulation have been used to find the optimal sizing of the configuration. It was found that TLBO was able to find the optimum design parameters of the stochastic simulation model. To observe the performance of the proposed method and system performance with respect to the designed control strategy, system simulation based on Shiraz weather data was performed. The total cost of the optimized system showed that the system can deliver energy in a stand-alone installation with an acceptable cost. Proper system reliability was another interesting result of this study.

REFERENCES

[1] A. Rouhani, "Feasibility Study and Developing Appropriate Hybrid Energy Systems in Regional Level", *International Journal of Electrical, Computer, Electronics and Communication Engineering*, Vol.9, No.3, pp. 170-177, 2015.

[2] Nader Barsoum, Wong Yew Yiin, Tan Kwong Ling, and Goh, W.C., "Modeling and Cost Simulation of Stand-alone Solar and Biomass Energy," *Proc. IEEE International Conference on Modeling & Simulation*, pp. 250-257, 2008.

[3] A. Rouhani, S.H. Hosseini, and M. Raoofat, 'Composite generation and transmission expansion planning considering distributed generation' *International Journal of Electrical Power & Energy Systems*, Vol.62, Jun 2014, pp. 792-805.

[4] Boquan Zhang, Yimin Yang, and Lu Gan, "Dynamic Control of Wind/Photovoltaic Hybrid Power Systems Based on an Advanced Particle Swarm Optimization," *Proc. IEEE Conference on Industrial Technology*, pp. 1-6, 2008.

[5] K. Agbossou, M. Kolhe, J. Hamelin, and T.K. Bose, "Performance of a Stand-Alone Renewable Energy System Based on Energy Storage as Hydrogen" *IEEE Trans. on Energy Conversion*, Vol. 19, No. 3, September 2004.

[6] F. Bonanno, A. Consoli, A. Raciti, B. Morgana, and U. Nocera, "Transient Analysis of Integrated Diese Wind Photovoltaic Generation Systems" *IEEE Trans. on Energy Conversion*, Vol. 14, No. 2, June 1999.

[7] M. Mousavi Badejani, M.A.S. Masoum and M. Kalanta, "Optimal Design and Modeling of Stand-Alone Hybrid PV-Wind Systems" *Proc. Int. Conf. on Power Engineering*. Australasia, pp. 1-6, Dec. 2007.

[8] D.B. Nelson, M.H. Nehrir, and C. Wang, "Unit Sizing of Stand-Alone Hybrid Wind/PV/Fuel Cell Power Generation Systems" *IEEE Power Engineering Society General Meeting,* PP 2116 – 2122, Vol. 3, 2005.

[9] A. Kashefi Kaviani, G.H. Riahy and SH.M. Kouhsari, "Optimal Design of a Reliable Hydrogen-based Stand-alone Wind/PV Generation System" *Proc. Int. Conf. on Optimization of Electrical and Electronic Equipment,* PP. 413 – 418, 2008.

[10] M. Hashem Nehrir, "A Course on Alternative Energy Wind/PV/Fuel Cell Power Generation" *IEEE Power Engineering Society General Meeting,* PP 6, 2006.

[11] T. Zhou, and B. Francois, "Modeling and control design of hydrogen production process for an active hydrogen/wind hybrid power system" *ELSEVIER. International Journal of Hydrogen Energy* 34 (2009) 21 – 30.

[12] D. Ipsakisa, S. Voutetakis, P. Seferlis, F. Stergiopoulos, and C. Elmasides, "Power management strategies for a stand-alone power system using renewable energy sources and hydrogen storage" *ELSEVIER. International Journal of Hydrogen Energy* (2008) 1 – 15.

[13] S. Jalilzadeh, A. Rouhani, H. Kord, and M. Nemati, "Optimum design of a hybrid Photovoltaic/Fuel Cell energy system for stand-alone applications," *IEEE Int. Conf. on Electrical Engineering, and Electronics (ECTI)*, vol. 1, pp. 152-155, May 2009.

[14] S. Jalilzadeh, H. Kord, and A. Rouhani, "Optimization and Techno-Economic Analysis of Autonomous Photovoltaic/Fuel Cell Energy System," *ECTI Transactions on Electrical Engineering, Electronics, and Communications*, Vol.8, No.2, pp. 118-125, February 2010.

[15] H. Kord and A. Rouhani, "An Integrated Hybrid Power Supply for Off-Grid Applications Fed by Wind/Photovoltaic/Fuel Cell Energy Systems," *Int. Power System Conference (PSC)*, Tehran, Nov. 2009.

[16] A. Rouhani, H. Kord, and M. Mehrabi, "A Comprehensive Method for Optimum Sizing of Hybrid Energy Systems Using Intelligence Evolutionary Algorithms," *Indian Journal of Science and Technology*, Vol.6, No.6, pp. 4702-4712, June, 2013.

[17] V. Rashtchi, H. Kord, and A. Rouhani, "Application of GA and PSO in Optimal Design of a Hybrid Photovoltaic-Fuel Cell Energy System," *24th International Power System Conference (PSC)*, November 2009.

[18] A. Rouhani, K. Mazlumi, and H. Kord, 'Modeling of a Hybrid Power System for Economic Analysis and Environmental Impact in HOMER' *18th Iranian Conference on Electrical Engineering*, Iran, May 2010.

[19] NASA Surface Meteorology and Solar Energy. (http://www.nasa.gov)

[20] S. Jalilvand, H. Kord, and A. Rouhani, "Design, Control and Energy Management of a Hybrid Photovoltaic-Wind-Fuel Cell for Stand-Alone Applications," *14th Electrical Power Distribution Conference (EPDC)*, May 2009.

[21] A. Kashefi Kaviani, G.H. Riahy and SH.M. Kouhsari, "Optimal Design of a Reliable Hydrogen-based Stand-alone Wind/PV Generation System," *Proc. IEEE International Conference on Optimization of Electrical and Electronic Equipment*, pp. 413-418, 2008.

[22] Jeremy Lagorse, Marcelo G. Simo˜es, Abdellatif Miraoui, and Philippe Costerg, "Energy cost analysis of a solar-hydrogen hybrid energy system for stand-alone applications," *International Journal of Hydrogen Energy* 33, pp. 2871–2879, 2008.

[23] Caisheng Wang, and M. Hashem Nehrir, "Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System," *IEEE Trans. on Energy Conversion*, Vol. 23, No. 3, September 2008.

[24] Lu Y, Burnett L et al. "Investigation on wind power potential on Hong Kong islands-an analysis of wind power and wind turbine characteristics," *International Journal of Renewable Energy*, vol 27(1), pp. 1–12, 2002.

[25] Shakyaa B D, Ayea L et al. "Technical feasibility and financial analysis of hybrid wind-photovoltaic system with hydrogen storage for Cooma," *International Journal of Hydrogen Energy*, vol 30(1), pp. 9–20, 2005.

[26] S. Diaf, D. Diaf, M. Belhamel, M. Haddadi,and A. Louche, "A methodology for optimal sizing of autonomous hybrid PV/wind system," *International Journal of energy policy,* 35, pp. 5708-5718, 2007.

[27] Rao RV, Savsani VJ, Vakharia DP, "Teaching-learning-based optimization: a novel method for constrained mechanical design optimization problems," *Computer-Aided Design* 43(3), pp.303-315, 2011.

[28] Rao RV, Savsani VJ, Vakharia DP, "Teaching-learning-based optimization: an optimization method for continuous non-linear large scale problems," *Inform Sci* 183(1), pp.1-15, 2012.

[29] Rao VJ, Savsani JB, "Teaching learning based optimization algorithm for constrained and unconstrained real parameter optimization problems," *Eng Optim*, 2012.